Sector CO2 and SOx emissions efficiency and investment: homogeneous vs heterogeneous estimates using the Italian NAMEA

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Abstract

The relationships between emissions ad economic drivers differ substantially both across countries and across sectors. In this paper I investigate cross-sector heterogeneity of emissions (CO_2 and SOx) / investments relationships of Italian branches for the period 1990-2006 by using the Italian NAMEA (National Accounting Matrix including Environmental Accounts). The 'environmental' direction of investments in different types of capital goods is crucial in the prediction of future patterns of environmental efficiency due to the persistence of the choices regarding the features of the capital stock.

Within this relationship, the role of variations in prices of energy fuels and in environmental taxes is considered to identify relevance and the direction of the technical changes induced by prices and taxes.

I compare homogeneous estimates (FE) with heterogeneous estimates (SUR): homogeneity of slopes across branches is always rejected (aggregation bias). Furthermore, results differ substantially between CO_2 and SOx, due to different environmental and economic features of the two types of emissions. Results show a relevant role of economic forces (investments) in explaining CO_2 dynamics while SOx trends are determined to higher extent by exogenous events. The potential role of ICTs in promoting more environmental efficient production processes has not been exploited yet by Italian manufacturing sectors.

Keywords: NAMEA, SUR, eco-innovation, emissions efficiency

1 Introduction

In this paper I investigate the direction in terms of emissions efficiency of investments in different goods by the Italian manufacturing sectors. The 'environmental' direction of investments in different types of capital goods is crucial in the prediction of future patterns of environmental efficiency due to the persistence of the choices regarding the features of the capital stock. The (environmental) features of current investments determines a lock-in in a particular technology for a relatively long period, with relevant effects on the costs associate to future (more stringent) environmental policies.

In recent years, a number of works has been published in the field of the identification of the economic drivers of sector emissions. These works use fairly heterogeneous specifications, all of them imposing homogeneity of the parameters across sectors[1]. Cole et al (2005) and Cole et al (2008) identify the drivers of different types of emissions of manufacturing sectors for, respectively, the UK and China. Some recent paper exploited the quite long time series of the NAMEA database for Italian emissions in order to estimate reduced form relationships between sector productivity and emissions performance (Mazzanti et al, 2008; Mazzanti and Zoboli, 2009; Marin and Mazzanti, 2009a,b), finding evidence of absolute delinking for pollutants and weak relative delinking for CO_2 emissions. Finally, the paper by Carrión-Flores and Innes (2010) investigates and estimates empirically a structural model of environmental innovation for the US manufacturing sectors as regards toxic air pollution.

In this paper, the analysis is restricted to manufacturing sectors. The focus of the analysis will be on two types of emissions: carbon dioxide (CO_2 henceforth) and sulphur oxides (SOx henceforth). Investments are likely to affect the two types of emissions in a different way. CO_2 is a global externality, with no local effects: for this reason no stringent specific policy has been introduced until recent years. Furthermore, due to the fact that CO_2 cannot be abated through end-of-pipe devices, the only channel through which it may be reduced is the improvement of energy efficiency. On the other hand, SOx is a pollutant characterized by local negative externalities: it has been strictly regulated through command-and-control policies since mid-80s in all European countries. The important difference of SOx relative to CO_2 is that it may be abated by the introduction of end-of-pipe devices to existing plants, even without any energy-saving technological change. In addition to investment behaviours, I test the possibility that the level of emissions has been influenced by variations in absolute and relative energy prices and environmental taxes through changes in the energy mix, (temporary) adjustment to the scale of production and induced technological change (for a survey on the relationship between the environment and technogical change see Popp et al (2009), while for an empirical study on the role of energy prices in inducing environmental patent creation see Popp (2002)).

One of the main empirical contribution of this paper is the comparison of homogeneous estimates with heterogeneous (SUR, seemingly unrelated regressions) estimates. Results suggest that investments/emissions relationship is characterized by highly heterogeneous sector-specific paths while homogeneous estimates are the result of compensations of different (and sometimes diverging) effects which are worth to be investigated. However, due to the reduced time series, heterogeneous results are fairly volatile.

The paper is organized as follows. Section 2 describes the methodology I use and the source and structure of the data. Section 3 presents and discusses the main findings for homogeneous and heterogeneous estimates. Section 4 concludes.

[1] The paper by Marin and Mazzanti (2009b) is an exception where sector heterogeneous estimates are performed on a reduced form model (emissions per worker as a polynomial function of labour productivity). Sector heterogeneity is found to be relevant, as well as the aggregation bias in homogeneous estimates.

2 Methodology and data

2.1 Methodology

The main objective of this empirical paper is to identify the direction in terms of environmental efficiency of investments by Italian manufacturing sectors.

We estimate the following model:

$$\begin{aligned} \ln(E_{st}) &= \alpha_s + \sum_i \beta_i ln(I_{ist-1}) + \delta ln(L_{st}) + \sum_j \gamma_j Energy\_prices_{jt} + \\ &+ \sum_k \eta_k Env\_tax_{kt} + \varepsilon_{st} \end{aligned} \quad (1)$$

where E_{st} are emissions of sector s in year t, I_{ist-1} are gross investment in five types of capital goods, L_{st} are sectoral full-time equivalent workers, $Energy\_prices_{jt}$ are relative industry real prices for coal, oil and gas and a price index for the actual mix of energy consumption by industry and Env_tax_{kt} are taxes as % of GDP on transportation, pollution and energy products.

I use lagged investments instead of contemporaneous investments for three reasons. First, new capital goods are likely to enter gradually the production process due to installation and test procedures that could take long time. Second, lagged investment are predetermined relative to current emissions, avoiding reverse causality problems determined by the links between the scale of production and the level of emissions. Third, the lag of investments relative to energy prices and environmental taxes allows to consider investments made in $t-1$ as a response to expected (proxied by actual) energy prices and environmental taxes in t.

