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Ilya Stepanov, Johan Albrecht

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Ilya Stepanov[1], *Johan Albrecht*[2]

DECARBONIZATION AND ENERGY POLICY INSTRUMENTS IN THE EU: DOES CARBON PRICING PREVAIL?

The issue of instrument choice is vital for climate policy. Carbon pricing is used next to a range of traditional energy taxes and renewable energy policies such as feed-in tariffs and minimal renewable generation targets. Several countries introduced carbon taxes alongside existing energy taxes such as excise duties on vehicle fuels. Since 2005, the EU Emissions Trading Scheme (EU ETS) has attached a direct price to the GHG emissions of ETS companies. The combination of multiple instruments and explicit and indirect carbon price signals created a complex and frequently changing institutional landscape that blurs the contribution of each policy instrument. Can the decarbonization of the European economy be attributed to carbon price instruments or to renewable energy policies together with other fiscal instruments?

This paper clarifies the relative impact of explicit carbon price instruments (carbon taxes and EU ETS) compared to other instruments, namely renewable energy policies and indirect carbon price signals (general energy taxes). The methodology is based on the calculation of the implicit carbon price in existing fiscal systems. On the basis of panel data for 30 European countries 1995–2016, several fixed-effect regression estimations were performed. The results indicate a greater but decreasing impact of price instruments on carbon intensity compared to renewable energy policies and a greater but decreasing relative impact of indirect price signals compared to explicit ones.

JEL Classification: Q52 Q58 Q48

Keywords: energy taxes, carbon tax, cap-and-trade, renewable energy policy, climate change, climate policy

[1] National Research University Higher School of Economics. Center for Comprehensive European and International Studies, junior research fellow, E-mail: iastepanov@hse.ru
[2] Ghent University. Faculty of Economics and Business Administration, PhD, Professor, E-mail: Johan.Albrecht@UGent.be

Introduction

Carbon pricing is often presented as the most cost-effective way to curb carbon dioxide emissions as it equalizes marginal abatement costs among various sources of emissions [Goulder, Parry, 2008]. In academic, public and political discussions different explicit carbon pricing instruments – carbon tax and ETS or a combination of both (carbon price floor, relative cap on emissions within ETS, etc.) – are often compared. These instruments primarily target the use of fossil fuels which are responsible for more than two thirds of global emissions [IEA, 2017]. At the moment, explicit prices on carbon are installed in more than forty countries [World Bank, 2018]. European countries have historically played a leading role with respect to energy and carbon taxation. The EU-wide emissions trading system (ETS) was introduced in 2005. Both ETS and domestic carbon taxes – mainly for non-ETS sectors such as transportation and household energy consumption – provide the backbone of European climate policy.

Carbon pricing can lead to undesired changes in industrial competitiveness and regressive changes in wealth distributions. These considerations restricted the use of carbon pricing policies. Today, an explicit carbon price – either a carbon tax or an emissions price from a trading scheme ─ is imposed only on 15% of global emissions [World Bank, 2018]**.** EU ETS nowadays only covers half of all greenhouse gas emissions in Europe [European Commission, 2019]. There is a huge contrast with the widespread use of conventional energy taxes (like excise duties) in developed and developing countries which significantly contribute to government revenues since the first half of 20^{th} century [Speck, 2008]. Explicit carbon pricing appeared in the late 1980s and gained popularity just during the last decade.

A direct price on carbon creates direct incentives for emitting industries to cut down emissions. General energy taxes like excise duties can also be differentiated based upon the carbon content of the fuels used. These taxes also provide an incentive to lower carbon emissions. Undifferentiated energy taxes like a flat VAT-rate for all energy products can have an impact on energy use; their impact on carbon emissions is however indirect. [Speck, 2008].

Because of the higher impact of explicit carbon pricing on the opportunity cost of carbon emissions, carbon prices attracted special attention in the academic literature on climate policy [Pizer, 2002; Hoel, Karp, 2001; Goulder, Schein, 2009; Stavins, 2007; Makarov, Stepanov, 2017, Weitzman, 1974; Pizer, 2002; Hoel, Karp, 2001; Stavins, 2007; Goulder, Schein, 2009].

At the same time, the impact of any fiscal instrument of regulation on the emissions level depends not solely on the tax rate and sectoral tax base but also on the scope of its application. A low undifferentiated excise duty on transportation fuels can have a higher impact than a high carbon tax for one specific industrial sector. General energy taxes historically have a larger institutional base and are used in a larger number of sectors relying on fossil fuels in comparison to explicit carbon prices. [OECD, 2018a]. Nevertheless, the literature on the impact of general energy taxes on the emissions dynamics is rather scant and does not focus on the relative role of undifferentiated energy taxes on emissions compared to explicit carbon pricing [Jeffrey, Perkins, 2015]. This gap could narrow the policy discussion on the contribution of carbon price signals to attain mitigation targets. We argue that changes in general energy taxes are of equal importance.

The literature points out key limitations of carbon pricing, including insufficient dynamic efficiency [Hood, 2011], possible tax interaction effects [Stavins, 1995; Goulder, 2013], and high administrative costs under weak market institutions [Stavins, 1995; Blackman, Harrington, 2000]. In order to avoid these obstacles, the carbon price instrument, if implemented, is usually combined with a set of other complementary policies including command-and-control regulation, technology support and information policies. The combination of multiple climate policy tools has created a complex and frequently changing institutional landscape that blurs the contribution of each policy instrument.

Direct carbon pricing and general energy taxes are used in complex policy environments with explicit technological goals such as the increase of renewable energy generation capacity. In regions with multiple energy and climate policy targets such as the EU, the debate on the optimal integration of various policy instruments is still ongoing. Some favour carbon prices and advocate for the abolishment of renewable targets. Others argue that taxes alone will not trigger investments in renewable energy capacity and emphasize the need for adequate support mechanisms such as feed-in tariffs (FIT), quota obligations with tradable green certificates, investment grants, tenders, tax incentives, Carbon pricing policies are most successful in stimulating incremental emissions reduction which is insufficient in the light of deep decarbonisation targets of the EU [Tvinnereim, Mehling, 2018]. As both policy approaches – carbon taxes and renewable policies − target the same goal of carbon dioxide emission reduction, we want to clarify the relative contribution of both approaches to emissions levels.

This paper specifies the relative impact of carbon pricing policies compared to renewable energy policies and distinguishes between direct price signals (carbon taxes and cap-and-trade) and indirect ones (general energy taxes). The methodology is based on the calculation of the implicit carbon price, i.e. – the total fiscal burden on ton of carbon dioxide in existing fiscal systems. On the basis of panel data for 30 European countries 1995–2016, several fixed-effect regression estimations were performed. The results indicate a greater impact of price instruments on carbon dioxide emissions compared to renewable energy policies and a greater but decreasing impact of indirect price signals compared to direct ones.

