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BOUNDS AND BUNCHING: DISTRIBUTIONS OF AIR POLLUTANTS PRODUCED BY NEW AUTOMOBILES

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Abstract

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Euro norms set limits on per-kilometer emissions of air pollutants produced by new cars. Satisfying these limits is always costly, the existing models generally assume that cars are produced as to just satisfy the norms. This theory predicts bunching of measured emissions below the limits. We find this not to be consistent with the data. In fact, medians of measured emissions are often at around one half or less of the respective limit and are supported by wide distributions. Implications for optimum tax policies are briefly discussed.

Keywords: Euro norms, air pollutants, bunching, carbon monoxide, hydrocarbon, nitrogen oxide, particulate matter, diesel, petrol

INTRODUCTION

The costs of air pollution produced by automobiles are nontrivial and well documented in the medical literature.[1] With the goal to mitigate these negative externalities, the European emission standards, also known as the Euro norms, state stringent per-kilometer limits of air pollutants, which are applicable to all passenger vehicles sold during the period when a particular norm is valid.[2] Tab. I summarizes the emission limits set by respective Euro norms for diesel and petrol passenger vehicles.

Car manufacturers can make their products satisfy these standards through two means: fuel economy and abatement equipment. Because both ways are costly, the models in the literature assume that cars are produced so that they satisfy the limits. Since the actual emissions are not usually presented to the customer as an advantage of certain vehicle, we expect no gain for the producer to build an engine to produce significantly less emissions than the norm sets. This means that producer has to compare costs on lowering the emissions with non-significant gains. As a result, all new cars should produce a similar amount of air pollutants per kilometer

1 For recent medical literature see references in Montag (2015). Schwartz (2004) provides an excellent review of the literature on child-specific effects of air pollution. See also Orzhenevych, Dehnen, Bröcker, Holtkamp, Meier, Gibson, Varma, and Cox (2014, ch. 4).

2 The first directive, called Euro 1, was enacted in 1992 and introduced gram per kilometer limits on carbon monoxide (CO), hydrocarbon and nitrogen oxide (HC + NOx), and for diesel vehicles also limits on particulate matters (PM). Today, the limits are given by Regulation (EC) No 715/2007, or Euro 5, which came into force on September 2009. The main change from its precedent, Euro 4, is the reduction in the limit for PM from 0.025 g/km to 0.005 g/km. The next directive, Euro 6, which will become effective in September 2014, will reduce the limit on NOx for diesel cars from 0.180 g/km to 0.080 g/km. Similarly conceived standards hold in the US and were introduced by the Clean Air Act Amendments of 1990.

I: *European emission standards for passenger cars (μg/km)*

Tier	Date	CO	THC	NMHC	NOx	HC+NOx	PM
				Diesel			
Euro 1	Jul 1992	2720	-	-	-	970	140
Euro 2	Jan 1996	1000	-	-	-	700	80
Euro 3	Jan 2000	640	-	-	500	560	50
Euro 4	Jan 2005	500	-	-	250	300	25
Euro 5	Sep 2009	500	-	-	180	230	5
Euro 6	Sep 2014	500	-	-	80	170	5
				Petrol			
Euro 1	Jul 1992	2720	-	-	-	970	-
Euro 2	Jan 1996	2200	-	-	-	500	-
Euro 3	Jan 2000	2300	200	-	150	-	-
Euro 4	Jan 2005	1000	100	-	80	-	-
Euro 5	Sep 2009	1000	100	68	60	-	5
Euro 6	Sep 2014	1000	100	68	60	-	5

Source: Wikipedia

driven (Fischer, Harrington, and Parry, 2007; Parry and Small, 2005; Parry, Walls, and Harrington, 2007; see also Montag, 2015). This assumption implies bunching of measured emissions below the thresholds shown in Tab. I. As can be seen on the table, new standards come into force every 4–5 years. Thus, our assumption is that there should be no perfect linearity in lowering the emission.

Assumption of bunching below legal limits may be interesting from the taxation point of view. In case that bunching below the limit occurs, it may be effective to set taxis according to the particular Euro norm which has lower demands on administration. On the other hand, if the distribution under the limit is more widespread, taxation according particular Euro norm hardly describes the externality p by the vehicle.

Using data from the UK Department for Transport's Vehicle Certification Agency, we set an aim of the paper which is to ascertain whether such bunching below the threshold levels actually occurs.

