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The role of non-waste 'product innovation' for waste production through reduced lifetime of goods

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The role of non-waste 'product innovation' for waste production through reduced lifetime of goods[*]

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Abstract

Environmentally-benign technological change is considered as a crucial component of sustainability. However, environmental objectives could be characterized by trade-offs. An example of this trade-off is innovation in the car market. On the one hand, newly released cars tend to be substantially more efficient (in terms of fuel use, CO2 emissions and pollutant emissions) than existing cars. On the other hand, faster ‘product innovation’ in the car market generates an acceleration in the obsolescence of the existing fleet, thus reducing the average lifetime of cars and consequently the production of waste from their scrapping.

The paper aims at investigating three different aspects of this issue for the Italian car market. First, we assess the extent to which product innovations, generally linked to improved fuel and environmental efficiency of cars, affect the rate of obsolescence of existing cars and their scrapping rate. Second, we want to evaluate the role played by national scrapping schemes in stimulating the upgrading of the car fleet. Finally, we aim at delivering some estimates of the environmental effects of ‘product innovations’ and scrapping schemes in terms of both increased fuel/environmental efficiency and greater generation of waste in terms of scrapped cars.

Analysis will be based on detailed information on the car fleet and the deregistration of cars in the Italian market provided by ACI (Automobile Club Italiano), further extended with information on newly released models of car by category and year (from Quattroruote, the most famous Italian magazine on cars).

Keywords: Durable goods, useful life, Product innovation, Car scrapping schemes

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1 Context and research questions

Environmentally-benign technological change is considered as a crucial component of sustainability. However, environmental objectives could be characterized by trade-offs. An example of this trade-off is innovation in the car market. On the one hand, newly released cars tend to be substantially more efficient (in terms of fuel use, CO2 emissions and pollutant emissions). On the other hand, faster 'product innovation' in the car market generates an acceleration in the obsolescence of the existing fleet, thus reducing the average lifetime of cars and the generation of waste from their scrapping. The combination of these effects give rise to conflicts between different environmental aims.

There exist a vast literature on the role played by innovation in deliberately reducing the useful lifetime of durable goods. The main objective of incumbent firms is to increase the frequency of purchase by consumers which fell they need to replace their current durable good even though it is still providing its services. This literature is both theoretical (Swan, 1972; Bulow, 1986; Fishman et al, 1993; Lee and Lee, 1998; Waldman, 1993) and empirical (e.g. Izuka, 2004).

In addition to economic inefficiencies due to an effective useful life of durable goods lower than the efficient level, planned obsolescence has the potential of generating negative environmental effects in terms of increased generation of waste. This has been investigated, among others, in the case of washing machines (Rechberger and Truttmann, 2006) and computers (Steubing et al, 2010).

In many cases, planned obsolescence strategies by producers are complemented by government policies aimed at renewing the current stock of durable goods with a variety of aims such as improving the average energy efficiency (e.g. with home appliances and lighting) or reducing pollutant and other emissions (e.g. with road vehicles). This raises the issue of conflicts among different environmental objectives that requires specific attention due to unintended consequences of an instrument of environmental policy on environmental goals subject to other specific legislations.

Starting from these two streams of literature, the paper aims at investigating three different aspects of the Italian car market. First, we assess the extent to which product innovations, generally linked to improved fuel and environmental efficiency of cars, affect the rate of obsolescence of existing cars and their scrapping rate. Second, we want to evaluate the role played by national scrapping schemes in stimulating the upgrading of the car fleet. Finally, we aim at delivering some estimates of the environmental effects of 'product innovations' and scrapping schemes in terms of both increased fuel/environmental efficiency and greater generation of waste in terms of scrapped cars.

The paper is organized as follows. Section 2 shows the results regarding the effect of product innovation on the car deregistration rate. Section 3 provides some evidence on the role played by scrapping schemes. Section 4 briefly discuss some environmental implications of the effect of innovation and policies.

2 The effect of product innovation on the rate of deregistration

Our main source of information here is the series of administrative databases on vehicles stock, vehicles registration and vehicle deregistration provided by the

Automobile Club Italiano (ACI henceforth)[2]. The database has different dimensions: by region (NUTS2 and NUTS3), by year of registration, by month, by type of vehicle (e.g. cars, trucks), by power (in kW), by environmental standard (e.g. Euro 0, Euro 1, etc.) and by brand for the period 2002-2012. Our unit of analysis will be either Italy as a whole or the NUTS2 region, due to some issue related to changes in NUTS3 regions in the considered period and in confidentiality thresholds which are sometimes binding for NUTS3 and not for NUTS2.

The first issue is to identify a suitable measure of product innovation. In principle, many alternative or complementary measures of innovation are available for the automotive sector. Among others, we could think about R&D expenditures by car producers, patent applications by car producers and by the members of the whole supply chain and indication on newly released 'products'. The latest indicator seems the most appropriate in our case, because consumers perceive innovation in cars only once they are embedded in a new car model.

In principle, new car models are introduced at the same time in the entire national market and, sometimes, in the entire world market. However, the use of an aggregate indicator of the number of new models is not satisfactory due to the substantial number of confounding factors occurring together with the release of new models, such as demand shocks, national policies, other aggregate shocks (e.g. energy price shocks). This prevents from identifying the aggregate effect of the introduction of new car models.

To be able to control for confounding factors, the indicator of innovation should be region-year specific, thus allowing to control for unobservable regional time-invariant features together with aggregate unobservable shocks common to all regions. We build an indicator of innovation based on the persistent differences in the preferences for brands across regions. Innovation is computed as the number of newly released models[3] by brand b in year t (or the sum between t and $t-2$) weighted by the share of each brand b in the stock of the car fleet in $t-1$. The distribution of the car fleet across brands in each region is assumed to reflect unobservable preferences for specific brands which could be correlated with other characteristics of the region (e.g. wealth, age, geography) or could be linked to unobservable tastes of car buyers. Persistence in brand preferences (i.e. brand loyalty) in the automobile market is a common finding in the literature (e.g. Anderson et al., 2012; Schiraldi, 2011), which justifies our choice for the proxy variable of product innovation.

Table 1 and Table 2 report the distribution by year across regions of our two alternative indicators of innovation. Even though the coefficient of variation across regions is rather small, the within-year standard deviation represents an important part of overall variation.

We measure the effect of product innovation on deregistration of cars by means of an econometric model. Our dependent variable is logarithm of the annual number of deregistered cars in region r and year t. Moreover, we also use as dependent variable the

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[2] http://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/autoritratto.html

[3] We retrieve information on newly released models by brand since 2001 from the online historical database maintained by the Italian magazine "Quattroruote" (http://www.quattroruote.it/archivio/listino/). The magazine is considered to be the most accurate source of information on the features of newly released cars in the Italian market. The number of new models by year and brand are reported in Table 3. We retrieved information on those brand for which we observe a share of car fleet by year and region greater than 0.5 percent at least once in our considered period.

number of deregistered cars older than a specific cut-off (cohort), ranging from 25 or more years to 1 or more years since the registration of the deregistered car. Our explanatory variable of interest is the indicator of innovation. Moreover, we control for the size of the car fleet by adding the logarithm of the lag of circulating cars in the region. Finally, we include a full set of year dummies to control for unobservable shocks common to all regions, including national policies, supply shocks and demand shocks. We report both weighted (by the average size of the car fleet of the region) and un-weighted estimates.

$$\log(deregistration_{i,t}) = \beta * Inno_{i,t} + \delta * \log(fleet\_size_{i,t-1}) + \mu_i + \tau_t + \varepsilon_{it} \quad (1)$$

We use various models. First, we employ a simple pooled OLS model. Second, we use a fixed-effect model which allows to control for unobservable region-specific and time-invariant fixed effects. This will be our preferred model (in its 'weighted' version)[4]. Moreover, as robustness checks we estimate a dynamic specifications by using standard dynamic panel models (System-GMM and Difference-GMM). Finally, being our dependent variable a count variable, we estimate the baseline specification with a negative binomial fixed effect model (Hausman et al, 1984).