Equation 1 is estimated for all 14 manufacturing branches (see Table 1) and separately for the 10 main emitters in 1990 of CO_2 (see Figure 1) and SOx (see Figure 2) respectively[2] with sector fixed effects and 3-years time dummies[3]. Results for the sub-samples of main emitters are relevant due the uneven distribution of emissions across sectors[4].

SUR (Seemingly Unrelated Regressions[5]) estimates use a similar specification. Due to the relatively short time span, I excluded alternatively environmental taxes or energy prices. For sake of brevity only results including energy prices are reported (results with environmental taxes are available upon request). SUR method allows to estimate in an efficient way individual (sector) specific parameters for the different independent variables. When dealing with sectors, sector-specific structural relations needs to be addressed by

[2] DA, DB, DE, DF, DG, DH, DI, DJ, DK and DM for CO_2 and DA, DB, DC, DD, DF, DG, DH, DI, DJ and DK for SOx

[3] Single-year time dummies are not allowed because they are collinear with the sector-invariant measures of energy prices and environmental taxes.

[4] In 1990, the 10 main emitters of carbon dioxide within manufacturing were responsible of 97.64% of emissions by manufacturing, 38.98% of emissions by economic activities and 37.09% of total Italian emissions while the role of the 10 main emitters of SOx within manufacturing was, respectively, of 97.12%, 40.49% and 33.05%.

[5] See Zellner (1962, 1963); Zellner and Huang (1962).

allowing a sufficient level of flexibility[6] to avoid implicit compensations as in the FE model. SUR estimates are performed on the sub-sample of the 10 main emitters for carbon dioxide and SOx respectively in order to have sufficient degrees of freedom.

[FIGURE 1 ABOUT HERE]

[FIGURE 2 ABOUT HERE]

Gross investments affect sector emissions through different channels.

Substitution of obsolete capital stock. New capital goods may replace obsolete and/or spoiled physical capital. If the scale of production does not increase, the effect on emissions depends on the relative energy/emissions efficiency of the new goods. I expect that the relative environmental efficiency depends on the expected relative and absolute energy prices and on the expected stringency of environmental regulations[7].

Extension of the productive capacity. An increase of the scale of production determined by the extension of the productive capacity for a given average level of emissions efficiency should increase total emissions. On the other hand, if the new additional capital goods are more (less) environmental efficient, total emissions in the long run may reduce (further increase) once obsolete physical capital, which is less (more) environmental efficient, will exit the production process. Finally, there is the possibility that new capital goods complement the existing stock in order to improve efficiency (both economic and environmental through energy savings)[8].

Role of 'light' investments. The level of investment in 'light' capital goods such as equipment for offices and communication and software may be seen as an indicator of the speed of adoption of information and communication technologies (ICTs henceforth) by the different sectors. As pointed out by recent works carried out by OECD (OECD, 2009c,b,a), ICTs may contribute to reduce emissions through three different channels (OECD, 2009a). The first, only marginal in the current analysis, passes through direct effects such as the direct production and disposal of ICT goods. The second channel regards the role of ICTs in improving the energy efficiency of the whole economic system (enabling effect). The third channel is related to systematic effects. ICTs have the potential of "*facilitate behavioural and organisational changes towards sustainability [...] moving beyond energy-efficiency improvements in existing processes towards the development of new innovative products and processes that radically alter (and improve) environmental footprints*" (OECD, 2009a).

[6] One case of relevant sector-specific patterns within the productivity/environmental efficiency relation framework is investigated by Marin and Mazzanti (2009b), finding highly heterogeneous relations between labour productivity and emissions per worker for Italian manufacturing sectors.

[7] As other European countries, Italy experienced a shift back to coal in periods of high oil and gas relative prices, with a negative effect on emissions efficiency.

[8] An example might be the substitution of an energy-inefficient engine of a machinery with a more energy- and/or time- efficient one, with an increase in the productive capacity accompanied by an overall increase in energy efficiency.

Finally, I account for the role of total and relative prices of energy fuels and for the intensity of environmental taxes to control for the effect on emissions of induced technological change (see Popp et al (2009) for a survey of the role of induced technological change for environmental efficiency and Popp (2002) as an example of empirical study on the role of energy prices as driver of environmental technological change).

2.2 Data

I use NAMEA tables for Italy (provided by Istat) for the period 1990-2006, with a 2-digit Nace disaggregation level. In the NAMEA tables, environmental pressures (for Italian NAMEA air emissions and virgin material withdrawal) and economic data (from national accounts) are assigned to the economic branches of resident units or to the household consumption categories directly responsible for environmental and economic phenomena[9].

I merge these data on emissions (considering emissions of carbon dioxide and sulphur oxides only) with national sectoral accounts on capital stock and investment trends for 9 categories of capital goods[10], with the same Nace disaggregation as NAMEA and coverage 1980-2006. Istat provides a disaggregation in 9 categories of investments: machinery, equipment for offices, equipment for communication, furniture, road vehicles, other vehicles[11], buildings, software and other goods not elsewhere specified.

To reduce the problems related to the instability and the truncation of some series for various sectors, I reduce to 5 the number of categories. I merge in a unique variable the investments in equipment for offices and communication, the investments in software and the investments in other goods not elsewhere specified because of problems of truncation of the data as regards the investments in some of these categories[12], high volatility of the series, small proportion of each of these categories on total investments and the possibility to identify them in the broad category of information and communication technologies (ICTs).

Data on environmental taxes come from the set of environmental accounts provided by Istat (coverage 1990-2006) and are expressed as % of GDP[13]. Finally, energy prices[14] (see Figure 3 for the trends of the price index and for relative prices) for industry come from IEA (coverage 1990-2006).

[FIGURE 3 ABOUT HERE]

[FIGURE 4 ABOUT HERE]

[9] For an exhaustive overview of the system of environmental accounts refer to the so-called SEEA 2003 (United Nations et al, 2003).