DATA AND RESULTS

The data analyzed in this paper was compiled from yearly (2000 to 2014) tables published by the Vehicle Certification Agency, UK Department for Transport.[3] The unit of observation is a car type specified at the engine level. More specifically, each

II: *Summary statistics: emissions produced by new passenger cars (μg/km), 2000–2014*

Tier	CO		THC		NOx		HC+NOx		PM		
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	N
						Diesel					
Euro 2	456.30	(13.78)	-	-	-	-	668.21	(9.89)	64.29	(1.50)	371
Euro 3	213.55	(2.79)	-	-	430.90	(2.03)	463.50	(2.14)	44.76	(0.52)	2852
Euro 4	159.02	(1.66)	-	-	216.58	(0.70)	240.68	(0.76)	13.78	(0.19)	4336
Euro 5	222.68	(1.34)	-	-	147.79	(0.37)	173.88	(0.40)	0.64	(0.01)	5643
Euro 6	185.85	(3.40)	-	-	48.61	(0.71)	78.67	(1.00)	0.35	(0.02)	587
						Petrol					
Euro 2	604.74	(10.29)	-	-	-	-	-	-	-	-	1271
Euro 3	616.35	(4.97)	91.73	(0.54)	51.90	(0.54)	117.88	(1.43)	-	-	4610
Euro 4	409.08	(2.04)	56.29	(0.24)	28.57	(0.21)	-	-	-	-	8526
Euro 5	374.39	(2.40)	42.71	(0.18)	25.66	(0.18)	-	-	0.75	(0.15)	5197
Euro 6	310.10	(4.80)	43.27	(0.37)	25.76	(0.35)	-	-	-	-	790

Data source: Vehicle Certification Agency, UK Department for Transport
Note: N stands for the number of observations; S.E. is standard error

3 The source data are available at http://carfueldata.direct.gov.uk/downloads.

car in a given year is identified by its producer, model, model description, transmission, fuel type, engine displacement, and the Euro norm it satisfies. The data further includes information on fuel consumption, CO_2 emissions, noise, and the emissions of respective air pollutants: carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), Hydrocarbons (HC). The data had to be unified, cleaned, and merged. We have dropped duplicated observations, which occur when the same car is found in more than one year of the data under a specific Euro norm.[4]

The final dataset is summarized in Tab. II, which lists means and their standard errors of respective declared air pollutants by the Euro norms and the two fuel types.[5] Directly comparing the estimates in Tab. II with emissions standards in Tab. I, one can see that, with a single exception, the mean values for petrol cars are always well below one half of the respective limit and the differences are always statistically significant at an arbitrary level.

This is also true for diesel cars in the case of CO and PM; most strikingly the emissions of PM produced by diesel vehicles decreased almost 200 times as we move from Euro 2 to Euro 6 in addition the average is less than one tenth of the norm. This is important because the adverse health effects of the particulate matter is well established (see, e. g., Atkinson *et al.*, 2001; Dejmek *et al.*, 1999; Pope *et al.*, 2004; Seaton *et al.*, 1995). A substantive decline is present also in the case of NO_x and $HC+NO_x$, although the estimated means are closer to the limits than in the case of above pollutants, nonetheless, the means are always statistically and substantively smaller than the limits permitted by the respective emission standards.

The distributions of declared per-kilometer levels of emissions of air pollutants produced by new cars are plotted in Fig. 1 and Fig. 2 for diesel and petrol cars, respectively. Figures plot individual data points, with colors indicating the year, and standard box plots indicating the median and the interquartile range.[6] Looking at diesel vehicles in Fig. 1 first, there is a striking decline in per-kilometer emissions associated with the Euro norms. The exception are emissions of CO, however there were no changes in the respective limits between Euro 4 and Euro 6 norms. In the other three cases, NO_x, PM, and $HC+NO_x$, the medians for Euro 6 emissions are small fractions of median emissions of cars produced earlier under the Euro 2 or the Euro 3. As already discussed above, the largest decline occurred in the case of PM. The changes appear to work through two channels, first the whole distributions are shifting downwards, second the upper tails are being "trimmed".