Figure 1 shows the trend of deregistered cars (in logarithm) by region, that is our dependent variable, while Figure 2 reports the average age of deregistered cars[5]. Average age of deregistered varies substantially across regions, with regions in the South characterized by greater age than regions in the North. When looking at the time trend, we observe a similar pattern in all regions, with the average age of deregistered cars that is initially declining up to 2007-2008 and then stabilizing or even increasing from 2009.

Figure 3 and Figure 4 report the trend of our variable of interest, that is the rate of product innovation, by region. We observe substantial variation in time of innovation, with an average increase in time in the number of models released each year.

Baseline results are reported in Table 4 and Table 5, using respectively innovation in *t* and a broader indicator of innovation for the years *t*, *t-1* and *t-2*. In all specifications but the dynamic and count specifications, standard errors are corrected for heteroskedasticity. Our main variable of interest, that is the indicator of product innovation, has always a positive effect on deregistrations, the effect being statistically significant in most specifications and both versions of the measure of innovation. The observed increased rate of product innovation in the car market tends to accelerate the rate of deregistration and, as a consequence, to reduce the average lifetime of cars.

Starting from these baseline results, we provide two extensions. First, we want to investigate whether the effect of innovation on deregistration patterns is more relevant for recent or old deregistered cars. Second, we aim at assessing the role played by the increasing rate of innovation observed during the 2000s by creating counterfactual in which the level of innovation remains constant at the level of 2003 and thus compute the number of cars actually deregistered due to the accelerated rate of innovation.

Our preferred specifications for the first extension are the ones of column 4 and 8 of Table 5. We repeat the same specification for the full set of 'cumulated' cohort of

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[4] Where indicated, weights refer to average number of registered car in the region.

[5] Data on age are truncated at 25 years. For simplicity, we assume that the age of cars older than 25 years is 25 years.

registered cars (e.g. cars older than 25 year, cars older than 24 years, and so on). We compute the estimated beta coefficient for the innovation variable for each level of the age cut-off and plot it in Figure 5. For both the FE and Diff-GMM specification, we observe an effect which is increasing in the average age of deregistered cars. That is, innovation tends to push older cars out of the car fleet rather than newer cars, thus resulting in lower average age of the car fleet and, assuming that older cars are characterized by worse fuel efficiency than newer cars, in an improved fuel efficiency of the car fleet.

In the second extension, we compute for each region and year the deviation of our innovation variable from its value of 2003 and multiply it by the estimated coefficient in our preferred specification (column 4 of Table 5). This indicates the estimated log-points of deregistrations due deviations in innovation from 2003 levels. To compute the actual number of deregistered cars due to deviations in innovation, we take the exponential minus one of the estimated log-points effect, thus obtaining the relative variation, and multiply it by the number of deregistered cars at *t-1*. Table 6 reports the number of cars deregistered due to innovation by year, compared to the number of total cars deregistered in the same year in Italy as a whole. Overall, out of about 15.5 millions of cars deregistered in Italy in the period 2004-2012, 1.5 million have been deregistered due to increased rate of innovation in the car industry, accounting for about 9.8 percent of overall deregistrations.

3 Effect of scrapping schemes on deregistration

Our second research questions deals with the evaluation of the effect of incentive schemes for car scrapping introduced at the national level on the rate and type of scrapping. Incentive schemes were, in all cases, introduced for the Italian market as a whole. Our focus here will be the scrapping scheme introduced in February 2009 by the Italian government (L. 33/09). The scheme, with no budget limit, awarded a subsidy of 1.500 euros for buying a new vehicle after scrapping of passenger vehicles registered before the 1st January 2000 and compliant with Euro2 or lower emission standard. The subsidy was further increased if the new car was fuelled with LPG. The program was active from the 7th February 2009 until the 31st December 2009. The program basically covered the whole 2009, thus allowing us to use yearly detailed data on the vehicles fleet and deregistration provided by the Automobile Club Italiano (ACI) for the period 2002-2012. The main econometric issue here is the absence of a clear counterfactual. The scheme covered the entire Italian territory, with no regional differences in its implementation. Moreover, 2009 is the year in which the financial crisis resulted in a reduction in nominal GDP of 3.5 percent, which is likely to have influenced car deregistration decisions of Italian car owners. Finally, we could reasonably expect that the policy had the effect of anticipating the decision of scrapping the car in 2010 or 2011, effect that is not easily assessable.

In our first set of specifications (Table 7) we estimate the effect of the scrapping scheme of 2009 (dummy for 2009 equal to 1) for a variety of dependent variables related to the age distribution deregistered cars. In columns 1 to 6 the dependent variable is, respectively, the logarithm of deregistered car with 8, 9, 10 (the first cohort subject to the scrapping scheme of 2009), 11, 12 and 13 years. Each year dummy should be compared to the dummy relative to the previous year to assess the year-to-year systematic differences in deregistration rates. We control for the year-region specific ‘propensity-to-deregister’ by adding as covariate the logarithm of deregistered cars of 9 years of less (7 and 8 years or less for columns 1 and 2, respectively), as a mean to control for unobservable shocks affecting the car market and to provide a sort of counterfactual. Moreover, we control for the role played by the average age of the car fleet. More specifically, a larger share of cars older than eleven years (in *t-1*) increases the expected rate of scrapping in 2009 because of the greater number of cars eligible for the scrapping scheme.

For deregistered cars of 8 or 9 year, the rate of deregistration in 2009 is slightly lower than the rate of deregistration in 2008, the difference being, respectively, -0.096 and -0.157. When looking at deregistered cars of 10 year, the youngest cohort for which the scrapping incentive was effective, we observe a substantial increase in the rate of scrapping, the difference with respect to 2008 being now positive and in the order of 0.533 log points. This positive difference is found also for cars of 11, 12 and 13 years, though decreasing in magnitude.

In column 7, the dependent variable is the logarithm of deregistered cars of 10 years or older. Cars in this group (in case they were compliant with Euro2 or lower emission standard) were eligible for the scrapping subsidy[6], making this specification our first baseline result. Table 8 reports the year-to-year differences in the coefficients for the dummy variables and their statistical significance (t-statistic). The average estimated increase in the deregistration rate due to the scrapping scheme of 2009 was 0.228 log points, which correspond to about 25.6 percent relative to 2008. In 2008, 1,313,441 cars older than 10 years have been deregistered in Italy (1,591,364 in 2009). According to our estimates, the program induced the deregistration of 336,241 cars (25.6*1,591,364/100), that is about 21 percent of total cars older than 10 years deregistered in 2009. We could try to assess some anticipation in future planning scrapping by evaluating whether the increased scrapping rate of 2009 was followed by a compensatory decline in the following years. In 2010 we observe a reduction in the deregistration rate of about 0.248 log points, which is in line with the increase observed for 2009. This means that the scheme induced little ‘anticipation’ effects: if all additional deregistrations occurred in 2009 were only deregistrations already planned for 2010, the differential effect for 2010 would have been two times the differential effect found for 2009, that is 0.228*2=0.456.

Finally, the dependent variable of column 8 is the ratio between deregistered cars older than 10 years and deregistered cars of 9 years of younger. We observe a substantial change in the composition in terms of age of the deregistered cars in 2009, the ration increasing (in favour of older cars) by 1.683 (3.38-1.697), confirming the effectiveness of the scheme.