[10] The list of the products included in each category is reported in Table 2. Data on investments come from the database 'Investimenti fissi lordi per branca proprietaria, stock di capitale e ammortamenti' by Istat.

[11] Investments in Other vehicles are not performed by manufacturing branches.

[12] An example is sector DF, for which no investments in Equipment for communication is reported for the period 2002-2005.

[13] See Figures 4 and 5 for the trends of taxes, in absolute and relative terms respectively.

[14] Expressed as real price index for industry.

[FIGURE 5 ABOUT HERE]

3 Results

3.1 Homogeneous estimates

Tables 4 and 5 summarize the homogeneous fixed effect estimates[15] for CO_2 and SOx respectively. In columns 1 and 2 (with 3-year time dummies) I report the estimates for all 14 manufacturing sectors while in columns 3 and 4 (with 3-year time dummies) I report the estimates for the 10 main emitters within manufacturing.

3.1.1 Homogeneous estimates for CO_2

Investments in machinery affect positively sector CO_2 emissions, with an elasticity which is significant and robust to the different specifications. The effect is likely to be linked to the role of the scale of production: new investments increase the scale (or the number) of the plants and, in absence of a significant improvement of energy efficiency, emissions of CO_2 should increase with the size (or the number) of the plants.

Investments in road vehicles affect negatively sector CO_2 emissions, even if the result is not robust to the inclusion of time dummies[16]. The negative effect is consistent to the replacement of the oldest (and most polluting) vehicles within the fleet with new (and more efficient) road vehicles as a response of increasing prices for energy fuels and fiscal incentives for new more efficient road vehicles.

The effect of investments in new buildings and in new furniture on sector emissions is negative, even if it is less statistically robust as regards investments in furniture. This evidence suggests that new buildings, built to substitute in the medium run old buildings, are on average more energy efficient (e.g. better insulation) than existing buildings. However, the size of the effect is relatively low suggesting limited possibility for further important improvements. Investments in furniture might be seen as a proxy for the relevance of administrative, commercial and managerial activities in improving the economic (and environmental) performance of the firms within each sector. The negative effect suggests an improvement of the environmental performance (weakly confirmed by the estimates on SOx emissions) linked to increases in the administrative, commercial and managerial activities within manufacturing firms.

'Light' investments have a weak positive effect on sector CO_2 emissions only when I consider the sub-sample of main emitters. This effect, confirmed by the estimates on SOx emissions, reflects the inability of Italian manufacturing sectors[17] of exploit extensively the potentialities of ICTs in order to improve the energy efficiency of the production processes.

[15] I report robust standard errors (clustered by sector) due to significant groupwise heteroschedasticity in all FE estimates.

[16] This may depend on the fact that investments in road vehicles have similar trends for all manufacturing sectors, given that the demand for road vehicle is highly elastic to variations of prices (e.g. periodical incentives for road vehicles).

[17] In section 3.2.1 I will show that some important capital-intensive sector had exploited effectively ICTs in order to improve energy (and environmental) efficiency.

A meaningful interpretation of the effect of relative and absolute energy prices and of environmental taxes may be done only in estimates which include 3-years dummy variables. In fact, these sector-invariant variables may capture temporal trends which are common to all sectors instead of induced technical changes. Relative and absolute energy prices and environmental taxes has no significant effect on CO_2 emissions dynamics.

Finally, the elasticity of emissions relative to the level of employment is positive (< 1), significant and robust to the different specifications. As pointed out in section 2, labour is a variable which represents the scale of the economic activity of a sector: the robust relationship between labour and emissions at the aggregate level is a signal of strong scale effects of sector emissions.

[TABLE 4 ABOUT HERE]

3.1.2 Homogeneous estimates for SOx

First note that, relative to CO_2, the explanatory power of investments as regards SOx emissions is much lower. This result is consistent with the evidence of delinking for Italy exposed in Marin and Mazzanti (2009b) where SOx abatements are not linked to phenomena at the sector level but to exogenous environmental command-and-control regulations since mid-80s and where sector heterogeneity in productivity/emissions dynamics was much higher than for CO_2.

[TABLE 5 ABOUT HERE]

Investments in machinery do not have any average significant effect on SOx, as well as 'light' investments[18] in road vehicles[19] and in furniture[20].

The effect of investments in new buildings is always positive and robust to the different specifications. This is at odds with the explanation given to the CO_2 emissions-saving effect linked to more energy efficient buildings. However, heterogeneous SUR estimates (see section 3.2.2) predict an average negative (SOx emissions-saving) effect of investments in buildings.

Investments in furniture and in ICTs have only marginal effects, the former weakly significant and negative only in one of the four specifications and the latter weakly significant and positive for the whole manufacturing only. This average picture hide opposite forces that can be disentangled in SUR heterogeneous estimates.

The same caveat as before applies for the interpretation of the effect of energy prices and environmental taxes in specifications without time dummies. Also in this case, SOx dynamics is not affected by absolute and relative energy prices. It will be more clear in the next section that this lack of significance reflects an high degree of heterogeneity in the responses of different sectors to changes in energy prices.

[18] With the exception of a weak positive effect for the manufacturing as a whole, probably driven to the sectors which play a minor role in terms of SOx emissions.

[19] The only significant effect, in column 2, may be linked to the shift of the commercial vehicles fleet towards the new generation of more efficient diesel engines.

[20] For which a weak negative effect is found in column 2.

Environmental taxes are highly significant for SOx emissions. Taxes on transportation, somewhat proportional to energy and environmental efficiency of the vehicles, had a significant and negative effect on SOx emissions, mainly linked to effects on the less polluting sectors (the coefficient is not significant for the regression on the sub-sample of the main SOx emitters in column 4). Taxes on pollution, introduced only since 1993, were somewhat effective[21] in reducing SOx emissions, with an effect which is robust to the various specifications. Finally, the positive effect on SOx emissions of taxes on energy depends on the disproportionate weight of taxes on gasoline and kerosene (with a medium potential of SOx emissions) relative to relatively low taxes on coal (with a high potential of SOx emissions).