The paper is organized as follows. The second section discloses theoretical and practical aspects of economic regulation in European energy complex; in particular, it characterizes carbon tax, ETS and general energy taxes. The third section dwells on methodological issues and describes key components of the implicit carbon price. The fourth and the fifth sections depict input data and regression model specification. Finally, in the last two sections, the results are summarized followed by conclusion.

The Theory and Practice of Carbon Pricing in Europe

The first gasoline tax was introduced in Denmark and Sweden in 1917 and 1924 respectively. In 1957, taxation in Sweden expanded to other fossil fuels, including oil products and coal [Speck, 2006]. It was import regulation and the generation of fiscal revenues that first motivated the taxation of energy use [Speck, 2008]. According to the Ramsey rule, the efficient tax rate (which minimizes total taxation costs) should be higher for products with relatively low price elasticity [Ramsey, 1927]. Therefore, taxation of energy consumption, which tends to have low sensitivity to price changes, provided an attractive and politically feasible tool of raising revenue for government budget [Bye, Bruvoll, 2008].

From the 1980s, motives for energy taxation started to shift towards environmental protection, including the prevention of local air pollution, and later, climate change mitigation. In particular, growing evidence for the negative effects of lead emissions on health drove the EU tax reduction policies for non-ethylene fuels. European countries were also the first to introduce incentive-based carbon regulation; the first carbon tax was introduced in Finland in 1991 while the first and the second-largest emission trading scheme was launched at the European market in 2005. From the inception of the Sixth Environment Action Programme of the European Community in 2002, the economic instruments for pollution control, including pollution taxes and fees, and emission allowance trading schemes, started to play a vital role in the promotion of the “polluter pays” principle in EU environmental policy [European Environment Agency, 2005]. In this regard, in EU statistics, energy taxes are depicted as a subgroup of environmental taxes [Eurostat]. This implicitly shows that even though all environmental taxes are used not only to regulate energy use, all energy taxes are introduced to fulfill environmental objectives.

The institutional framework of incentive-based or fiscal instruments was to a large extent based on the economic theory. The introduction of a Pigouvian tax equal to marginal external costs will maximize welfare and contribute to the Pareto-optimum [Pigou, 1932]. In this case, tax regulation seeks to include the social costs of pollution into the production function of the polluting entity. Alternatively, the negative externality may be internalized by means of Coasian bargaining. R. Coase, one of the founders of new-institutional economic theory, pointed out that under specific circumstances market failures can be eliminated by means of the efficient allocation of the property rights of economic agents. In the context of air pollution, clean air is considered to be a common resource, while the negative effect of pollution, which is not regulated by the market, may be internalized by the specification of the rights to emit (or to use clean air). In this case, economic agents may reach an efficient equilibrium by means of bargaining which will help eliminate the externality [Coase, 1960].

Even though these theoretical approaches are hard to realize in a non-idealized market environment, their fundamental principles are reflected in the existing economic climate policies of the EU. The Pigouvian tax approach laid the foundation for carbon tax use while Coasian bargaining to some extent inspired the launch of EU ETS. A carbon tax is currently used in 15 European countries while EU ETS covers 31 countries (Table 1).

Table 1 – Existing Direct Instruments of Emissions Regulation in European Countries

Country	Type of regulation	Year of introduction	Volume of emissions under regulation, mn t of CO_2 eq.	Coverage,%	Sector/types of energy under regulation	Carbon price level (national currency /USD per t of CO_2 eq.)	Revenue (mn USD)
United Kingdom	Carbon tax (carbon price floor)	2013	136	23	Carbon dioxide emissions from all types of fossil fuels in the power sector	18 GBP (24 USD)	1169
Denmark	Carbon tax	1992	22	40	Carbon dioxide emissions from all types of fossil fuels mostly in transportation and construction industries	172 DKR (27 USD)	532
Ireland	Carbon tax	2010	31	49	Carbon dioxide emissions from all types of fossil fuels in all sectors	20 EUR (24 USD)	465
Iceland	Carbon tax	2010	3	55	Carbon dioxide emissions from liquid fuels and gaseous fossil fuels in all sectors	1190 ISK (12 USD)	31
Latvia	Carbon tax	2004	2	15	Carbon dioxide emissions from all types of fossil fuels (except peat) in industry and power sector not included in EU ETS	5 EUR (5 USD)	6
Lichtenstein	Carbon tax	2008	0.32	26	Carbon dioxide emissions from all types of fossil fuels mostly in industry, power, construction and transportation sector	84 CHF (87 USD)	5
Norway	Carbon tax	1991	38	60	Greenhouse gas emissions from liquid fuels and gaseous fossil fuels in all sectors	Higher rate: 445 NOK (56 USD). Lower rate: 29 NOK (4 USD)	1487
Poland	Carbon tax	1990	16	4	Greenhouse gas emissions from all types of fossil fuels in all sectors	0.29 PLZ (0.08 USD)	1
Portugal	Carbon tax	2015	21	29	Carbon dioxide emissions from all types of fossil fuels mostly in industry,	7 EUR (8 USD)	133

					construction and transportation sectors		
Slovenia	Carbon tax	1996	5	24	Carbon dioxide emissions from all types of fossil fuels mostly in construction and transportation sectors	17 EUR (20 USD)	79
Finland	Carbon tax	1990	25	36	Carbon dioxide emissions from all types of fossil fuels (except peat) mostly in industry, construction and transportation sectors	Liquid transport fuel: 62 EUR (73 USD). Other types of fuels: 58 EUR (69 USD)	1262
France	Carbon tax	2014	176	35	Carbon dioxide emissions from all types of fossil fuels mostly in industry, construction and transportation sectors	31 EUR (US$36)	4063
Switzerland	Carbon tax	2008	18	33	Carbon dioxide emissions from all types of fossil fuels mostly in industry, power, construction and transportation sectors	84 CHF (87 USD)	1002
Sweden	Carbon tax	1991	26	40	Carbon dioxide emissions from all types of fossil fuels mostly in industry, construction and transportation sectors	1128 SEK (140 USD)	2556
Estonia	Carbon tax	2000	1	3	Carbon dioxide emissions in industry and power sector	2 EUR (2 USD)	3
EU ETS: 28 EU countries plus Iceland, Norway, and Lichtenstein	Emissions trading system	2005	2132	45	Carbon dioxide emissions in industry, power and aviation sector as well as N_2O emissions in chemical industry and PFC emissions in aluminum industry	5 EUR (6 USD)	4215
Switzerland	Emissions trading system	2008	6	11	Greenhouse gas emissions in industry and power sectors	7 CHF (7 USD)	4

Source: World Bank. Carbon Pricing Dashboard (available at: https://carbonpricingdashboard.worldbank.org/map_data)

EU ETS represents a market for emission allowances where the amount of trade is limited by a cap on emissions set by the regulator. The pool of emission allowances are distributed though auction to emitters participating in the system. The maximum level of emissions serves as a precondition for the formation of the allowance price which is established on the basis of market transactions. Each of the emitters is required to cover all their emissions with the corresponding amount of allowances; if there is a deficit it buys extra allowances while in the opposite case it sells extra allowances. As in the case of carbon taxes, each of the emitters faces the same level of marginal abatement costs which guarantees the minimization of the aggregate level of emission reductions. The minimization of the total abatement cost is an important advantage of direct instruments to regulate emissions. In theory, it implies that emissions can be reduced in the most cost-efficient way. With information on the emission price, each emitter can choose the easiest way to reduce emissions considering the specifics of its industry or business model: from increasing the energy efficiency of the equipment to the development of C&S technologies [Makarov, Stepanov, 2017].