The inability to find a proper counterfactual and the diverse confounding common to all regions and year-specific may affect the reliability of our baseline results. For that reason, we perform several robustness checks to assess the causality of the relationship between the scrapping scheme and the rate of deregistration. One possibility is to exploit the discontinuity of the scheme which covers only cars registered before the 31st December 2001. It is reasonable to assume that, while owners of cars not eligible for the subsidy (car with less than 10 years) will not be affected by the scrapping scheme in their choice to scrap the car or not, owners of cars older than 10 years will be the ones

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[6] It should be noted cars pertaining to the oldest cohorts were also eligible for past scrapping schemes, making the distribution of deregistration by cohort partly influenced by deregistrations in the past that took advantage of past scrapping schemes.

reacting to the policy. Some evidence of that possible discontinuity is already visible in Figure 6, Figure 7 and Figure 8 which report the age distribution of deregistered cars by region for 2008 (prior to the scrapping scheme), 2009 (year of the scheme) and 2010 (after the scheme). While no substantial discontinuity is visible for 2008 and 2010 at age ten, such a discontinuity is visible in the year of the scheme (2009), with cars older than 10 years having an higher deregistration rate than cars younger than 10 years.

To provide more robust statistical evidence on the effect of the scrapping scheme we exploit this discontinuity by applying a regression discontinuity design. We cannot use the point estimates of a regression discontinuity design (RDD) to assess the overall magnitude of the effect due to the 'local' nature of the estimated treatment effect. However, the presence of a local treatment effect suggests that the additional deregistration observed in 2009 was actually due to the scrapping scheme and not by other confounding factors. We estimate year-by-year regressions using as dependent variable the logarithm of deregistered cars by region and age (year-by-year for age between 1 and 24 and a residual category of cars older than 25 years) and as covariates linear (Table 9) and quadratic (Table 10) trends of age that is specific for 'treated' (cars older than 10 years) and 'control' (cars younger than 10 years) cohorts. Moreover, we also include a dummy variable that is equal to 1 for all cohorts of cars older than 10 years (treated group) and zero otherwise, that captures the magnitude of the jump (if any) in the distribution of scrapped cars by age category. Regressions are performed year-by-year for the interval 2005-2012.

We observe a jump in the distribution in basically all years for both the linear and quadratic version of the RDD (the only exception being 2006 in the quadratic RDD). However, we observe a substantially (and significantly different) greater effect in 2009. In the linear RDD, this differential effect with respect to 2008 is about 0.645 (5.562 - 4.917) log points for the linear version of the RDD and 1.707 (2.649 - 0.942) log points for the quadratic version of the RDD. This strong effect, much greater (but reasonable only for age close to 10 years) than the one estimated in our baseline result, confirms the role played by the scrapping scheme, above and beyond other possible confounding factors).

4 Environmental effect of deregistration: preliminary assessment

Our empirical analysis suggests that a substantial amount of the rate of deregistration in the last decade has been driven by accelerated innovation and by scrapping schemes. This accelerated rate of scrapping is accompanied by two main potential effects on the environment. First, new cars that substitute scrapped cars are on average more fuel efficient and less polluting than average existing cars. This is due both to strategies of producers and to stringent environmental standards imposed by the European Commission on the adoption of 'Euro' standards[7] and on the amount of CO2 emission per km of new cars[8]. Second, the accelerated rate of scrapping has strong implications in terms of useful life and thus on the generation of waste from end-of-life vehicles.

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[7] Once the 'Euro' standard is operative, car producers are required to stop selling cars with lower emission standard. Standars were operative in the following years: Euro1 – 1992; Euro2 – 1995; Euro3 – 2000; Euro4 – 2006; Euro5 – 2009; Euro6 – 2014.

[8] Regulation 443/2009 mandates a target of maximum 130 g/km emissions of CO2 for new passenger cars, to be reached by 2012-2015.

As regards fuel efficiency and emission reduction, we report the evolution of the distribution of the car fleet across ‘Euro’ standards for the period 2005-2012 in

Table 13. The renewal of the car fleet, also driven by scrapping policies and innovation, allowed to double the share of cars compliant with the Euro3 or higher standards, passing from about 35 percent in 2005 to about 66 percent in 2012. As regards CO2 emission from transportation, we observe a substantial reduction in average CO2 emission per kilometre of new cars for a selection of EU countries (Table 14), in line with the target set by the European Commission of 130 g/km by 2015. For Italy, we observe a reduction of about 16.5 percent in the average CO2 emission per kilometre between 2007 and 2012.

Regarding the amount of waste generated by end-of-life vehicles, Table 15 show the total amount of waste generated by end-of-life vehicles in a selection of EU countries. Even though we cannot identify a clear trend for Italy, we observe that after a decline in 2009 (with respect to 2008), the amount of waste from end-of-life vehicles increased substantially again in 2010, possibly due to the scrapping of cars deregistered throughout 2009 as a consequence of the scrapping scheme.

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Figure 1: Deregistered cars by year and region (own elaboration on ACI data)

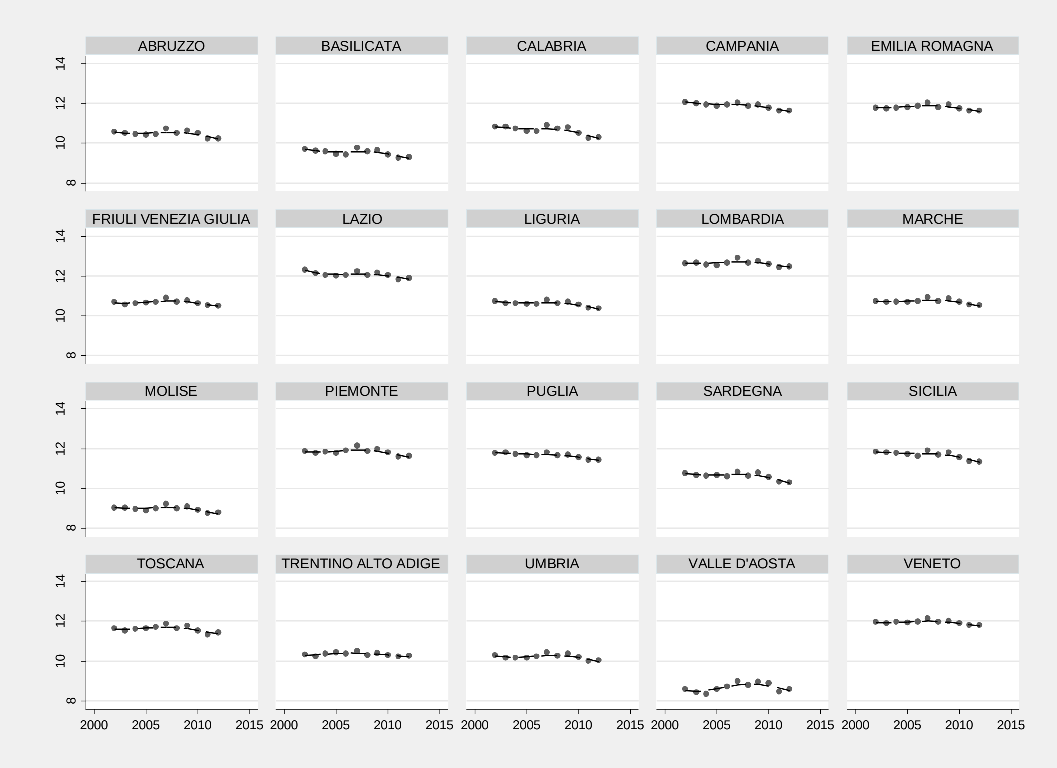

Figure 2: Average age of deregistered cars by year and region (own elaboration on ACI data)