III: *Ratio of the difference between 10th and 90th percentiles and the respective emission standards*

	CO	THC	NOx	HC+NOx	PM
			Diesel		
Euro 2	0.68	-	-	0.67	0.83
Euro 3	0.51	-	0.60	0.52	1.18
Euro 4	0.55	-	0.47	0.43	0.92
Euro 5	0.52	-	0.31	0.29	0.22
Euro 6	0.19	-	0.39	0.19	0.60
			Petrol		
Euro 2	0.44	-	-	-	-
Euro 3	0.35	0.43	0.57	-	-
Euro 4	0.49	0.61	0.54	-	-
Euro 5	0.46	0.35	0.58	-	-
Euro 6	0.36	0.30	0.43	-	-

Data source: Vehicle Certification Agency, UK Department for Transport

More importantly, there is a substantial variation in the data. This is especially apparent in the case of CO, where the values spread from zero to the respective limit. This spread is summarized in Tab. III, which reports the ratio of the difference between 10th and 90th percentiles and respective emission standards. The entries thus state how wide is the distribution emissions of 80 percent of cars relative to the range permitted by the respective Euro norm (that is the difference between the limit and zero). The general pattern is that the spread is shrinking with each new Euro norm. It however remains quite large, when looking at Euro 5 and Euro 6, the ratio is between 0.2 and 0.5. These patterns are even more pronounced in the case of petrol-engine vehicles as can be seen in Fig. 2.

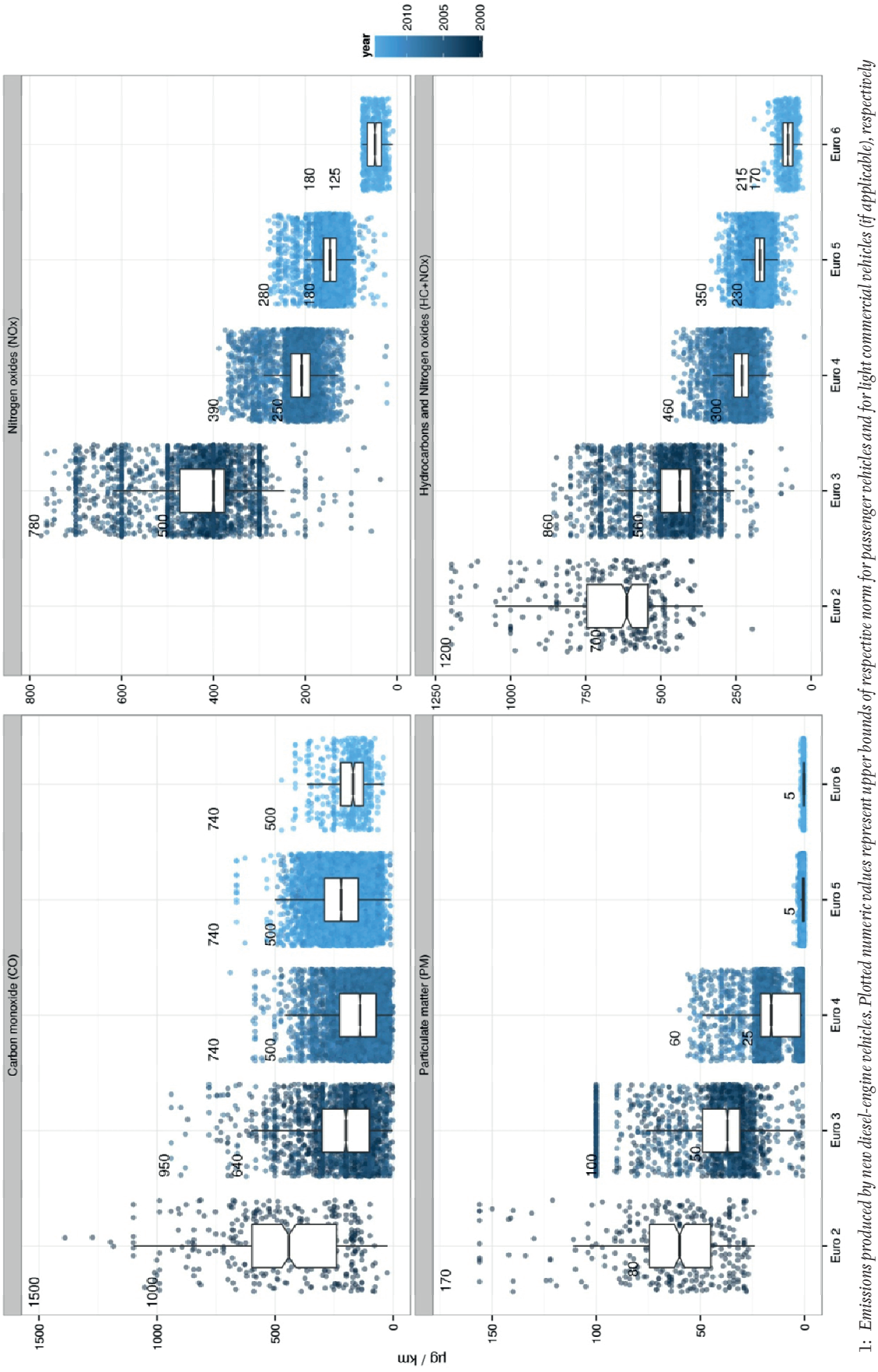
Even though results do not seem to show any major bunching that was expected, a minor bunching, as we call it, can be seen. Euro norms that set the limits may cause non-linearity in vehicles development. In normal competitive environment, emissions should follow quite linear downward sloped trend, thus continuously doing better performances in exhalations.