Nevertheless, the Table 1 shows that even though direct emission regulation instruments are becoming more and more popular in European countries, their coverage is on average still relatively modest. The largest emissions coverage of 60% is in Norway which has used carbon taxes since 1991. On average, in countries with carbon taxes, they cover around a quarter of total emissions. EU ETS covers only 45% of the emissions of total emissions in the EU [European Commission, 2019]. Furthermore, there are some cases when direct instruments of emissions regulation overlap and cover the same sources of emissions [Coria, Jaraite, 2015].

In this regard, it is important to take a closer look at the indirect regulation of carbon dioxide emissions by means of general taxes on energy use. Fiscal regulation is especially noticeable in the transportation sector: fees and excise duties for vehicle fuels represent a substantial part of the final price. The share of taxes in the final price for vehicle fuels in European countries can surpass 60% meaning that the variation of consumption depends to a large extent on governmental fiscal decisions. Figure 1 represents the contribution of taxes to the final price of automotive diesel in the industrial sectors of OECD EU countries in 2017. The tax share varies from 38.5% in the Czech Republic up to 63.2% in Switzerland. The biggest fiscal burden falls on the transportation sector, while the role of taxes on other types of energy use is significant but secondary [OECD, 2018b].

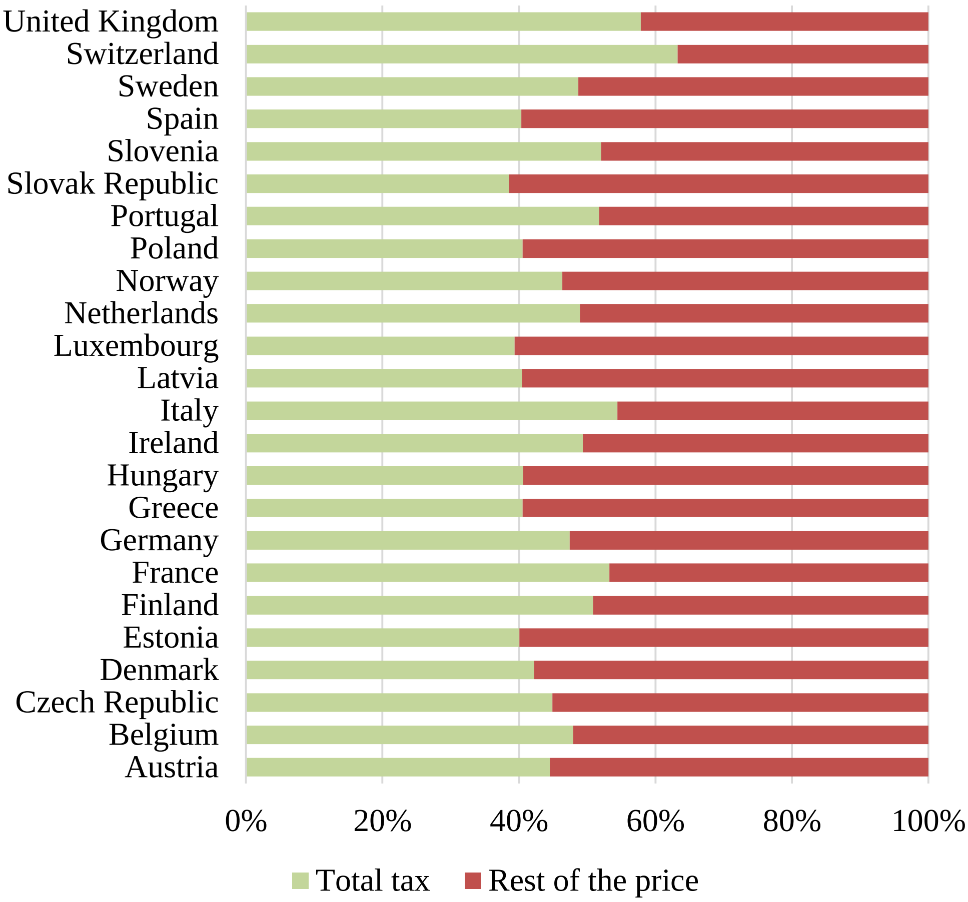

Figure 1 – Share of Total Taxes in the Final Prices for Automotive Diesel in Industry Use in EU OECD Countries in 2017

Source: OECD (2018b). Energy Prices and Taxes Statistics

Such an extensive use of energy taxes suggests they have an important role as indirect price signal for carbon dioxide dynamics. Despite the fact that it is hard to compare the emissions coverage of direct and indirect price signals, the revenue raised by both types of instruments can serve as an approximate estimation. The total revenue raised from indirect instruments[4] outstrips the revenue collected from direct instruments, defined as revenues from carbon tax and allowances distribution auctions, even in the countries with a long history of carbon taxation. In Norway, the revenue collected from indirect instruments is 1.5 times larger than the revenue from direct ones. In Sweden the difference is twofold, while in Denmark it is more than fivefold [Eurostat].

[4] In this paper, the total energy tax revenues from indirect instruments do not include revenue from electricity tax since Eurostat revenue statistics does not distinguish between electricity produced by fossil fuels and non-carbon energy sources (nuclear and renewable energy).

Implicit Carbon Price

In order to compare the contribution of direct and indirect price signals to the evolution of emissions, the **implicit carbon price** for a ton of carbon dioxide was calculated. The implicit carbon price can be defined as a fiscal burden on a ton of carbon dioxide emissions from fossil fuels combustion which consists of the two main types of price components or signals: a **direct one,** equal to the price impact of carbon taxation and EU ETS, and an **indirect one** or price signal of general energy taxes (e.g. excise duties).