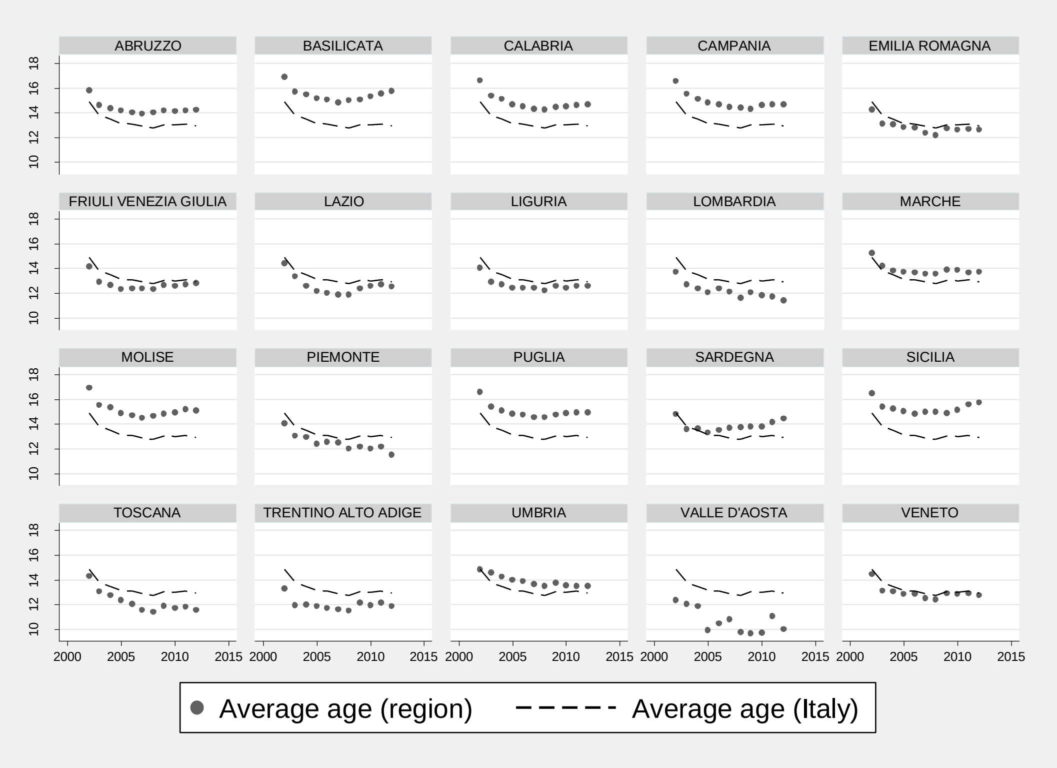

Figure 3: Innovation (at t) by region and year (own elaboration on ACI and Quattroruote data)

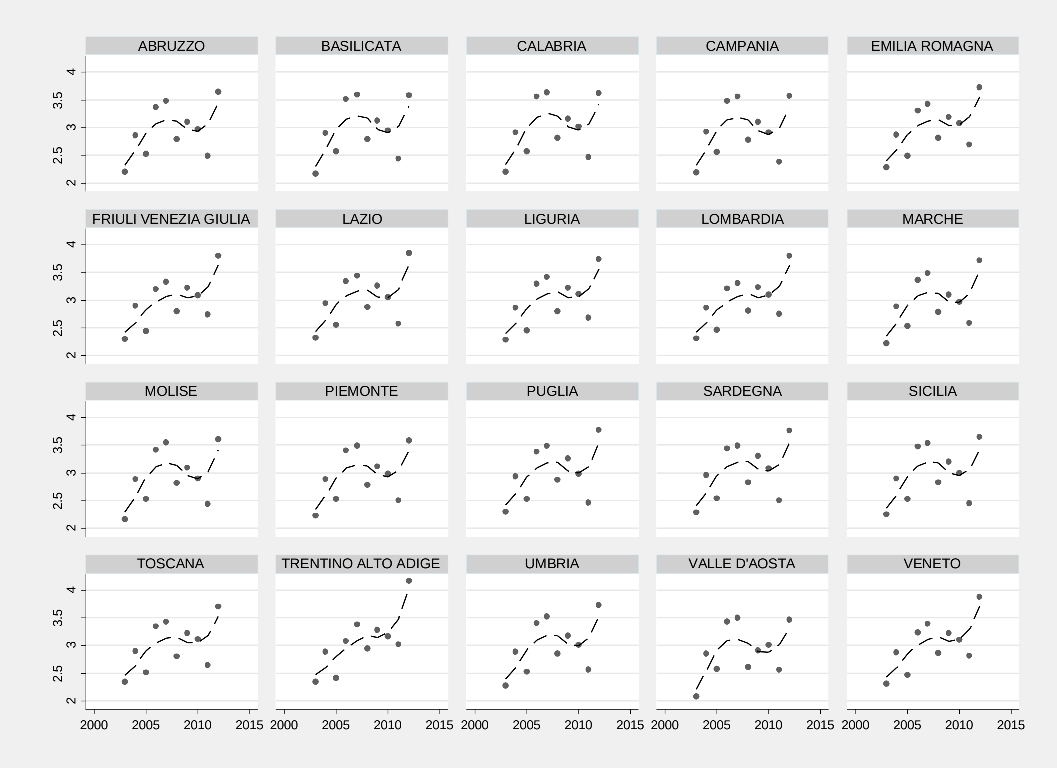

Figure 4: Innovation (at t, t-1, t-2) by region and year (own elaboration on ACI and Quattroruote data)

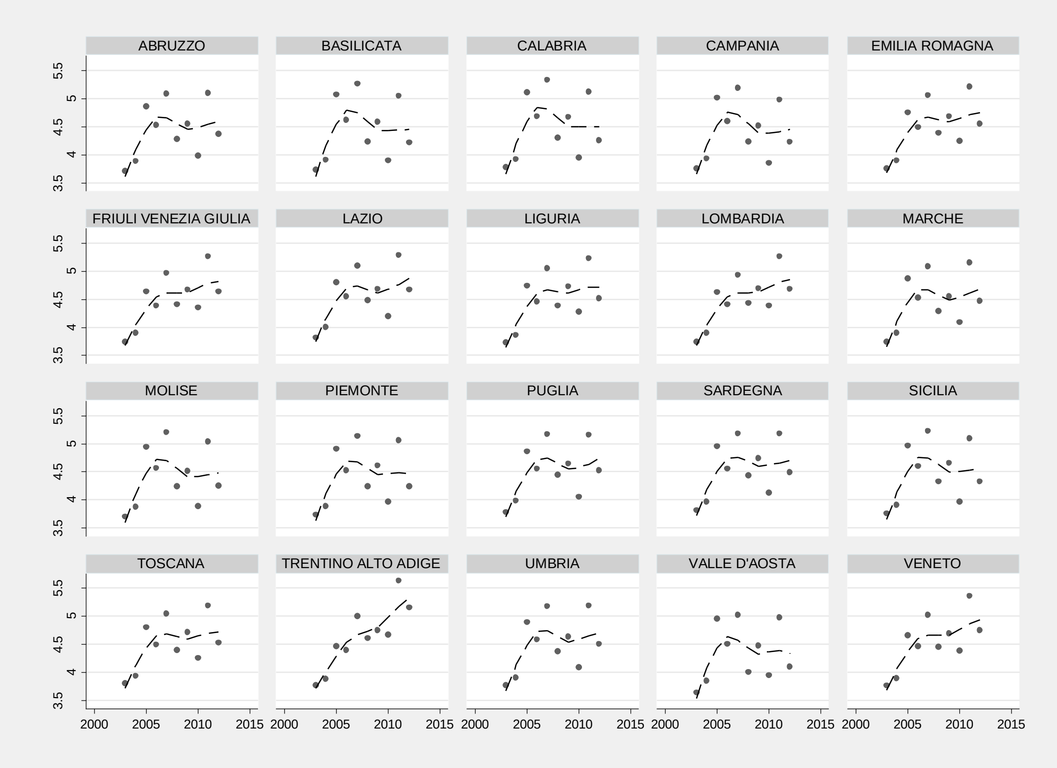

Table 1: Innovation variable (t) – detailed descriptive statistics

Innovation (t)	Mean	Std Dev	Coef Var	Min	Max	P(10)	P(25)	Median	P(75)	P(90)
2003	1.501	0.047	0.031	1.418	1.572	1.440	1.461	1.503	1.536	1.567
2004	1.019	0.018	0.018	0.990	1.064	0.998	1.007	1.013	1.029	1.042
2005	2.328	0.122	0.053	2.054	2.540	2.166	2.259	2.337	2.415	2.471
2006	1.164	0.053	0.046	1.064	1.323	1.116	1.128	1.158	1.185	1.221
2007	1.642	0.038	0.023	1.526	1.693	1.611	1.625	1.639	1.667	1.688
2008	1.537	0.077	0.050	1.386	1.661	1.438	1.478	1.547	1.602	1.618
2009	1.463	0.041	0.028	1.383	1.565	1.411	1.440	1.462	1.493	1.503
2010	1.102	0.149	0.135	0.941	1.507	0.945	0.978	1.076	1.174	1.284
2011	2.588	0.070	0.027	2.422	2.700	2.509	2.541	2.599	2.633	2.688
2012	0.757	0.099	0.130	0.631	0.991	0.640	0.663	0.757	0.824	0.881
SD overall	0.550									
SD between	0.024									
SD within	0.550									