Scale effect induced by the dynamics of the employment of the manufacturing sectors is relevant also for SOx, even though the lower statistical significance (the elasticity is significant at the 5% level only in all specifications) implies more space to improvements in SOx emissions efficiency beyond reductions of the scale of production[22].

The results of homogeneous fixed effect estimates are robust to the inclusion of total capital as additional covariate and on slightly different lag structures. For sake of brevity I do not report additional estimates which are available upon request.

3.2 Heterogeneous estimates

Tables 6 and 7 summarize the heterogeneous SUR estimates for CO_2 and SOx respectively while Table 8 contains the results for the test of aggregation bias.

The results for heterogeneous estimates has to be interpreted with caution. In fact, due to the high number of covariates and sectors and to the relatively short time series, the heterogeneous estimates are quite volatile, especially as regards the most persistent variables (i.e. employment). For this reason, in the following sections I will briefly comment on the most relevant deviations of sector-level estimates from the average picture.

Note that the results differ substantially across sectors. The null hypothesis of common slope is rejected for all variables (jointly and separately) and both for CO_2 and SOx (Table 8). Homogeneous estimates are then the result of a compensation among different and sometimes opposite effects, giving only a general (even if interesting) picture.

3.2.1 Heterogeneous estimates for CO_2

The positive effect of investments in machinery on CO_2 emissions is confirmed only for sector DG (chemicals) and, weakly, for sector DI (other non-metallic mineral products) while the effect is negative for DK (Machinery and equipment n.e.c.) and especially for DB (textiles and textile products). This positive effect on environmental efficiency of new machineries, strongly confirmed by sector DB as far as SOx emissions are concerned, is the result of a radical process of structural change of the textile sector during the last two decades in order to compete with new competitors in the world market. The strong negative effect suggest that new capital goods have substituted obsolete goods without significant increases in the productive capacity. On the other hand, the strong positive coefficient

[21] Or highly correlated with other effective environmental policies.

[22] As reminded in the first section, a relatively high proportion of SOx emissions for a given level of energy consumption and a given mix of fuels may be abated through end-of-pipe devices.

for DG (chemicals) might reflect either an extension of the productive capacity or a move to more capital (and energy) intensive production processes. Note that also this sector experienced a strong structural change over the last two decades.

Investments in road vehicles affect positively, on average (with the exception of sectors DH and DJ), sector CO_2 emissions. The effect is particularly robust for sectors DB, DI, DG and DM. As pointed out in the previous section, the only significant effect, in column 2, may be linked to the shift to more economically efficient diesel engines with a negative impact on CO_2 emissions efficiency.

The carbon emissions-saving effect of investments in buildings is on average confirmed with the significant exceptions of sectors DM and DH (possible scale effects).

With the only exception of sector DB (for which the same comments a above applies as regards the radical structural change experienced by this sector) and DH, the (weak) negative aggregate effect of investments in furniture is confirmed.

As far as investments in ICTs are concerned, the effect is significant for most of the sectors (except for DB, DF and DI) but with heterogeneous sign and size. For a group of sectors (DA, DE and DK) the effect is positive (emissions-increasing) while for sectors DG, DH, DJ and DM is negative (emissions-saving). Virtuous sectors are characterized by the presence of big firms and plants for which the impact on production costs of ICTs-induced energy savings (e.g. advanced factory automation) is likely to be huge relative to more segmented sectors.

Finally, note that, differently from homogeneous estimates, the effect of energy prices is significant. Each sector reacted in a different way to relative and absolute energy price changes. On average[23], an increase (decrease) of the relative price of coal gives rise to a decrease (increase) of CO_2 due to changes in the energy mix towards more efficient (inefficient) fuels, which is consistent with the anecdotal evidence of a recoupling of CO_2 emissions in periods of low relative prices for coal. The effects linked to the relative prices of gas and oil and to absolute energy prices are less straightforward, with no clear average effect and presence of both positive and negative effects.

[TABLE 6 ABOUT HERE]

3.2.2 Heterogeneous estimates for SOx

First, note that the poor significance of homogeneous estimates for the effect of investments and energy prices was hiding highly heterogeneous patterns, with greater dispersion than CO_2 heterogeneous estimates.

Sector DB (textile) is also in this case a sort of outlier, characterized by a shift towards more environmental efficient production processes in its phase of deep structural change. A shift to more SOx-efficient machinery has involved most of the most polluting manufacturing sectors.

The role of investments in road vehicles is relevant for sectors DB (strong positive effect even though investments in road vehicles by this sector represent only a small proportion of total investments) and DG (negative effect) only.

[23] Sectors DA, DE, DK and DM.

Investments in buildings have an average negative effect on SOx emissions, a result which is more plausible than the positive effect estimated in homogeneous regressions. A negative effect, in fact, is in line with the robust negative effect found for CO_2 and probably linked to more isolated new buildings.

The role of investments in furniture varies widely across sectors, from a strong and relevant emissions-increasing effect (sector DB) to a set of sectors characterized by emissions-saving effects (DF and DJ).

Finally, investments in ICTs determine, on average, a reduction of emissions with the exception of DD (wood and wood products) for which the potential for ICT-induced emissions saving is low due to the average small dimension of firms belonging to this sector.

The results regarding the role of absolute and relative energy prices confirm the high degree of variance of the effects across sectors, with an evidence of important sector-specific responses to changes in energy prices.

[TABLE 7 ABOUT HERE]

[TABLE 8 ABOUT HERE]

4 Conclusions

This paper investigates the environmental direction in terms of CO_2 and SOx emissions of investments in different capital goods of the Italian manufacturing sectors. Once I relax the implicit hypothesis of homogeneity of the patterns of different sectors, heterogeneous estimates, even though quite volatile, offer interesting insights on the conflicting forces that determine the aggregate picture.

