

TRANSPORT FINDINGS

Green Vehicles' Responses to an Expiring Congestion Toll Exemption: Findings from a Natural Experiment in Stockholm, Sweden

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Findings

Stockholm established time-varying congestion pricing in 2007, and adopted a toll exemption as a temporary incentive for green vehicles (GVs) that ended in 2012. We examine the behavioral effects of phasing out the exemption by studying the change in cordon crossing events for GV morning commuters between May 2012 and May 2013, with a random sample of conventional vehicles (CVs) as control. The results suggest i) a significant drop in the total number of crossings; ii) a slight shift towards later journeys in the morning; and iii) a reduction in the ratio of peak-toll period crossings to other ones.

1. QUESTIONS

In 2007, the city of Stockholm established congestion charges for the purpose of increasing accessibility and improving air quality (Karlström and Franklin 2009). The scheme consisted of a time-varying cordon toll, with peaks in the morning (7:30-8:30 am) and in the afternoon (4:00-5:30 pm) (Table S1). Over an introductory period, green vehicles (GVs) were exempt from charges to incentivize their purchase, while conventional vehicles (CVs) were subject to tolls. (Here, GV is defined as vehicles following the description of “clean vehicles” in Hugosson and Algers (2011) regarding fuel type.) Nevertheless, following a rapid increase in GV sales and a concern that the congestion reductions could be undermined, the exemption was phased out on January 1st, 2009, for newly registered GV, and on July 1st, 2012, for GV registered prior to January 1st, 2009. Consequently, in 2012, older GV faced a toll price increase while CV and newer GV saw no toll price change.

Seeing the temporary exemption for a *subset* of the fleet as a natural experiment, the objective of the current study is to investigate whether GV changed their cordon-crossing behavior after the termination of the exemption. In this assessment, CV constitute the control group. Specifically, the research questions are:

- Was there a reduction in the number of cordon crossings (i.e. number of times that vehicles crossed toll stations)?
- Focusing on cars that traveled *both* years, was there a shift in cordon crossing times (i.e. time of the day that a vehicle crossed the toll station), in terms of mean and variance?
- Did the number of crossings in the peak toll period decrease?

Table 1. The statistical tests implemented.

Test	Description and motivation
Normality	We use the Kolmogorov-Smirnov (KS) test (Massey 1951), with a 0.05 significance level to test the normality of the samples.
Comparing medians	We apply the Wilcoxon signed-rank test for dependent (paired) data, with the null hypothesis is that there is no significant difference between the medians of the paired samples.
Comparing variances	For paired data, we use the Fligner-Killeen test, as proposed by Michael and Edwardes (2001) for data with many ties. The null hypothesis is that the variances of the two distributions are equal. For the whole distributions, we use Levene's test for equality of variances.
Distribution shape	We conduct KS-tests with regard to the number of times each vehicle crossed the cordon during peak hours, and the ratio of this and number of crossing events.

2. METHODS

2.1. Data

The Swedish Transport Agency operates Sweden's congestion pricing systems, billing vehicle owners monthly through the use of automated number plate recognition. During tolling periods, such data are collected continuously, and then linked to vehicle registry data and archived for billing and reporting. For the current study, the agency provided a set of anonymized records for all detected GV's and a random sample of CV's. While the vehicle identification numbers were encrypted, a recycled encryption key allowed matching between similar 2-week periods in 2012 and 2013 records so that changes in crossing patterns for the same vehicle could be measured. Data were collected in 2012 and 2013 on working days between May and June from 6:30 am to 6:30 pm.

2.2. Study samples

We select a sample of vehicles, based on the anonymized encrypted vehicle ID numbers, with relatively consistent behavior and define them as morning commuters, namely cars that crossed the toll cordon in 2012 and 2013 on at least three different days, before 12:00, on each year's 2-week study period.

2.3. Statistical analyses

The empirical analyses were grounded in various statistical tests, as listed in [Table 1](#). Essentially, we compare cordon crossing events in 2012 and 2013 for both GV's and CV's (control), focusing on morning trips (6:30 am – 12:00 am). As the data was not normal, all tests are non-parametric. Primarily, we examine whether there was a change in the number of trips after the introduction of the toll. Here, we account for cars present in the data set in either year.

Then, we investigate the change in prevailing crossing time, focusing on vehicles in the data set that travel *both* years. To compare crossing times in the presence of different numbers of trips by the same vehicle, we analysed all pairwise comparisons between the study years for the vehicle; for instance, if a vehicle has three observations in 2012 and two in 2013, we create six pairs.

Lastly, we study peak-toll behavior by comparing the number of crossings in the peak toll interval both years, as well as the share of peak-toll crossings to other crossings.