Table 2: Innovation variable (t, t-1, t-2) – detailed descriptive statistics

Innovation (t, t-1, t-2)	Mean	Std Dev	Coef Var	Min	Max	P(10)	P(25)	Median	P(75)	P(90)
2003	3.753	0.041	0.011	3.637	3.815	3.705	3.736	3.758	3.774	3.810
2004	3.913	0.038	0.010	3.856	4.006	3.867	3.892	3.905	3.927	3.975
2005	4.844	0.163	0.034	4.468	5.116	4.625	4.741	4.869	4.953	5.042
2006	4.524	0.078	0.017	4.378	4.684	4.401	4.476	4.531	4.574	4.613
2007	5.112	0.105	0.020	4.925	5.327	4.978	5.038	5.096	5.187	5.246
2008	4.349	0.128	0.029	4.000	4.610	4.236	4.263	4.381	4.431	4.471
2009	4.638	0.079	0.017	4.481	4.755	4.519	4.572	4.658	4.695	4.731
2010	4.129	0.214	0.052	3.847	4.670	3.889	3.960	4.089	4.267	4.386
2011	5.177	0.145	0.028	4.981	5.627	5.010	5.082	5.170	5.243	5.315
2012	4.474	0.240	0.054	4.109	5.146	4.220	4.255	4.498	4.597	4.714
SD overall	0.472									
SD between	0.061									
SD within	0.468									

Table 3: Newly released models by brand and year (own elaboration on Quattroruote data)

Brand	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
ALFA ROMEO	0	1	3	1	2	1	0	1	0	1	0	0
AUDI	0	1	1	2	1	3	1	1	3	3	0	2
AUTOBIANCHI	0	0	0	0	0	0	0	0	0	0	0	0
BMW	3	0	2	2	1	3	5	2	3	2	3	1
CHEVROLET-DAEWOO	1	2	1	1	7	2	0	2	1	2	3	0
CITROEN	1	1	2	2	2	0	1	4	2	2	2	1
FIAT	1	1	2	1	4	1	2	1	2	0	3	0
FORD	0	3	0	1	0	2	3	4	0	1	9	1
HYUNDAI	3	2	0	1	0	3	1	1	1	3	0	2
KIA	0	1	3	3	1	3	1	1	2	2	1	1
LANCIA	0	2	1	1	0	1	1	0	0	0	3	0
MERCEDES	3	2	1	3	4	2	2	2	2	1	6	4
NISSAN	1	1	2	2	1	2	1	2	2	3	2	0
OPEL	1	1	2	1	1	3	2	1	0	1	2	2
PEUGEOT	1	1	0	1	2	0	3	2	3	2	0	0
RENAULT	1	4	2	1	3	0	2	3	1	2	1	2
ROVER	0	0	1	0	0	0	0	0	0	0	0	0
SEAT	1	1	0	2	1	0	0	1	1	1	0	2
SKODA	0	1	0	1	0	1	1	1	1	0	0	1
SMART	0	0	1	2	0	0	1	0	0	0	0	0
SUZUKI	1	1	1	0	1	2	0	1	1	1	0	1
TOYOTA	3	0	1	2	2	1	1	2	5	0	2	1
VOLKSWAGEN	1	2	2	0	3	1	1	2	2	5	3	1
VOLVO	0	1	1	1	1	2	1	0	0	0	0	2

Table 4: Aggregate deregistered cars - innovation at t

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dep: total deregistered cars	OLS	OLS	FE	FE	Sys-GMM	Sys-GMM	Diff-GMM	Diff-GMM	NB FE
ln(fleet size,t-1)	1.028***	1.044***	0.876	-0.703	0.0474	0.0156	1.223***	0.419	0.454***
	(0.0208)	(0.0369)	(1.125)	(0.597)	(0.0412)	(0.0398)	(0.264)	(0.338)	(0.0824)
Innovation (t)	0.215*	0.296**	0.0643	0.133***	0.0273	0.0231	0.0445	0.0339	0.121**
	(0.108)	(0.113)	(0.0497)	(0.0437)	(0.0550)	(0.0527)	(0.0485)	(0.0422)	(0.0590)
Lag dep variable					0.950***	0.987***	0.513***	0.313***	
					(0.0397)	(0.0378)	(0.0798)	(0.117)	
Constant	-3.702***	-4.036***	-1.350	21.81**	-0.138	-0.0782			-0.852
	(0.254)	(0.522)	(15.67)	(8.761)	(0.170)	(0.179)			(1.177)
Weights	No	Yes	No	Yes	No	Yes	No	Yes	No
N	200	200	200	200	200	200	180	180	200
R sq	0.985	0.973	0.807	0.872					
R sq within			0.807	0.872					
F	1146.9	487.9	224.8	221.5					
Chi sq					66849.6	42812.1	1759.1	2466.1	997.6
Sargan					71.37	55.75	62.23	63.32	
Sargan (p-value)					0.0470	0.372	0.0363	0.0296	
AR(1) test					-3.573	-3.875	-3.890	-2.576	
AR(1) p-value					0.000353	0.000106	0.000100	0.00999	
AR(2) test					-1.893	-1.453	-1.359	-1.342	
AR(2) p-value					0.0583	0.146	0.174	0.180	

Standard errors in parenthesis. Standard errors are clustered by region in columns 1, 2, 3 and 4. * p<0.1; ** p<0.05; *** p<0.01

Table 5: Aggregate deregistered cars - innovation at t, t-1, t-2

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dep: total deregistered cars	OLS	OLS	FE	FE	Sys-GMM	Sys-GMM	Diff-GMM	Diff-GMM	NB FE
ln(fleet size,t-1)	1.027***	1.044***	0.941	-0.611	0.0534	0.0203	1.344***	0.537	0.463***
	(0.0209)	(0.0368)	(1.122)	(0.598)	(0.0412)	(0.0402)	(0.268)	(0.349)	(0.0825)
Innovation (t,t-1,t-2)	0.182**	0.228***	0.0717**	0.112***	0.0426	0.0233	0.0826**	0.0576*	0.0938**
	(0.0781)	(0.0782)	(0.0316)	(0.0217)	(0.0332)	(0.0334)	(0.0350)	(0.0327)	(0.0368)
Lag dep variable					0.944***	0.982***	0.522***	0.307***	
					(0.0398)	(0.0382)	(0.0799)	(0.118)	
Constant	-4.034***	-4.451***	-2.435	20.22**	-0.324	-0.183			-1.139
	(0.273)	(0.545)	(15.64)	(8.793)	(0.231)	(0.250)			(1.194)
Weights	No	Yes	No	Yes	No	Yes	No	Yes	No
N	200	200	200	200	200	200	180	180	200
R sq	0.985	0.973	0.810	0.875					
R sq within			0.810	0.875					
F	1073.7	635.5	295.1	286.0					
Chi sq					67435.4	43058.9	1746.0	2464.8	1012.1
Sargan					70.59	56.19	56.84	60.91	
Sargan (p-value)					0.0534	0.356	0.0928	0.0463	
AR(1) test					-3.545	-3.853	-3.774	-2.437	
AR(1) p-value					0.000393	0.000117	0.000161	0.0148	
AR(2) test					-1.916	-1.452	-1.315	-1.429	
AR(2) p-value					0.0554	0.147	0.189	0.153	