The results of the current paper have to be interpreted cautiously. First, the comparison between the results for SOx and CO_2 and between homogeneous and heterogeneous estimates highlights some inconsistency. These inconsistencies are the result of: (i) the volatility of sector data on employment and most of all on investments, which are characterized by wide fluctuations in response to the business cycle[24]; (ii) the relatively short time series that does not allow to capture structural shifts in (environmental) technology; (iii) the need of a structural to explain theoretically and test empirically possible interactions between different investments behaviour, energy prices, environmental taxes and supply-use linkages between sectors.

Further research should be directed to cross-country studies made possible by the increasing availability of NAMEA-like database at the European level. Furthermore, firm-level analyses on the environmental direction of investments in capital goods are needed in order to identify the features of the firms which are moving to more environmental efficient production processes and the firms which are lagging behind.

[24] This problem can be solved through the use of averages instead of single-year data, a strategy that is limited in this case by the short time series.

A Appendix

Tab. 1: Nace branches classification

Nace	Sector description
DA	Food products, beverages and tobacco
DB	Textiles and textile products
DC	Leather and leather products
DD	Wood and wood products
DE	Pulp, paper and paper products; publishing and printing
DF	Coke, refined petroleum products and nuclear fuel
DG	Chemicals, chemical products and man-made fibres
DH	Rubber and plastic products
DI	Other non-metallic mineral products
DJ	Basic metals and fabricated metal products
DK	Machinery and equipment n.e.c.
DL	Electrical and optical equipment
DM	Transport equipment
DN	Other manufacturing industries

Tab. 2: Capital goods

Capital good	Ateco91 categories
Machinery	01.1, 01.2, 05.0, 17.4, 17.5, 19.1, 19.2, 20.1, 22.0, 25.2, 26.1, 26.2, 26.6, 27.2, 28.1, 28.2, 28.3, 28.6, 28.7, 29.1, 29.2, 29.4, 29.5, 29.6, 29.3, 29.7, 31.1, 31.2, 31.5, 31.6, 33.1, 33.2, 33.3, 33.4, 33.5, 36.4, 36.5, 36.6
Equipment for offices	30.0
Equipment for communication	32.1, 32.2, 32.3
Furniture	36.1, 36.3
Road vehicles	34.1, 34.2, 34.3, 35.4, 35.5
Other vehicles	35.1, 35.2, 35.3
Buildings	45.0
Software	72.0
Other goods	50.2, 70.3, 74.1, 74.2, 92.0

Tab. 3: Descriptive statistics

Variable	Unit	Mean	Median	Min	Max	St. dev.
CO_2	Tons	10,473,126	4,272,202	906,283	50,538,698	12,168,924
SOx	Tons of SO_2 eq.	28,126	5,069	200	288,605	53,688
L	1000 FTE	356	277	24	894	211
Inv_machin.	Million of Euro	2,203	2,045	199	6,971	1,392
Inv_transp.	Million of Euro	168	135	6.49	539	113
Inv_build.	Million of Euro	787	646	37.8	2,530	496
Inv_furn.	Million of Euro	95.3	74.7	2.74	323	67.9
Inv_'light'	Million of Euro	407	389	25.4	1,502	271
Energy p. index	2005=100	77.5	71.5	55.1	108	13.2
P. coal (rel)	2005=1	0.977	0.958	0.758	1.420	0.129
P. oil (rel)	2005=1	1.030	1.040	0.935	1.090	0.051
P. gas (rel)	2005=1	0.890	0.888	0.741	1.130	0.092
Tax energy	% of GDP	2.710	2.840	2.170	3.130	0.351
Tax transp.	% of GDP	0.519	0.500	0.430	0.590	0.056
Tax pollut.	% of GDP	0.026	0.030	0.000	0.050	0.017

Fig. 1: CO_2 emissions of manufacturing sectors

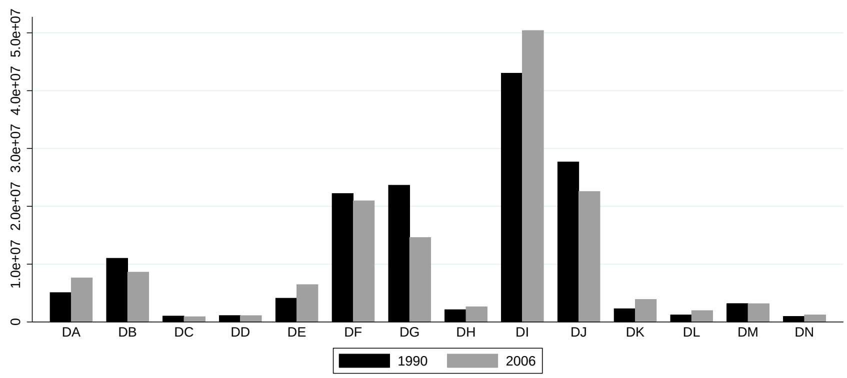


Fig. 2: SOx emissions of manufacturing sectors

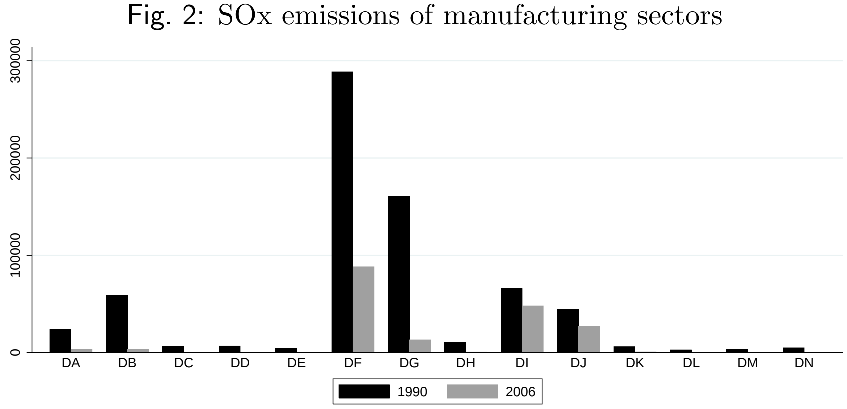


Fig. 3: Trends of energy prices (1990=1)