3. FINDINGS

The analyses suggested three key findings:

- For GVVs, but not for CVs, the number cordon crossings decreased substantially between 2012 and 2013, from 69,563 to 46,764 (32.8%) ([Table 2](#)). A whole-sample comparison of the distributions of the number of crossings per car each year confirmed that there was a significant difference for GVVs, with $p = 1.7\text{E-}11$ in a two-sided Wilcoxon test, but not for CVs ($p = 0.08$). A one-sided Wilcoxon test confirmed that the number of trips for GVVs was reduced in 2013 ($p = 8.6\text{E-}12$).
- The ending of the toll exemption seems to have resulted in a slight shift towards later travel times for GVVs. In a comparison of the average crossing time per vehicle in 2012 vs. 2013 (two-sided Wilcoxon tests), we found significant shifts for GVVs ($p = 4.3\text{E-}6$), but not for CVs. One-sided tests revealed that this shift was towards later times for GVVs ($p = 2.2\text{E-}6$). However, analyses per car showed that the tendency to shift crossing time between 2012 and 2013 was *similar* for GVVs and CVs (Table S1).
- The omission of the toll exemption resulted in a reduction of traffic in the peak-toll period (7:30-8:30 am) in 2013 vs. 2012, as illustrated in [Figure 1](#). Statistical tests that compare the number of cordon crossings during this time interval show a significant difference between 2012 and 2013 for GVVs ($p = 3.5\text{E-}4$), but not for CVs ([Table 3](#)). A one-sided test confirmed that there was a significant decrease in the number of peak crossings for GVVs in 2013 ($p = 1.7\text{E-}4$). Consistently, the ratio of peak-toll crossings to crossings at other times in the morning was different for GVVs, but not for CVs ([Table 3](#)). Further, the variance was different in 2013 vs. 2012 for GVVs (Levene test of variance $p = 7.2\text{E-}3$), but not for CVs.

Table 2. Descriptive statistics for commuters' toll cordon crossing events that we analyzed (6:30-12:00 am).

	CVs		GVs	
	2012	2013	2012	2013
Number of all observations	13,051	13,868	69,563	46,764
Number of all unique cars	4628		17,059	
Number of unique commuters	359		2076	
Median crossing time of day	8:28	8:29	8:29	8:34
Mean crossing time of day	8:35	8:37	8:34	8:40
Std crossing time of day	49'	49'	40'	43'
Skewness crossing time of day	23'	19'	19'	17'
Average number of trips per car	5.79	5.55	6.23	5.90
<i>p</i> -value of KS-normal ^a	3.5E-11	9.2E-11	2.4E-52	6.3E-49

^a A Kolmogorov-Smirnov normality test with a *p*-value < 0.05 indicates that the distribution is significantly different from the normal distribution.

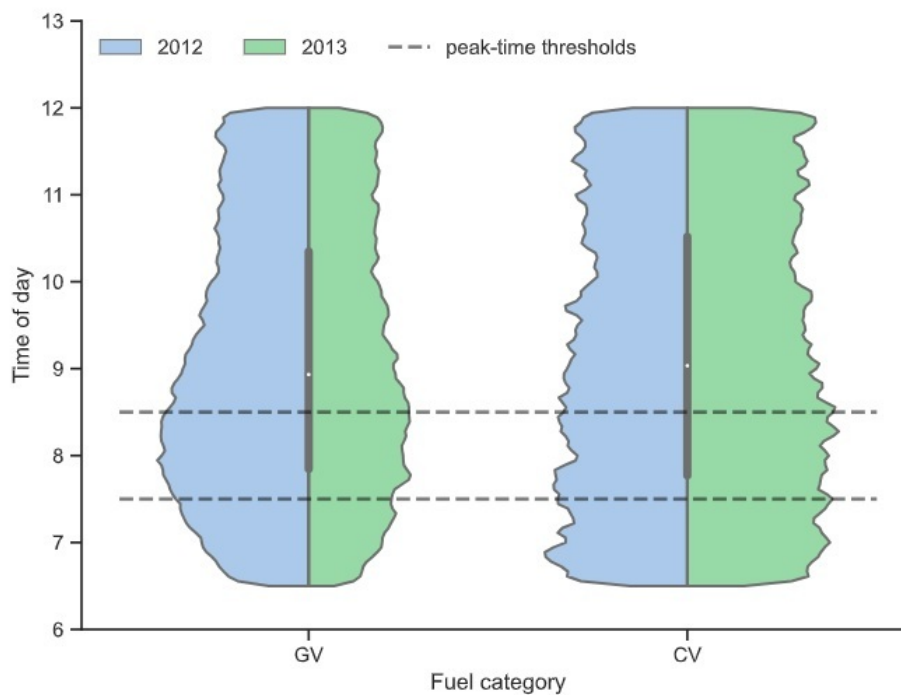


Figure 1. Density plots of time of the day crossings based on different fuel categories. The width of each plot reflects the number of vehicles observed at the toll stations at any given time.

In conclusion, the results indicate that the termination of the toll exemption for GV's had a considerable effect on the number of morning crossings, in particular on the number of crossings in the peak-toll period. There is also some, albeit limited, evidence that remaining trips shifted towards later morning crossing times. Note that we lacked information regarding which vehicles were exempted from payment, which suggests our findings to be an underestimate of the true behavioral impact of the toll.

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Table 3. Results of non-parametric statistical tests that compared cordon crossing events in the peak morning toll interval (7:30-8:30 am) in 2012 and 2013.

Peak toll interval crossing time shift	CVs		GVs	
	Statistic	<i>p</i> -val	Statistic	<i>p</i> -val
Number of peak crossings (Wilcoxon two-sided)	7,835	0.65	255,529	3.5E-4
Number of peak crossings (Wilcoxon one-sided: higher in 2013)	8,456	0.68	327,132	1
Number of peak crossings (Wilcoxon one-sided: lower in 2013)	8,456	0.32	327,132	1.7E-4
Ratio of peak interval and other crossings (KS ^a)	0.11	0.16	0.10	2.0E-5
Variance test (L ^a)	0.10	0.75	7.2	7.1E-3

^a Abbreviations: KS: Kolmogorov-Smirnov test; L: Levene test.



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SUPPLEMENTARY MATERIALS

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