Standard errors in parenthesis. Standard errors are clustered by region in columns 1, 2, 3 and 4. * p<0.1; ** p<0.05; *** p<0.01

Table 6: Simulation of deregistration keeping innovation at 2003 levels ($\beta^{INNO} = 0.112$; own elaboration on ACI data)

	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total
Deregistrations predicted by deviations from innovation in 2003	32,174	216,001	147,144	281,557	154,962	185,595	91,032	286,188	125,417	1,520,070
Actual deregistrations	1,739,460	1,685,639	1,767,420	2,158,630	1,761,276	1,918,254	1,638,759	1,388,641	1,411,695	15,469,774
Share of deregistrations induced by innovation	1.85%	12.81%	8.33%	13.04%	8.80%	9.68%	5.55%	20.61%	8.88%	9.83%

Figure 5: Average effect of innovation (t, t-1, t-2) on deregistration by age cutoffs (weighted FE and Diff-GMM estimates)

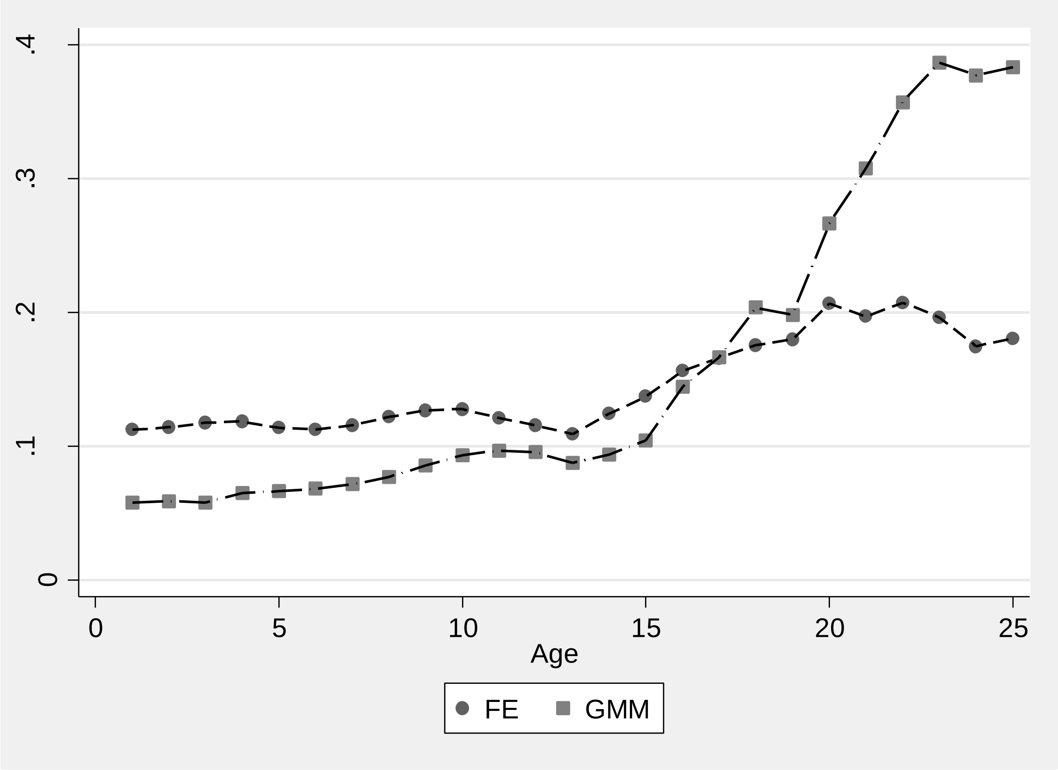

Table 7: Effect of the 2009 scrapping scheme on deregistration rate. Baseline specification (fixed effects model)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	log(radiation) age=8	log(radiation) age=9	log(radiation) age=10	log(radiation) age=11	log(radiation) age=12	log(radiation) age=13	log(radiation) 10 or older	10 or older / 9 or younger
log(radiation) age=7 or older	0.315***							
	(0.0845)							
log(radiation) age=8 or older		0.389***						
		(0.104)						
log(radiation) age=9 or older			0.396***	0.345***	0.244***	0.212***	0.217***	
			(0.0973)	(0.0577)	(0.0436)	(0.0645)	(0.0669)	
Share flett (t-1) with age 11 or older	-2.808***	-1.816***	-0.822	0.154	0.986	2.605***	2.289***	47.93***
	(0.624)	(0.560)	(0.749)	(0.617)	(0.747)	(0.569)	(0.625)	(15.80)
D_2004	0.213***	0.0365	-0.0112	-0.506***	-0.175***	-0.125***	-0.0846***	-1.848***
	(0.0303)	(0.0370)	(0.0299)	(0.0221)	(0.0189)	(0.0280)	(0.0255)	(0.225)
D_2005	0.443***	0.100*	-0.00510	-0.555***	-0.549***	-0.0275	-0.135**	-2.005***
	(0.0384)	(0.0546)	(0.0548)	(0.0394)	(0.0399)	(0.0526)	(0.0529)	(0.533)
D_2006	0.568***	0.345***	0.00474	-0.603***	-0.680***	-0.476***	-0.167**	-2.736***
	(0.0472)	(0.0630)	(0.0672)	(0.0536)	(0.0490)	(0.0597)	(0.0600)	(0.572)
D_2007	0.628***	0.458***	0.273***	-0.472***	-0.454***	-0.218***	0.00187	-2.701***
	(0.0752)	(0.0861)	(0.0901)	(0.0659)	(0.0586)	(0.0743)	(0.0671)	(0.593)
D_2008	0.528***	0.313***	0.169**	-0.470***	-0.539***	-0.489***	-0.210***	-3.380***
	(0.0728)	(0.0792)	(0.0773)	(0.0551)	(0.0484)	(0.0576)	(0.0577)	(0.502)
D_2009	0.432***	0.156***	0.702***	0.100**	0.0327	-0.351***	0.0186	-1.697***
	(0.0493)	(0.0528)	(0.0442)	(0.0395)	(0.0310)	(0.0351)	(0.0353)	(0.346)
D_2010	0.484***	0.339***	0.261***	-0.289***	-0.325***	-0.270***	-0.229***	-3.508***
	(0.0443)	(0.0479)	(0.0553)	(0.0356)	(0.0279)	(0.0270)	(0.0321)	(0.349)
D_2011	0.404***	0.248***	0.173***	-0.527***	-0.698***	-0.611***	-0.424***	-4.620***
	(0.0429)	(0.0472)	(0.0567)	(0.0243)	(0.0331)	(0.0221)	(0.0277)	(0.571)
D_2012	0.385***	0.172***	0.0487	-0.574***	-0.715***	-0.777***	-0.498***	-5.946***
	(0.0643)	(0.0581)	(0.0649)	(0.0301)	(0.0355)	(0.0228)	(0.0330)	(0.927)
F	522.4	517.4	476.3	161.3	748.0	489.0	131.8	31.01
R sq	0.938	0.913	0.922	0.908	0.945	0.931	0.885	0.803
N	200	200	200	200	200	200	200	200