In order to estimate the impact of both direct and indirect price signals on the level of emissions, data on energy tax revenues as well as on average allowances price at ETS and ETS emissions coverage (verified emissions) were used. The ratio of tax revenues to the volume of annual carbon dioxide emissions served as an indicator of price signal for both carbon tax and general energy taxes. A similar approach is used in European statistics where implicit energy tax rate is calculated as a ratio of tax revenues and energy consumption. In this paper, we use a similar indicator reflecting the ratio of tax revenue and carbon dioxide emissions. Such approach helps avoid the issue of differences in coverage and specifics of fiscal regulation (various tax rates in different sectors or for various sources of energy) in different countries. It is also dedicated to include the effects of hidden subsidies (tax-exemptions) since their effect may be captured by total tax revenues. ETS price signal was calculated based on the volume of verified emissions and the average annual allowances price. The implicit carbon price ($\boldsymbol{ICP}$) for country *i* in a period *t* is defined as **(1).**

$$ICP = \frac{1}{E} * (\underbrace{CT^{REV} + P^{ETS} * E^{VER}}_{\textbf{Direct price signal}} + \underbrace{\sum_l ET_l^{REV}}_{\textbf{Indirect price signal}}) \qquad (1)$$

where E – carbon dioxide emissions from the combustion of fossil fuels;

ET_l^{REV} – energy tax revenue from the energy tax of type *l*;

CT^{REV} – carbon tax revenue;

P^{ETS} – average annual allowance price of EU ETS;

E^{VER} – verified emissions under EU ETS.

The figures below represent the estimations of implicit carbon prices for 30 countries in 2006 and 2016 and the change of the implicit carbon price in different countries 1995–2016. In most cases, they have grown with time, reflecting the increasing fiscal burden on a ton of carbon dioxide emissions.

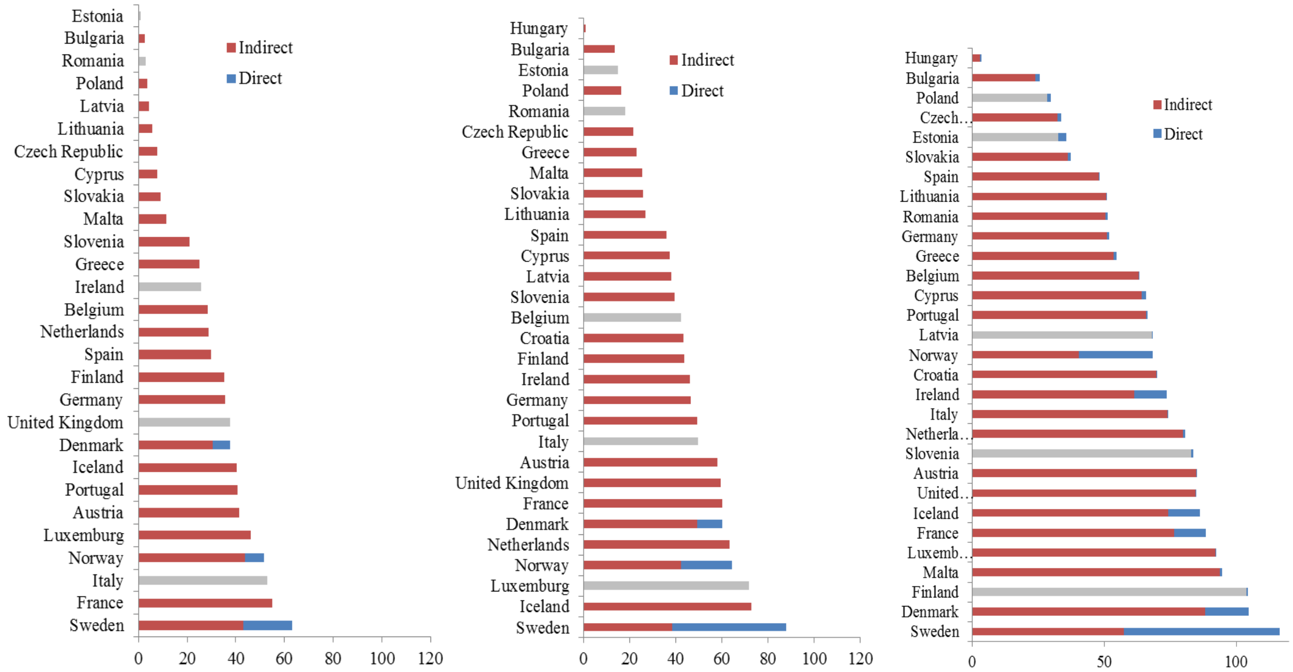

Figure 2 – Implicit Carbon Price (Direct + Indirect Price Signals) in European Countries in 1995 (left), 2006 (middle) and in 2016 (right), Euro per Ton of Carbon Dioxide Emissions from Fossil Fuel Combustion

Note: for the countries marked in grey, it is hard to distinguish contributions of each of the three price signals to implicit carbon for statistical reasons. In particular, in the mid-1990s, Finland has moved to a combined energy-carbon tax which uses both amount of consumption and the carbon component as a tax base, therefore, making it hard to split total revenue flow into carbon tax revenues and general energy taxes revenues.

Source: authors' calculation based on [Eurostat] and [Euromonitor International]