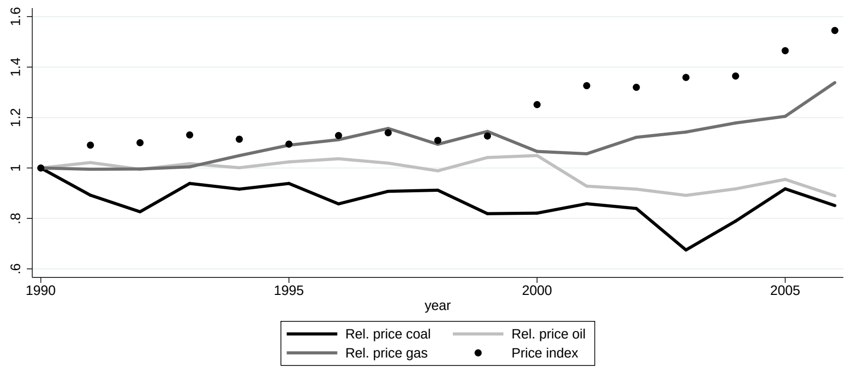


Fig. 4: Trends of environmental taxes (as % of GDP)

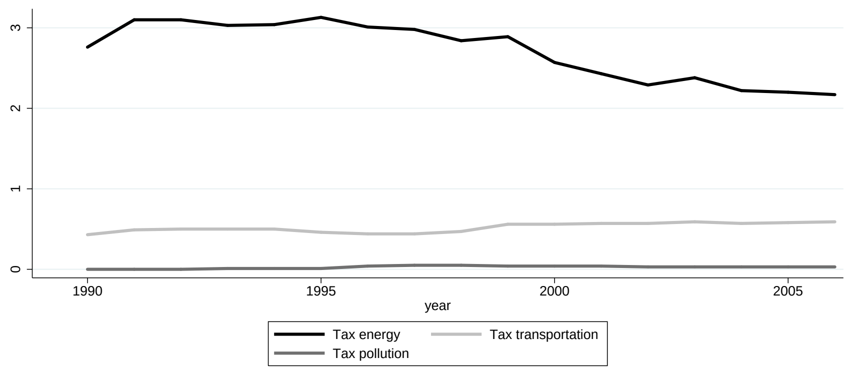
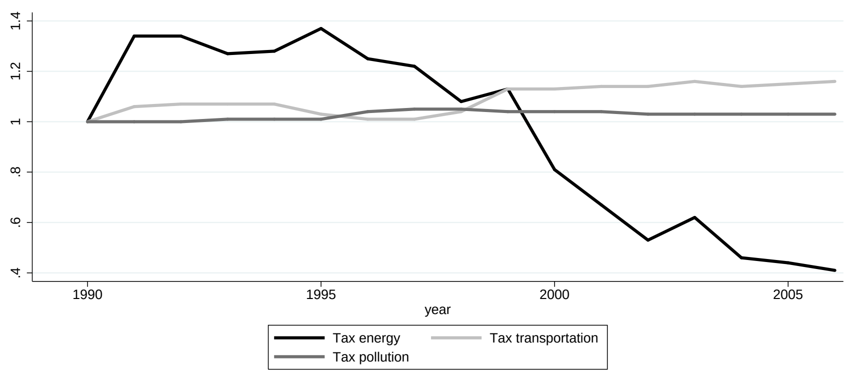


Fig. 5: Trends of environmental taxes (as % of GDP, 1990=1)



Tab. 4: Fixed effect estimates for CO_2 (dependent variable: $\ln(CO_{2\ st})$)

	Manufacturing (1)	Manufacturing (2)	Main emitters (3)	Main emitters (4)
$\ln(\text{inv\_machinery}_{st-1})$	0.21***	0.23***	0.21***	0.24***
	[0.05]	[0.05]	[0.05]	[0.05]
$\ln(\text{inv\_transportation}_{st-1})$	-0.11***	-0.04	-0.12***	-0.06
	[0.03]	[0.04]	[0.04]	[0.05]
$\ln(\text{inv\_building}_{st-1})$	-0.08***	-0.09***	-0.10***	-0.12***
	[0.03]	[0.03]	[0.03]	[0.03]
$\ln(\text{inv\_furniture}_{st-1})$	-0.01	-0.08**	-0.07*	-0.13**
	[0.02]	[0.03]	[0.03]	[0.05]
$\ln(\text{inv\_`light'}_{st-1})$	0.05	0.06	0.20**	0.21**
	[0.05]	[0.05]	[0.08]	[0.09]
$\ln(L_{st})$	0.70***	0.72***	0.64***	0.68***
	[0.12]	[0.12]	[0.15]	[0.14]
Price coal $(\text{rel})_{st}$	-0.12	-0.37	-0.18	-0.31
	[0.14]	[0.30]	[0.18]	[0.36]
Price oil $(\text{rel})_{st}$	0.22	0.18	0.24	0.32
	[0.22]	[0.32]	[0.25]	[0.38]
Price gas $(\text{rel})_{st}$	0.02	-0.27	-0.14	-0.40
	[0.16]	[0.27]	[0.20]	[0.36]
Energy price index_{st}	0.00	0.01	0.01*	0.01*
	[0.00]	[0.00]	[0.00]	[0.00]
Tax on energy_{st}	0.05	0.13	0.11	0.19
	[0.07]	[0.13]	[0.09]	[0.16]
Tax on $\text{transportation}_{st}$	0.33	-1.32*	-0.10	-1.26
	[0.32]	[0.76]	[0.42]	[0.99]
Tax on pollution_{st}	2.74***	4.78	0.68	0.91
	[0.71]	[3.94]	[1.01]	[5.87]
t_9395		0.12**		0.12
		[0.05]		[0.08]
t_9698		-0.07		0.02
		[0.18]		[0.27]
t_9901		0.08		0.11
		[0.15]		[0.22]
t_0204		0.14		0.16
		[0.14]		[0.19]
t_0506		0.16		0.16
		[0.17]		[0.23]
Constant	10.01***	10.59***	10.54***	10.51***
	[0.84]	[1.32]	[0.98]	[1.60]
Test time dummies (F)		2.34**		5.12***
Sector fixed fx (F)	994.78***	1043.39***	1032.69***	1038.62***
F test	9.11***	8.39***	6.81***	5.68***
R sq. Within	0.39	0.45	0.38	0.42
N	238	238	170	170