Robust standard errors in parenthesis. * p<0.1; ** p<0.05; *** p<0.01

Table 8: Differential effect year-by-year for specification 7 of Table 7

Year	Coeff	t stat
2004	-0.085	-3.317
2005	-0.050	-1.662
2006	-0.033	-2.082
2007	0.169	9.592
2008	-0.212	-15.978
2009	*0.228*	*8.347*
2010	-0.248	-19.013
2011	-0.195	-9.671
2012	-0.074	-5.090

Figure 6: Quadratic fit (different for age<10 and age>=10) by region in 2008

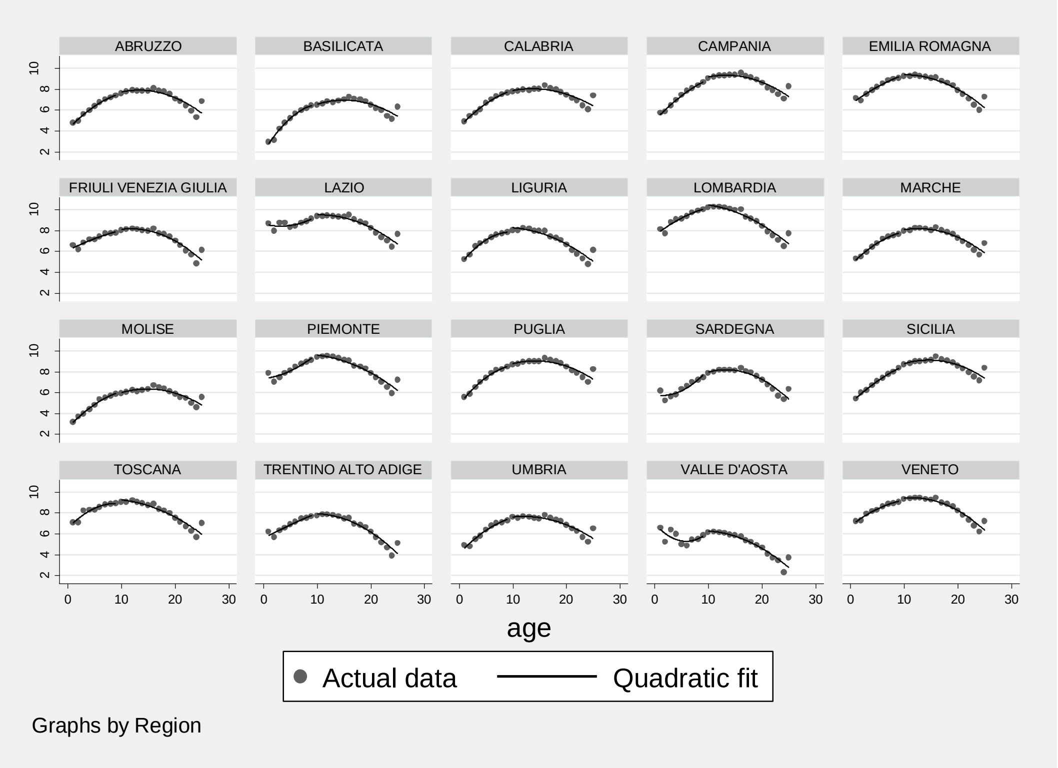

Figure 7: Quadratic fit (different for age<10 and age>=10) by region in 2009

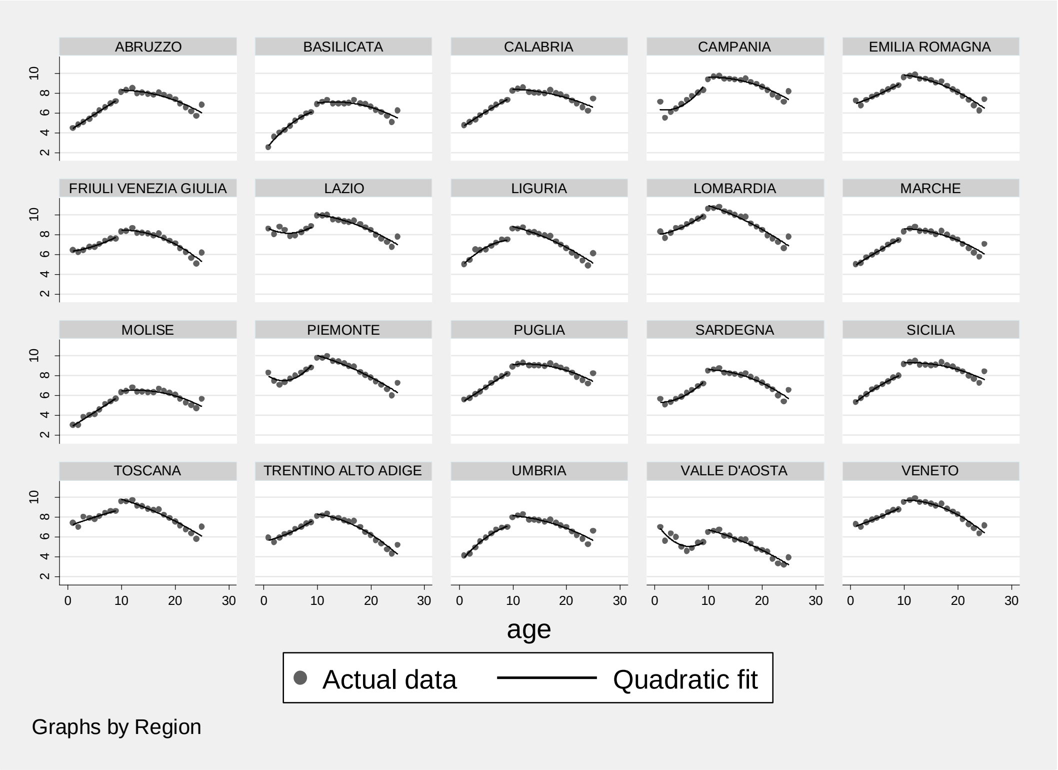

Figure 8: Quadratic fit (different for age<10 and age>=10) by region in 2010

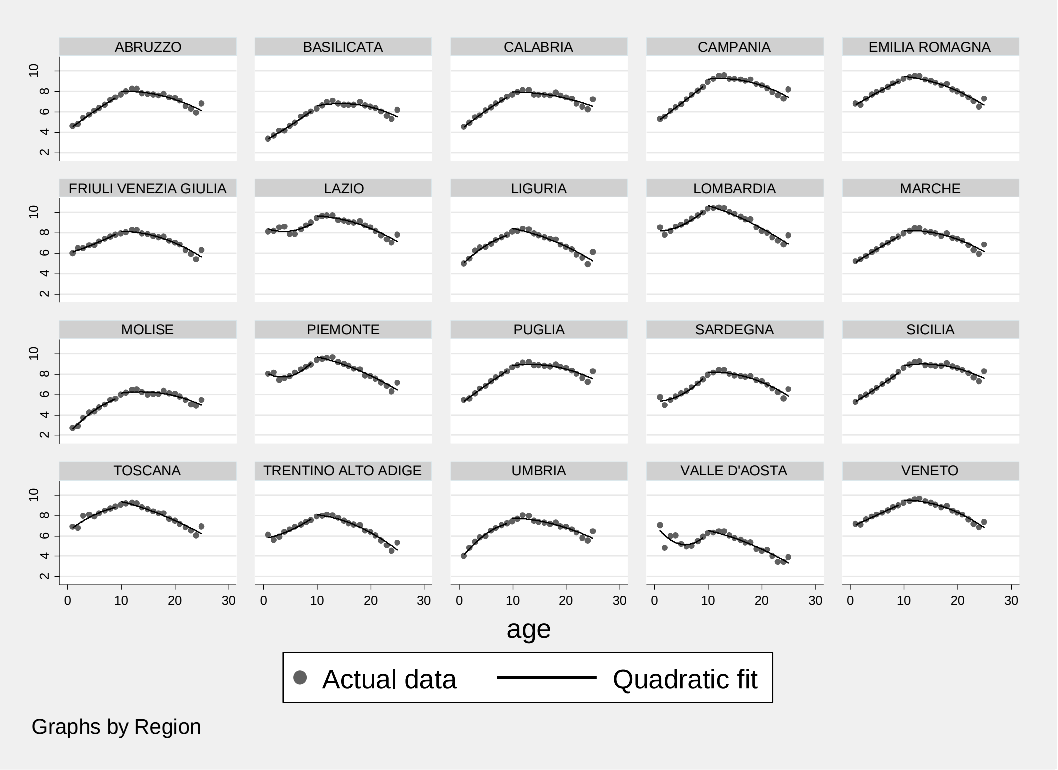

Table 9: RDD (linear fit)