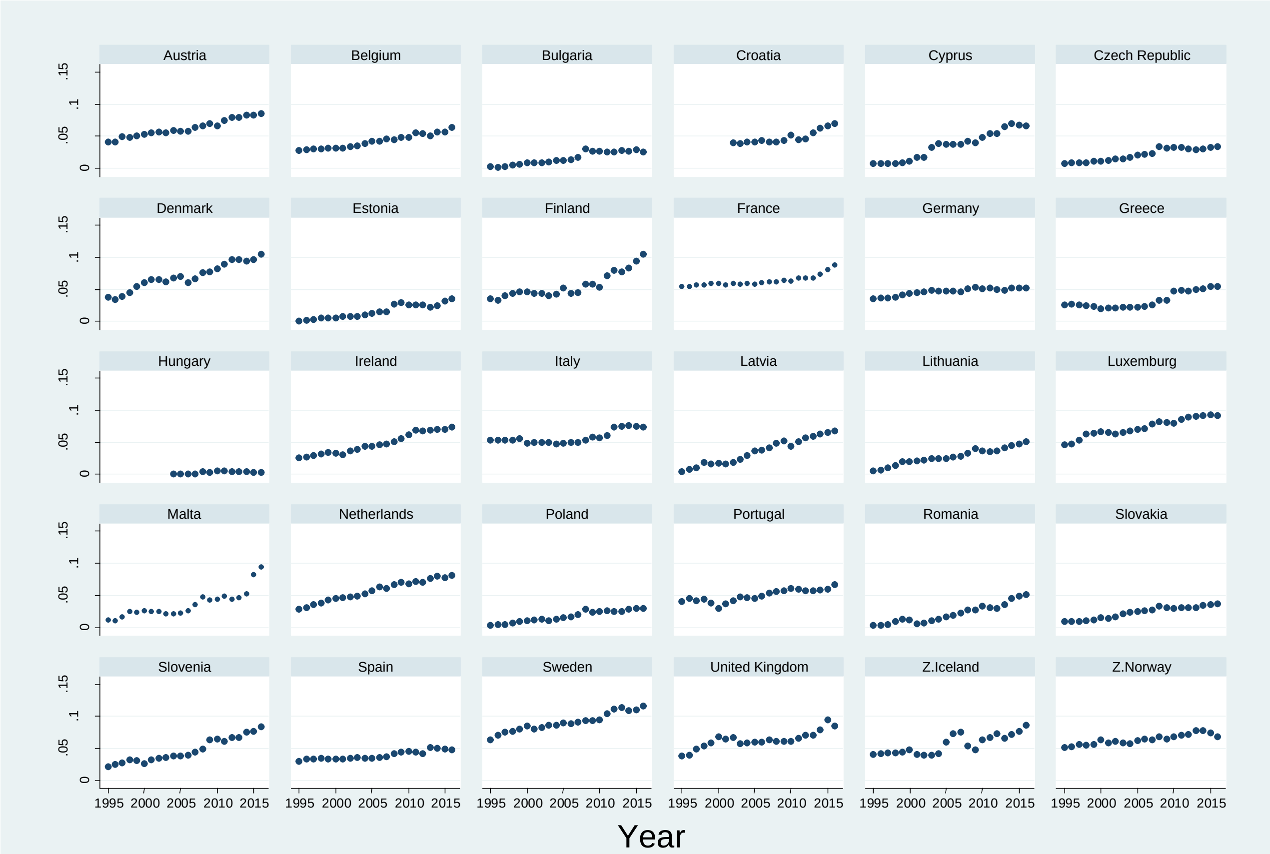

Figure 3 – Dynamics of Implicit Carbon Price in European Countries in 1995-2016, Thousand Euro per Ton of Carbon Dioxide Emissions from Fossil Fuel Combustion

Source: authors' calculation based on [Eurostat] and [Euromonitor International]

Figure 2 shows that the highest fiscal burdens on a ton of carbon from fossil fuel consumption is found in Sweden, Finland, Denmark and Malta – the level of the implicit carbon price is 117, 106, 104 and 96 euro per ton of carbon dioxide in 2016 respectively. Poland, Bulgaria and Hungary have the lowest implicit carbon price – 37, 27 and 4 euro per ton respectively. In Italy which does not have carbon taxation but participates in EU ETS, there is a relatively high value of implicit carbon price – 74 euro for a ton of carbon dioxide. This is, to a large extent, the result of the high contribution of general taxes, especially taxes on vehicle fuels. In Malta, there is a similarly high contribution of general energy taxes and a minor role of direct price signals, primarily due to high excise taxes on gasoline.

Input Data

The analysis is based on panel data and the initial sample includes 22 time periods – the years 1996–2016 – and 30 countries. The carbon intensity of GDP is used as a proxy dependent variable for carbon dioxide emissions. The carbon intensity of GDP is measured in tons of carbon dioxide emissions from fuel combustion per USD 1000. The level of output is used to normalize the cross-sectional distribution – i.e. to make countries comparable. The list of independent variables include the implicit carbon price (*implicit_cp*) which is the sum of the three types of price signals (carbon taxes, EU ETS and general energy taxes), direct carbon price signals *(direct_cp)* which include the price signal from carbon taxes and from EU ETS, indirect carbon price signals (the price signals from general energy taxes) (*indirect_cp*), and the share of renewable energy (*resshare*) in primary energy consumption. The share of renewable energy in total energy consumption is used as a proxy for European renewable policies. Renewable energy generation will replace the use of fossil energy sources and hence lead to lower carbon dioxide emissions. Although market specifications determine the impact of renewable capacity increases on total emissions, the long-term impact can be comparable to that of carbon taxation. In this paper, we focus on the short-term contribution of renewable policies on carbon dioxide emissions. Accumulated empirical evidence suggests weak or no relation between carbon pricing and renewable energy capacities expansion, so renewable energy development is to a large extent considered to be the result of policies other than carbon pricing including feed-in-tariffs, quotas, tenders, and tax incentives, etc. [Kilinc-Ata, 2016; Liu, Zhang, Feng, 2019; Tvinnereim, Mehling, 2018].

A detailed description of the variables is summarized in Table 2 while the descriptive statistics (min, max, mean, st. dev) are provided in Annex 1.

Table 2 – Description of the Input Variables

Variable Name	Dimension	Description	Calculations based on data from
$carbon\ intenisty$	tons per thousand US dollars	Carbon intensity – carbon dioxide emissions from the combustion of fossil fuels per unit of GDP at PPP	[Euromonitor International]
ICP	thousand Euro	Implicit carbon price – sum of all direct and indirect price signals *See (1)*	[Eurostat]
$indirect\_cp$	thousand Euro	Price signal of general energy taxes – sum of all tax revenues (excluding carbon tax) withdrawn from the taxation of energy use (excluding electricity use) per ton of carbon dioxide emissions from the combustion of fossil fuels $\frac{1}{E} * \sum_l ET_l^{REV} -$ *see (1)*	[Eurostat]
$direct\_cp$	thousand Euro	Sum of price signals of carbon tax and EU ETS	[Eurostat]
ct_price	thousand Euro	Price signal of carbon tax – carbon tax revenues per ton of carbon dioxide emissions from the combustion of fossil fuels $\frac{1}{E} * CT^{REV} -$ *see (1)*	[Eurostat]
ets_price_m	thousand Euro	Price signal of ETS – amount of verified emissions multiplied by annual average allowances price per ton of carbon dioxide emissions from the combustion of fossil fuels $\frac{1}{E} * P^{ETS} * E^{VER}$ – *see (1)*	[European Environment Agency]
$resshare$	%	Share of renewable energy in primary energy consumption	[IEA]
$country$	1 or 0	Set of dummy variables for country-specific fixed-effects	–

The Pearson correlation matrix (Annex 2) and the graphs below depict the negative relationship between carbon intensity and the implicit carbon price, direct and indirect price signals and the share of renewable energy in primary energy consumption.