Tab. 5: Fixed effect estimates for SOx (dependent variable: $\ln(\mathrm{SOx}_{st})$)

	Manufacturing (1)	Manufacturing (2)	Main emitters (3)	Main emitters (4)
$\ln(\mathrm{inv\_machinery}_{st-1})$	0.05	0.11	0.17	0.24
	[0.13]	[0.14]	[0.18]	[0.19]
$\ln(\mathrm{inv\_transportation}_{st-1})$	0.14	0.28**	0.02	0.12
	[0.11]	[0.12]	[0.16]	[0.19]
$\ln(\mathrm{inv\_building}_{st-1})$	0.16**	0.17**	0.17*	0.18**
	[0.07]	[0.07]	[0.09]	[0.09]
$\ln(\mathrm{inv\_furniture}_{st-1})$	0.01	-0.19**	0.05	-0.14
	[0.07]	[0.09]	[0.10]	[0.12]
$\ln(\mathrm{inv\_‘light’}_{st-1})$	0.27*	0.23*	0.29	0.26
	[0.14]	[0.13]	[0.18]	[0.17]
$\ln(\mathrm{L}_{st})$	0.81**	0.81**	0.95**	0.94**
	[0.36]	[0.34]	[0.41]	[0.41]
Price coal $(\mathrm{rel})_{st}$	0.15	0.76	0.23	0.90
	[0.41]	[0.77]	[0.56]	[1.03]
Price oil $(\mathrm{rel})_{st}$	-0.78	-0.97	-0.81	-0.99
	[0.71]	[0.95]	[0.89]	[1.27]
Price gas $(\mathrm{rel})_{st}$	-1.07**	-0.43	-0.92	-0.38
	[0.45]	[1.03]	[0.60]	[1.39]
Energy price index_{st}	0.00	0.01	0.00	0.01
	[0.01]	[0.01]	[0.01]	[0.01]
Tax on energy_{st}	1.07***	1.16***	1.09***	1.17**
	[0.18]	[0.41]	[0.23]	[0.54]
Tax on $\mathrm{transportation}_{st}$	-3.93***	-5.17**	-3.60***	-4.36
	[0.75]	[2.56]	[1.00]	[3.35]
Tax on $\mathrm{pollution}_{st}$	-12.80***	-39.80***	-11.95***	-39.72**
	[2.13]	[12.81]	[2.55]	[17.26]
t_9395		0.43***		0.40*
		[0.16]		[0.22]
t_9698		1.19**		1.23
		[0.58]		[0.79]
t_9901		1.14**		1.14*
		[0.46]		[0.63]
t_0204		0.79*		0.80
		[0.44]		[0.61]
t_0506		0.43		0.46
		[0.54]		[0.75]
Constant	1.85	0.38	0.63	-0.88
	[2.41]	[3.64]	[3.11]	[4.78]
Test time dummies (F)		3.13***		1.41
Sector fixed fx (F)	243.42***	251.72***	163.62***	159.95***
F test	98.57***	77.44***	54.36***	40.6***
R sq. within	0.84	0.85	0.81	0.82
N	238	238	170	170

Tab. 6: Heterogeneous SUR estimates for CO_2 (dependent variable: $\ln(CO_{2\ st})$)

	DA	DB	DE	DF	DG	DH	DI	DJ	DK	DM
$\ln(\text{inv\_machin.}_{st-1})$	-0.35	-0.71***	-0.18	-0.01	0.26***	0.15	0.13*	0.14	-0.30***	-0.31*
	[0.33]	[0.20]	[0.17]	[0.04]	[0.04]	[0.09]	[0.07]	[0.11]	[0.11]	[0.17]
$\ln(\text{inv\_transp.}_{st-1})$	0.04	0.52***	-0.17*	-0.05	0.23***	-0.15***	0.25***	-0.15**	0.11*	0.15***
	[0.09]	[0.15]	[0.09]	[0.07]	[0.04]	[0.05]	[0.08]	[0.07]	[0.06]	[0.04]
$\ln(\text{inv\_build.}_{st-1})$	0.08	-0.46***	0.20*	0.08*	-0.25***	0.15***	-0.39***	0.14**	-0.60***	0.33***
	[0.13]	[0.11]	[0.10]	[0.04]	[0.03]	[0.04]	[0.12]	[0.05]	[0.07]	[0.07]
$\ln(\text{inv\_furn.}_{st-1})$	-0.09	0.63***	-0.19***	0.03	-0.26***	0.32***	-0.12*	-0.17***	-0.29***	0.00
	[0.10]	[0.12]	[0.06]	[0.02]	[0.04]	[0.07]	[0.06]	[0.06]	[0.04]	[0.04]
$\ln(\text{inv\_`light'}_{st-1})$	0.46**	-0.05	0.37***	0.03	-0.15**	-0.21**	0.02	-0.38***	0.68***	-1.12***
	[0.23]	[0.13]	[0.12]	[0.08]	[0.06]	[0.10]	[0.10]	[0.08]	[0.14]	[0.29]
$\ln(L_{st})$	0.16	-1.37***	-0.44	0.07	0.55***	1.65***	-0.56	0.46	-0.96**	-0.52**
	[1.07]	[0.41]	[0.51]	[0.31]	[0.08]	[0.29]	[0.41]	[0.34]	[0.38]	[0.26]
P. coal $(\text{rel})_{st}$	-0.68**	-0.33	-0.38**	0.04	0.29***	0.13	0.08	0.24*	-0.96***	-0.72***
	[0.28]	[0.25]	[0.16]	[0.18]	[0.08]	[0.11]	[0.23]	[0.13]	[0.15]	[0.17]
P. oil $(\text{rel})_{st}$	0.50	-0.91*	0.48	0.03	0.20	0.37*	-0.54	0.70**	0.91***	0.13
	[0.64]	[0.48]	[0.33]	[0.34]	[0.15]	[0.22]	[0.39]	[0.29]	[0.32]	[0.28]
P. gas $(\text{rel})_{st}$	-0.67	-0.91***	-0.07	0.40	-0.02	0.56***	-0.09	0.17	0.57***	0.24
	[0.46]	[0.29]	[0.23]	[0.34]	[0.11]	[0.19]	[0.20]	[0.21]	[0.20]	[0.16]
Energy p. index_{st}	0.01*	-0.02***	0.01***	-0.01**	-0.01***	0.01*	0.01**	-0.00	0.00	0.00
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Constant	14.73*	32.14***	17.03***	16.48***	14.09***	3.35**	21.49***	15.18***	23.62***	24.74***
	[7.96]	[3.53]	[3.47]	[0.87]	[0.75]	[1.45]	[2.86]	[1.99]	[2.18]	[3.75]
Breusch-Pagan test of independence: χ^2=57.394, p-value= 0.1018										