Dep: log(radiation)	(1) Y=2005	(2) Y=2006	(3) Y=2007	(4) Y=2008	(5) Y=2009	(6) Y=2010	(7) Y=2011	(8) Y=2012
Age	0.268***	0.300***	0.296***	0.279***	0.247***	0.271***	0.270***	0.224***
	(0.0188)	(0.0180)	(0.0175)	(0.0170)	(0.0167)	(0.0155)	(0.0146)	(0.0153)
Age x D(age>=10)	-0.446***	-0.471***	-0.472***	-0.448***	-0.436***	-0.428***	-0.413***	-0.354***
	(0.0204)	(0.0195)	(0.0189)	(0.0184)	(0.0181)	(0.0168)	(0.0158)	(0.0166)
D(age>=10)	5.245***	5.180***	5.199***	4.917***	5.562***	4.962***	4.687***	4.132***
	(0.178)	(0.170)	(0.165)	(0.161)	(0.158)	(0.147)	(0.138)	(0.145)
F	98.61	107.3	109.3	110.2	129.0	134.2	151.4	125.0
R sq	0.820	0.832	0.835	0.836	0.856	0.861	0.875	0.852
N	500	500	500	500	500	500	500	500

Region dummies included. Robust standard errors in parenthesis. * p<0.1; ** p<0.05; *** p<0.01

Table 10: RDD (quadratic fit)

Dep: log(radiation)	(1) Y=2005	(2) Y=2006	(3) Y=2007	(4) Y=2008	(5) Y=2009	(6) Y=2010	(7) Y=2011	(8) Y=2012
Age	0.254***	0.352***	0.410***	0.370***	0.157**	0.215***	0.302***	0.298***
	(0.0808)	(0.0742)	(0.0723)	(0.0711)	(0.0729)	(0.0677)	(0.0633)	(0.0678)
Age sq	0.00140	-0.00517	-0.0114	-0.00912	0.00905	0.00560	-0.00320	-0.00741
	(0.00788)	(0.00724)	(0.00705)	(0.00693)	(0.00711)	(0.00661)	(0.00617)	(0.00661)
Age x D(age>=10)	0.0460	0.0612	-0.0387	-0.0301	-0.00825	-0.0502	-0.115	-0.170**
	(0.103)	(0.0950)	(0.0925)	(0.0910)	(0.0932)	(0.0867)	(0.0810)	(0.0868)
Age sq x D(age>=10)	-0.0151*	-0.0115	-0.00423	-0.00542	-0.0187**	-0.0148**	-0.00622	0.0000558
	(0.00809)	(0.00743)	(0.00724)	(0.00712)	(0.00729)	(0.00678)	(0.00634)	(0.00679)
D(age>=10)	1.324**	0.515	0.950*	0.942*	2.649***	2.238***	2.059***	2.172***
	(0.567)	(0.521)	(0.508)	(0.499)	(0.511)	(0.475)	(0.444)	(0.476)
F	102.9	122.5	123.4	121.7	128.1	133.5	152.7	121.0
R sq	0.839	0.861	0.862	0.860	0.866	0.871	0.885	0.859
N	500	500	500	500	500	500	500	500

Region dummies included. Robust standard errors in parenthesis. * p<0.1; ** p<0.05; *** p<0.01

Table 11: RDD with linear region-specific fit

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dep: log(radiation)	Y=2005	Y=2006	Y=2007	Y=2008	Y=2009	Y=2010	Y=2011	Y=2012
D(age>=10)	5.245***	5.180***	5.199***	4.917***	5.562***	4.962***	4.687***	4.132***
	(0.136)	(0.136)	(0.129)	(0.114)	(0.105)	(0.0912)	(0.0875)	(0.0878)
F	68.28	66.75	71.88	88.10	118.0	140.3	150.2	139.3
R sq	0.903	0.901	0.908	0.923	0.942	0.950	0.954	0.950
N	500	500	500	500	500	500	500	500

Region-specific linear included. Robust standard errors in parenthesis. * p<0.1; ** p<0.05; *** p<0.01

Table 12: RDD with quadratic region-specific fit

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dep: log(radiation)	Y=2005	Y=2006	Y=2007	Y=2008	Y=2009	Y=2010	Y=2011	Y=2012
D(age>=10)	1.324***	0.515	0.950***	0.942***	2.649***	2.238***	2.059***	2.172***
	(0.400)	(0.377)	(0.354)	(0.307)	(0.295)	(0.252)	(0.249)	(0.258)
F	55.10	61.29	66.83	85.60	102.5	127.3	127.5	110.9
R sq	0.932	0.939	0.944	0.955	0.963	0.970	0.970	0.965
N	500	500	500	500	500	500	500	500

Region-specific quadratic included. Robust standard errors in parenthesis. * p<0.1; ** p<0.05; *** p<0.01

Table 13: Distribution of the car fleet by 'Euro' environmental standard and year (own elaboration on ACI data)

Year	Euro0	Euro1	Euro2	Euro3	Euro4	Euro5	Euro6	Other	Total
2005	23.59%	15.10%	26.63%	27.45%	7.19%	0.00%	0.00%	0.15%	100%
2006	18.32%	11.88%	28.90%	24.71%	16.11%	0.00%	0.00%	0.01%	100%
2007	15.93%	9.61%	27.26%	24.05%	22.96%	0.00%	0.00%	0.05%	100%
2008	14.45%	8.20%	25.29%	23.28%	28.53%	0.00%	0.00%	0.06%	100%
2009	13.32%	6.92%	22.76%	22.73%	33.33%	1.07%	0.00%	0.07%	100%
2010	12.50%	6.02%	20.52%	21.90%	36.24%	2.82%	0.00%	0.07%	100%
2011	11.93%	5.30%	18.80%	21.01%	34.77%	8.21%	0.01%	0.02%	100%
2012	11.53%	4.79%	17.30%	20.23%	34.23%	11.84%	0.03%	0.02%	100%

Table 14: Average CO2 emissions (g/km) of new cars (own elaboration on Eurostat data)

Country	2007	2008	2009	2010	2011	2012	2013
France	149.4	140.1	133.5	130.5	127.7	124.4	117.4
Germany	169.5	164.8	154	151.1	145.6	141.6	136.1
Italy	146.5	144.7	136.3	132.7	129.6	126.2	122.4
Spain	153.2	148.2	142.2	137.9	133.8	128.7	122.4
United Kingdom	164.7	158.2	149.7	144.2	138	132.9	128.3
EU27	158.7	153.6	145.7	140.3	135.7	132.2	127

Table 15: Waste generated from end-of-life vehicles for selected EU countries (in tons, own elaboration on Eurostat data)

Country	2007	2008	2009	2010	2011
France	837,000	875,144	1,046,624	1,464,843	1,548,451
Germany	449,280	420,424	387,693	1,596,831	516,128
Italy	1,310,050	1,472,446	1,106,929	1,379,027	1,240,204
Spain	885,689	839,194	712,440	913,787	805,623
United Kingdom	970,582	1,105,480	1,175,195	1,289,019	1,123,872
EU26 (Malta not included)	5,781,185	6,030,229	5,938,676	8,371,553	7,196,107