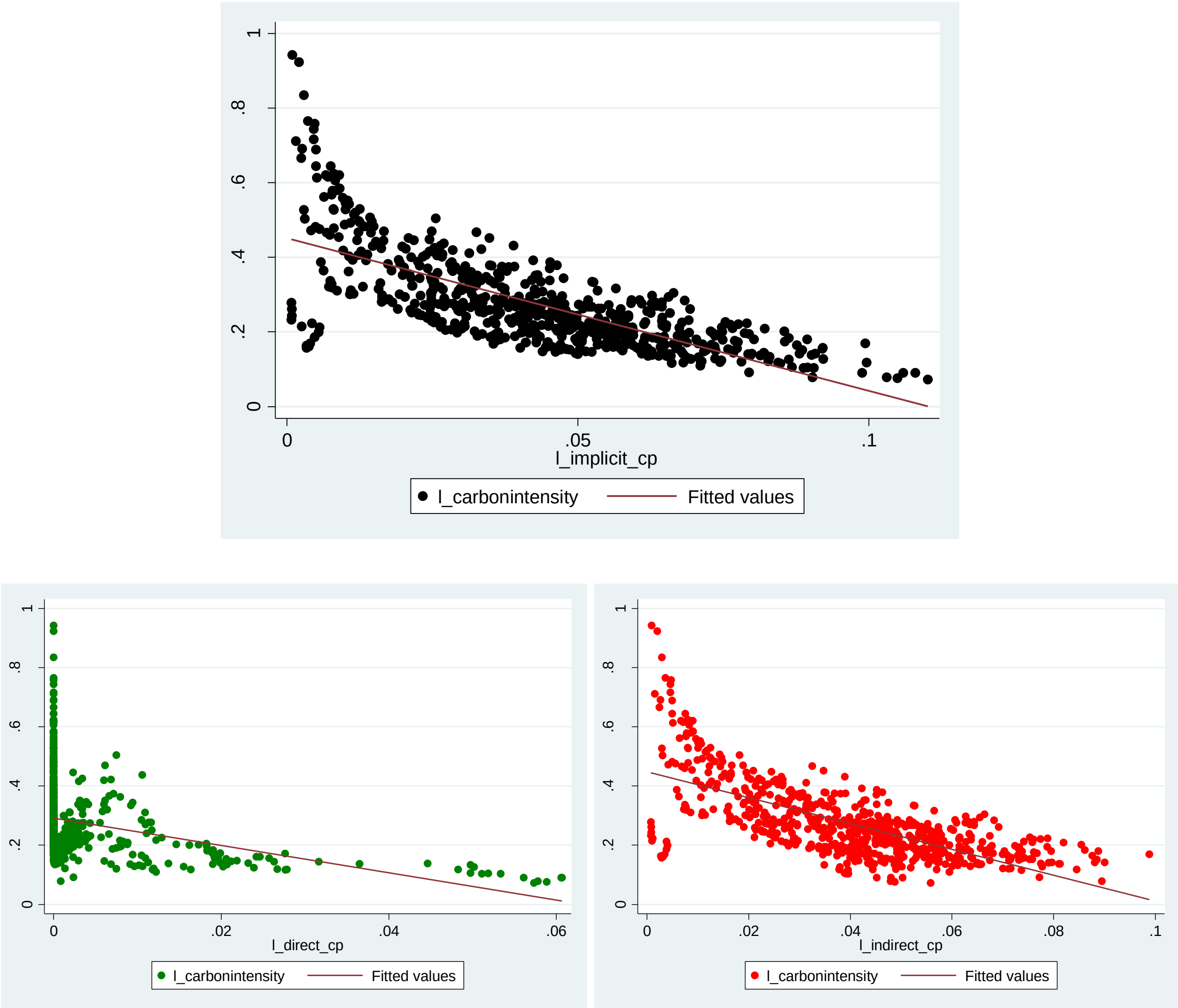

Figure 3 – Scatter Plots for Carbon Intensity and Implicit Carbon Price (top) and Carbon Intensity and Direct Price Signals (bottom left) and Indirect Price Signals (bottom down) for 1995-2016 in 30 European Countries

Source: authors' calculation based on [Eurostat] and [Euromonitor International]

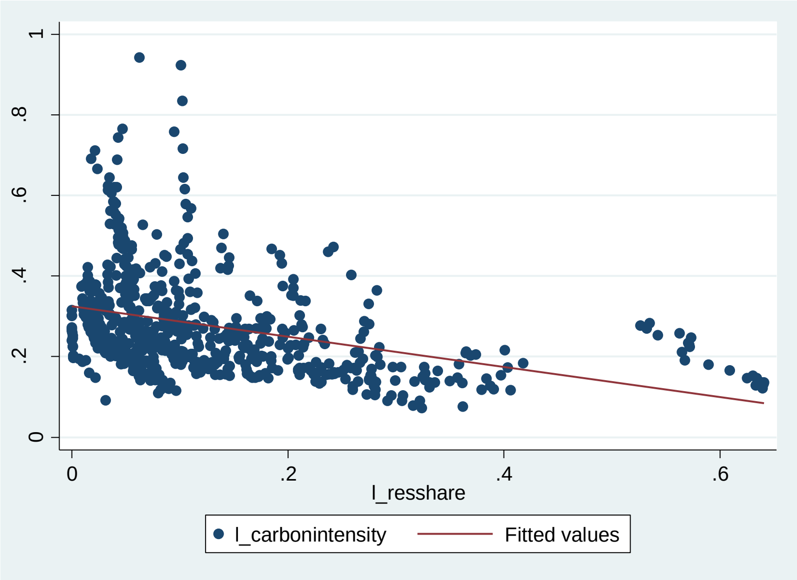

Figure 4 – Scatter Plot for Carbon Intensity and Share of Renewable Energy in Total Primary Energy Supply for 1995-2016 in 30 European countries

Source: authors' calculation based on [Eurostat] and [Euromonitor International]

The Specification of the Models

In order to estimate the causal relationship between different energy/carbon price signals, renewable policies and the level of carbon intensity, several panel regression models were built. They account for the heterogeneity across cross-sections since the independent variables included in the analysis are not able to capture the latent characteristics of the countries which may have an impact on the dependent variable – the carbon intensity of output. These latent characteristics may include a range of country-specific features, which are hard to quantify (quality of institutions, peculiarities of fiscal regimes, market power, etc.). Omission of these latent characteristics may lead to biased estimations of the coefficients, therefore the least squares dummy variable or the fixed-effect and random-effects models were built. For all regressions, the fixed-effect estimation outperformed the random-effects estimation.

The research checks the following hypotheses by means of the corresponding regression equations presented below. All estimations use natural logarithms of both the dependent and independent variables for the ease of interpretation.

H1: Both price signals (the implicit carbon price) and renewable energy policies have had a negative impact on carbon intensity, while the impact of the former was stronger than the impact of the later *(2)*

$$lnCarbonIntensity_{it} = c + \alpha_1 * lnICP_{it} + \alpha_2 * lnResshare_{it} + \sum_k^K \alpha_3 * Country_k + e_{it} \qquad (2)$$

The estimation was made for two time periods 1995–2016 and 2005–2016 and for all 30 countries included in the initial sample.