Some bunching can be seen when evaluating some specific types of emissions, namely NOx and particulate matter in diesel engines. Fig. 1 and 2 show how emission standards make small bunches below the limit set by the Euro norm. As Fig. 3 shows,

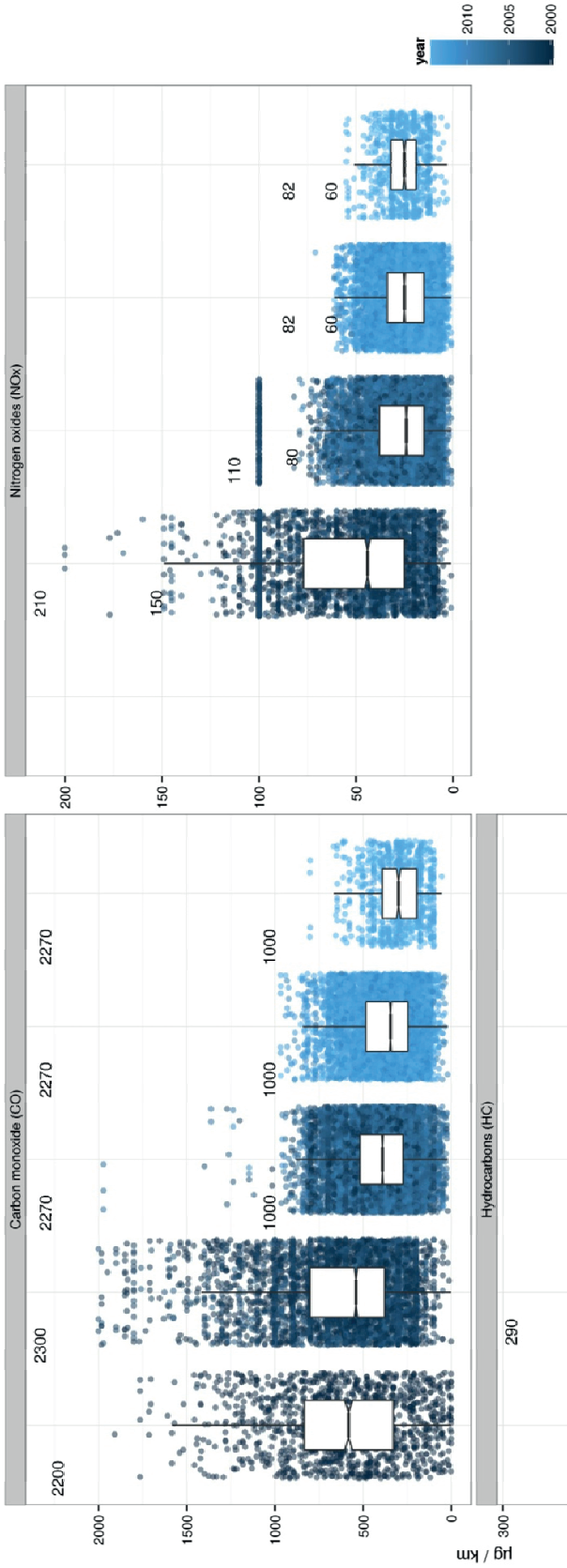
4 The code producing the final dataset and the reported results in this paper was written in R 3.1.1 (R Core Team 2014) and is available from the authors upon request.