Tab. 7: Heterogeneous SUR estimates for SOx (dependent variable: $\ln(SOx_{st})$)

	DA	DB	DC	DD	DF	DG	DH	DI	DJ	DK
ln(inv_machin.$_{st-1}$)	-1.39***	-2.25***	-0.67**	-3.78***	0.25**	0.34	-0.01	0.10***	0.31	0.53*
	[0.39]	[0.63]	[0.32]	[0.61]	[0.12]	[0.31]	[0.60]	[0.04]	[0.36]	[0.28]
ln(inv_transp.$_{st-1}$)	-0.01	2.23***	0.42*	-0.11	-0.08	-0.85***	-0.23	-0.02	-0.11	0.33**
	[0.09]	[0.47]	[0.25]	[0.28]	[0.19]	[0.27]	[0.37]	[0.05]	[0.20]	[0.14]
ln(inv_build.$_{st-1}$)	-0.68***	-1.92***	0.22	0.32	-0.07	-0.55***	-0.43*	0.08	-0.04	-0.08
	[0.13]	[0.34]	[0.18]	[0.46]	[0.12]	[0.16]	[0.23]	[0.06]	[0.20]	[0.17]
ln(inv_furn.$_{st-1}$)	0.24***	2.22***	0.44***	-0.18	-0.11**	-0.13	-0.49	-0.02	-0.40**	0.43***
	[0.09]	[0.32]	[0.13]	[0.21]	[0.06]	[0.25]	[0.37]	[0.03]	[0.18]	[0.10]
ln(inv_'light'$_{st-1}$)	-0.67***	-0.83**	-0.14	0.92**	-0.40*	-1.27***	1.18*	-0.31***	-0.96***	-0.41
	[0.21]	[0.34]	[0.25]	[0.46]	[0.21]	[0.40]	[0.60]	[0.06]	[0.25]	[0.32]
$\ln(L_{st})$	-6.16***	-1.04	5.67***	8.60***	-0.57	3.30***	-7.83***	1.31***	1.42	-5.60***
	[0.89]	[0.98]	[1.07]	[2.05]	[0.89]	[0.60]	[1.81]	[0.26]	[1.12]	[0.88]
P. coal (rel)$_{st}$	-0.44*	-0.81	0.81	-3.48***	0.96*	-0.11	-0.43	-0.41***	0.77**	0.21
	[0.26]	[0.75]	[0.76]	[1.04]	[0.52]	[0.58]	[0.84]	[0.15]	[0.37]	[0.43]
P. oil (rel)$_{st}$	1.36**	-3.85***	0.06	4.14**	0.18	2.16**	-1.50	0.02	2.50***	-1.27
	[0.66]	[1.36]	[1.44]	[1.95]	[0.99]	[1.01]	[1.68]	[0.26]	[0.81]	[0.91]
P. gas (rel)$_{st}$	-1.14**	-2.65***	1.93*	-2.13*	-1.01	-3.83***	-2.75**	-0.47***	0.66	0.40
	[0.49]	[0.79]	[0.99]	[1.23]	[0.96]	[0.76]	[1.26]	[0.14]	[0.62]	[0.56]
Energy p. index$_{st}$	-0.01**	-0.09***	-0.01	0.01	-0.01	-0.01	-0.05***	0.01*	-0.01	-0.03***
	[0.00]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.00]	[0.01]	[0.01]
Constant	66.91***	43.85***	-24.50***	-18.22	14.66***	8.12	56.99***	4.73***	4.36	41.63***
	[7.09]	[9.38]	[7.69]	[12.04]	[2.61]	[5.54]	[9.11]	[1.79]	[6.50]	[5.05]
Breusch-Pagan test of independence: χ^2=94.960, p-value= 0.0000										

Tab. 8: Test of aggregation bias (χ^2)

	CO_2	SOx
Inv_machin.	60.36***	66.25***
Inv_transp.	114.71***	49.00***
Inv_build.	277.51***	75.11***
Inv_furn.	189.03***	76.90***
Inv_'light'	85.42***	33.97***
L	113.88***	214.77***
Energy p. index	82.59***	83.77***
P. coal (rel)	100.01***	41.36***
P. oil (rel)	32.43***	49.86***
P. gas (rel)	34.13***	93.22***
Joint test	5325.62***	4253.71***

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