H2: Both indirect carbon price signals (general energy taxes) and direct carbon price signals (carbon tax and EU ETS) have had a negative impact on carbon intensity, while the impact of the former was stronger than the impact of the later *(3)*

$$lnCarbonIntensity_{it} =$$
$$c + \alpha_1 * lnIndirect\_cp_{it} + \alpha_2 * lnDirect\_cp_{it} + \alpha_3 lnResshare_{it} + \sum_k^K \alpha_4 * Country_k + e_{it} \qquad (3)$$

The estimation was made for two time periods: 1995–2016 and for 2005–2016 (because of the launch of EU ETS in 2005) and for all countries except those for which it is statistically impossible to distinguish carbon tax revenues from general energy tax revenues.

H3: All three types of price signals have had a negative impact on carbon intensity, while the EU ETS price signal had a stronger negative impact compared to the carbon tax price signal *(4)*

$$lnCarbonIntensity_{it} = c + \alpha_1 * lnIndirect\_cp_{it} + \alpha_2 * lnCt\_price_{it} + \alpha_3 * lnETS\_price_{it} +$$
$$\alpha_4 * lnResshare_{it} + \sum_k^K \alpha_5 * Country_k + e_{it} \qquad (4)$$

The estimation was made for 2005–2016 for two groups of counties (a) for the 6 countries which used three types of carbon price signals simultaneously and (b) for the 19 countries covered by EU ETS but without carbon taxes.

Results

According to the F-test, the results of all models show that there is a significant increase in goodness-of-fit in the fixed effect or random-effect models in comparison to the pooled OLS regression. For all three regression model estimations, the Hausman test shows that the fixed-effect model outperforms the random-effects model, which supports the assumption that the latent characteristics of countries are fixed or time-invariant. All coefficients (apart from some coefficients of country-specific dummy variables) are significant at at least the 0.1 significance level (Table 3). All estimations use robust standard errors to account for heteroscedasticity.

Table 3 – Results of the Estimations

Variable	**H1 model:** Coeff. Est (Rob. Std. Err.)	**H1 model:** Coeff. Est (Rob. Std. Err.)	**H2 model:** Coeff. Est (Rob. Std. Err.)	**H2 model:** Coeff. Est (Rob. Std. Err.)	**H3 model:** Coeff. Est (Rob. Std. Err.) *Countries with EU ETS and carbon tax starting from 2005*	**H3 model:** Coeff. Est (Rob. Std. Err.) *Countries with EU ETS and without carbon tax starting from 2005*
l_ICP	-4.1381*** *(0.2494)*	-1.5337*** *(0.1659)*				
l_direct_cp			-2.3268*** *(0.4704)*	-1.2955*** *(0.4278)*		
l_indirect_cp			-4.0450*** *(0.2681)*	-1.6219*** *(0.2093)*	-1.3572*** *(0.3445)*	-1.3991*** *(0.2564)*
l_ct_price					-1.8599*** *(0.5332)*	-
l_ets_price					-2.8638* *(1.6632)*	-2.9741*** *(0.9380)*
l_resshare	-0.6831*** *(0.1028)*	-0.7178*** *(0.0686)*	-0.6837*** *(0.0905)*	-0.7061*** *(0.0706)*	-0.4189*** *(0.0890)*	-0.8941*** *(0.0830)*
constant	0.6089*** *(0.0185)*	0.4575*** *(0.0125)*	0.6031*** *(0.0178)*	0.4606*** *(0.1259)*	0.3894*** *(0.0144)*	0.4932*** *(0.0156)*
Country-specific fixed effects	+	+	+	+	+	+
R-sq	84%	94%	84%	92%	90%	90%
Time period	1995-2016	2005-2016	1995-2016	2005-2016	2005-2016	2005-2016
Number of countries	30	30	25	25	6	19
Number of observations	638	354	528	294	72	222

**0.1 ** 0.05 ***0.01 significance level*

H1 is not rejected: *both price signals (the implicit carbon price) and renewable energy policies have had a negative impact on carbon intensity, while the impact of the former was stronger than the impact of the later*

Estimation of the **first model** shows that the implicit carbon price had an almost 6-times higher impact on carbon intensity compared to the renewable energy share in 1995–2016: a 1%

increase in the implicit carbon price led, on average, to a decrease in carbon intensity by 4.1%, while the same increase in the share of renewable energy in the energy consumption brought only a 0.7% reduction. This indicates that price instruments have historically played a more important role than renewable energy policies in carbon intensity reduction. Results partly support the wide-shared consensus on the central role of carbon pricing in climate policy. It should however be emphasized that renewable energy policies in many countries only have only been introduced around 2002. Not surprisingly, the same regression estimation built for 2005-2016 indicates a smaller difference between implicit carbon price and renewable energy policies. This implies growing relative role of renewable energy policies after 2005.

H2 is not rejected: *both indirect carbon price signals (general energy taxes) and direct carbon price signals (carbon tax and EU ETS) have had a negative impact on carbon intensity, while the impact of the former was stronger than the impact of the later. However, for the period 2005-2016, there is no statistically significant difference between direct and indirect price instruments, although both of them still had a strong negative impact on carbon intensity*

The second model compares the effect of direct and indirect price instruments on carbon intensity. A 1% increase in the direct carbon price leads on average to a 2.3% carbon intensity reduction, while a 1% increase in the indirect carbon price reduces carbon intensity by 4.0% for the period 1995–2016. Therefore, the results indicate that the role of indirect carbon price signals 1995–2016 was twice as high as the role of direct ones.

However, the difference between the estimations of the coefficients of the direct and indirect price signals is not statistically significant for the period 2005–2016, so we cannot conclude that indirect price signals had, on average, a greater impact on carbon intensity during this timeframe. Nevertheless, results support the assumption that, being created primarily for revenue generating purposes, indirect price instruments like excise duties had a profound impact on the emissions level which is comparable to the effect of direct price signals.

The results of the second model also support H1 showing that both direct and indirect carbon price signals have had a stronger negative impact on carbon intensity compared to renewable energy policies. Nevertheless, the comparison of the regression estimations for 1990–2016 and 2005–2016 show that the relative advantage of both direct and indirect carbon pricing over renewable policies decreases over time.

H3 is rejected: *both carbon tax and EU ETS have had a negative impact on carbon intensity, although there is no statistically significant difference between them*

The estimation of the **third model** for the group of countries which used carbon taxes and ETS simultaneously shows that both carbon taxes and EU ETS had a significant negative impact on carbon intensity in 2005–2016. The difference between the estimations of the coefficient of direct price signals is not statistically significant, so we reject H3. The estimation of the **third model** for the group of countries which did not use carbon taxes but were included in EU ETS also shows the negative impact of the EU ETS price signal on carbon intensity. The results indicate that indirect price signals and EU ETS had on average a greater impact on the carbon intensity compared to renewable energy policies which also supports H1.