5 Note that the first year of our data is 2000, so we do not have any Euro 1 vehicles in the data.

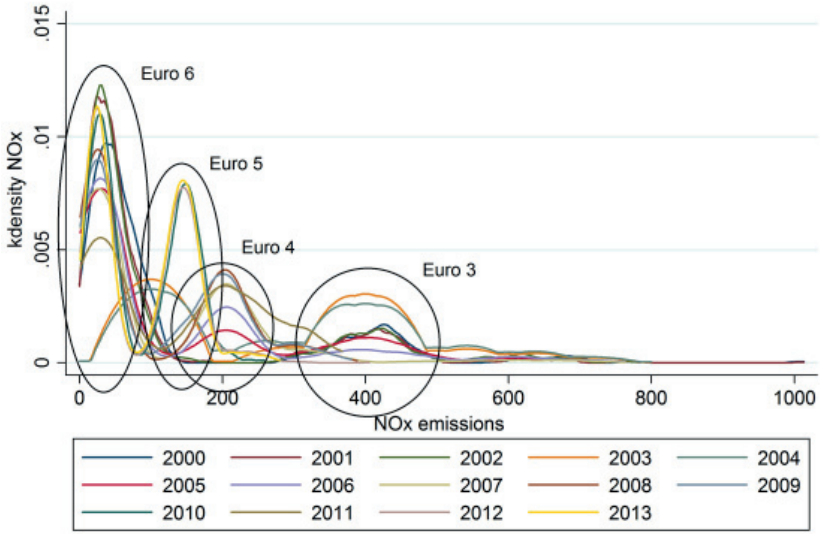
6 The upper and lower 'hinges' correspond to the 25th and 75th percentiles. The upper (lower) whisker extends from the hinge to the highest (lowest) value that is withinof the hinge, where is the distance between the 25th and 75th percentiles. The notches extend, where is the number of observations, roughly a 95 percent confidence interval for comparing medians (McGill, Tukey, and Larsen, 1978).



1: *Emissions produced by new diesel-engine vehicles. Plotted numeric values represent upper bounds of respective norm for passenger vehicles and for light commercial vehicles (if applicable), respectively*



2: *Emissions produced by new petrol-engine vehicles. Plotted numeric values represent upper bounds of respective norm for passenger vehicles and for light commercial vehicles (if applicable), respectively*



3: *Emissions of NOx in diesel engines. The peaks described on the figure are bunches under particular Euro norm*

emissions are much more dependent on the euro norm than on the year making development in time highly non-linear. Similar pattern can be seen in particulate matter in diesel vehicles (see Fig. 1). Sharp decline in this kind of emissions was caused by *de facto* obligatory use of Diesel Particulate Filter (DPF). Although some of Euro 4 vehicles were able to fulfill the limit, Euro norm 5 cut the majority lying above.

CONCLUSION

Contrary to the assumption, we find wide distributions of values of respective pollutants produced by new cars. In most cases, medians of measured emissions are estimated at less than one half of the respective limits and they are smaller than the limits at an arbitrary level of statistical significance. Furthermore, in most cases the distributions of measured emissions are wide. In sum, the validity of the assumption of bunching below the thresholds is not warrant-ed.

The interpretation of these patterns is straightforward. The prediction, that cars are produced to just satisfy the limits is not valid. Indeed, declared emissions for most cars lie far below the maximum limits. Second, the prediction that there is bunching of emissions per kilometer below the thresholds is incorrect, with some qualifications discussed above. Rather, values are distributed across the permitted range. As a result, there is apparently substantial variation in the amount of emissions of air pollutants per kilometer produced by new cars.

This finding has important repercussions for the optimum policy addressing externalities produced by motor vehicles. Optimum policies, in the classical sense, should (i) tax the marginal externalities and (ii) the tax rate should match the marginal social cost produced by a unit of activity (in our case kilometer driven, or liter of fuel burned). The findings in this paper suggest that the marginal social cost of air pollution resulting from car driving varies considerably across cars produced under the same emission standard. This means that possible taxation based on the satisfaction of Euro norm may affect vehicles across range unevenly.

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