Conclusion

European countries have always stayed at the forefront of economic environmental policies and climate change mitigation effort. A wide range of regulatory measures are being used to further correct energy production and consumption patterns. The fiscal systems of European countries are gradually transforming in order to foster the low-carbon transition and help change the conditions of inter-fuel competition in favor of the least carbon-intense. Several countries use carbon taxation while, from 2005 an EU-wide emissions trading system has attached a direct price to carbon dioxide emissions. Explicit carbon pricing works alongside a range of general energy taxes (e.g. excises on vehicle fuels) and renewable energy policies which help frame more efficient climate policies.

This paper establishes the relative impact of policy measures on carbon intensity, attaching special importance to distinguishing the impacts of carbon pricing measures versus renewable energy polices as well as the impact of direct carbon pricing (carbon tax and ETS) versus indirect carbon pricing. The analysis is based on the calculation of the implicit carbon price defined as the fiscal burden on a ton of carbon dioxide resulting from both direct and indirect fiscal instruments. The results indicate that carbon pricing has historically played a larger role in carbon intensity dynamics compared to renewable energy policies (feed-in-tariffs, quotas, tenders, tax incentives), although, the high relative impact of carbon pricing tends to decrease with time.

Another important result is that indirect carbon price signals play an important role in carbon dioxide emission changes against the background of direct instruments of emission regulation. Although created primarily for purposes not climate-related, general energy taxes have had a profound impact on carbon intensity which is, on average, twice as high as the impact of direct price signals for 1995–2016. However, from 2005 (the launch of EU ETS) to 2016, there is no statistically significant difference between the direct and indirect price instruments although both of them have had a strong negative impact on carbon intensity. The paper also compares the relative impact of carbon taxes on carbon intensity against the background of the EU ETS, but the regression estimations do not indicate the superiority of any of them.

All in all, emissions dynamics highly depends on the conditions of inter-fuel competition which varies in accordance to comparative prices for different types of energy. In this regard, level of price is just the half of the story – scope and the coverage of an emissions regulation instrument makes a critical difference. Changes in general energy taxes are at least of equal importance as the increasingly popular explicit carbon pricing instruments. Therefore, the results highlight the importance of a broader climate policy framework based on fiscal regulation rather than the one limited to explicit carbon pricing.

The European experience may be especially valuable for developing or transition economies. The cost-efficiency of carbon regulation and its overall impact on emission levels to a large extent depend on the allocation of property rights, transaction costs in the economic system, the level of uncertainty of economic growth and technological development, and other institutional factors. All of these may overstate the administrative costs of managing economic instruments for carbon regulation. Thus, high monitoring, verification and enforcement costs may further undermine the cost-efficiency of carbon-based regulation making simple command-and-control regulatory measures a better alternative.

This is a burning issue especially for countries which are yet to develop mature market institutions. The introduction of new carbon-based incentive instruments with no regard for the existing fiscal framework and the specific features of the institutional environment may bring no added value, and may, in fact, even hurt the economy. In contrast to carbon taxes, which can often be embodied in the existing fiscal infrastructure, the launch of a cap-and-trade system requires the creation of new institutes (platforms and for trade and allowances distribution, etc.) leading to a higher risk of corruption. For the sake of the sustainable use of carbon-based incentive instruments, their introduction should be gradual while their development should be synchronized with existing fiscal measures. Alternatively, if the institutions and market environment are too weak to manage these instruments cost-efficiently, a possible solution could be to modify the existing price signals towards higher environmental efficiency. In particular, a gradual increase of the carbon component in the tax base of existing energy taxes may help make energy policy more environmentally focused. In developing economies, such an approach may, on the one hand, help avoid high administrative costs of newly-launched instruments, and, on the other hand, help better consider the contribution of existing fiscal regulatory measures to more effective climate policies.

Annex 1 - Descriptive Statistics of the Input Data

Variable		Mean	Std. Dev.	Min	Max	Observations
country	overall	15.5	8.662006	1	30	N = 660
	between		8.803408	1	30	n = 30
	within		0	15.5	15.5	T = 22
year	overall	2005.5	6.349101	1995	2016	N = 660
	between		0	2005.5	2005.5	n = 30
	within		6.349101	1995	2016	T = 22
carbon~y	overall	.3287724	.1887482	.0756987	1.566948	N = 660
	between		.1374913	.1302035	.7790488	n = 30
	within		.1316224	-.0474746	1.116671	T = 22
implic~p	overall	.0444254	.0239497	.000718	.1163652	N = 644
	between		.0203401	.0030738	.0909861	n = 30
	within		.0136715	.0083778	.1028887	T-bar = 21.4667
indire~p	overall	.040897	.0209808	.000718	.1038988	N = 644
	between		.0175441	.0022232	.0729774	n = 30
	within		.0124946	.0095712	.1008314	T-bar = 21.4667
direct~p	overall	.0034429	.0093498	0	.0625256	N = 660
	between		.0088344	.0000331	.0450127	n = 30
	within		.0034436	-.02148	.0209558	T = 22
ct_price	overall	.0027703	.0093228	0	.0623697	N = 660
	between		.0089341	0	.0448921	n = 30
	within		.0031048	-.0220319	.0202479	T = 22
ets_pr~m	overall	.0006725	.0014762	0	.0147326	N = 660
	between		.0005929	2.19e-09	.0022898	n = 30
	within		.001356	-.0016173	.0131153	T = 22
resshare	overall	.1473913	.1652026	0	.8974506	N = 654
	between		.1632405	.005006	.8098658	n = 30
	within		.0364024	.0301613	.2916494	T = 21.8

Annex 2 - Pearson correlation matrix

	carbon~y	implic~p	indire~p	direct~p	ct_price	ets_pr~m	resshare
carboninte~y	1.0000						
implicit_cp	-0.6931*	1.0000					
indirect_cp	-0.6603*	0.9199*	1.0000				
direct_cp	-0.2924*	0.4920*	0.1112*	1.0000			
ct_price	-0.2783*	0.4912*	0.1159*	0.9875*	1.0000		
ets_price_m	-0.0942*	0.0124	-0.0279	0.0972*	-0.0608	1.0000	
resshare	-0.3251*	0.3556*	0.2550*	0.3353*	0.3517*	-0.0975*	1.0000

* *marks 0.05 significance level*

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Ilya A. Stepanov
National Research University Higher School of Economics (Moscow, Russia). Center for Comprehensive European and International Studies, junior research fellow
E-mail: iastepanov@hse.ru

Johan Albrecht
Ghent University (Ghent, Belgium). Faculty of Economics and Business Administration, PhD, Professor, E-mail: Johan.Albrecht@UGent.be