# Determinants of sectoral effective carbon rates on energy use

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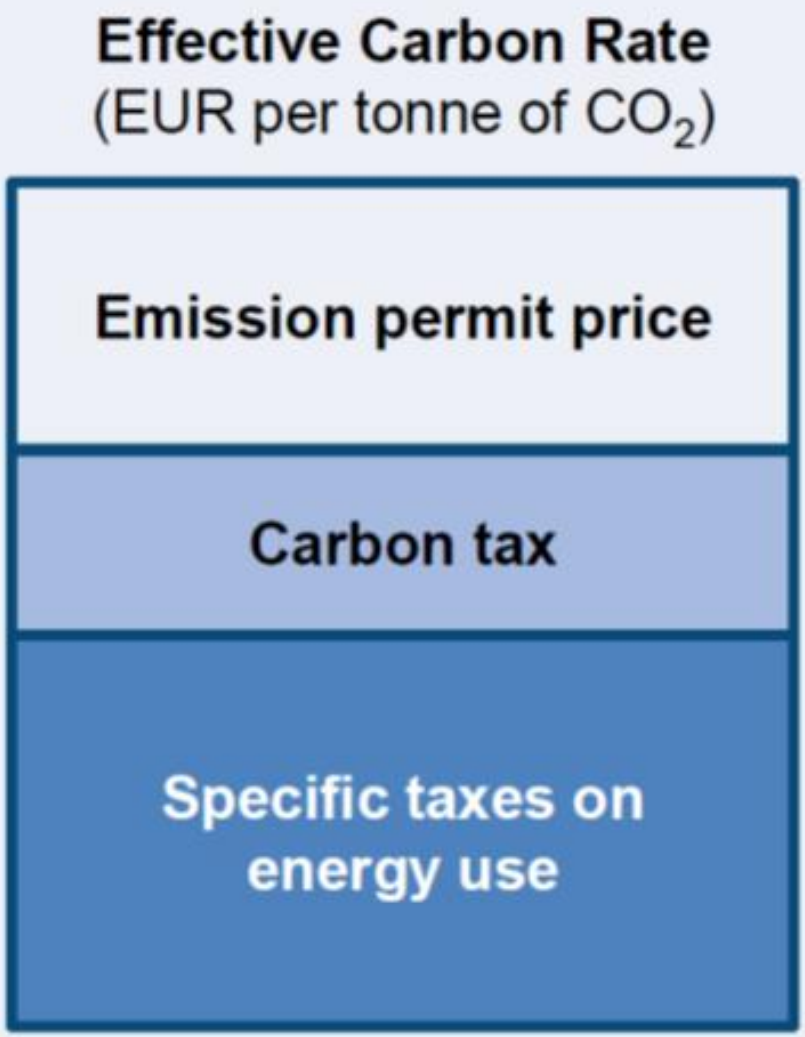
# ECR= Excises+Carbon Taxes+ETS prices

**Figure 1.1. Components of effective carbon rates**

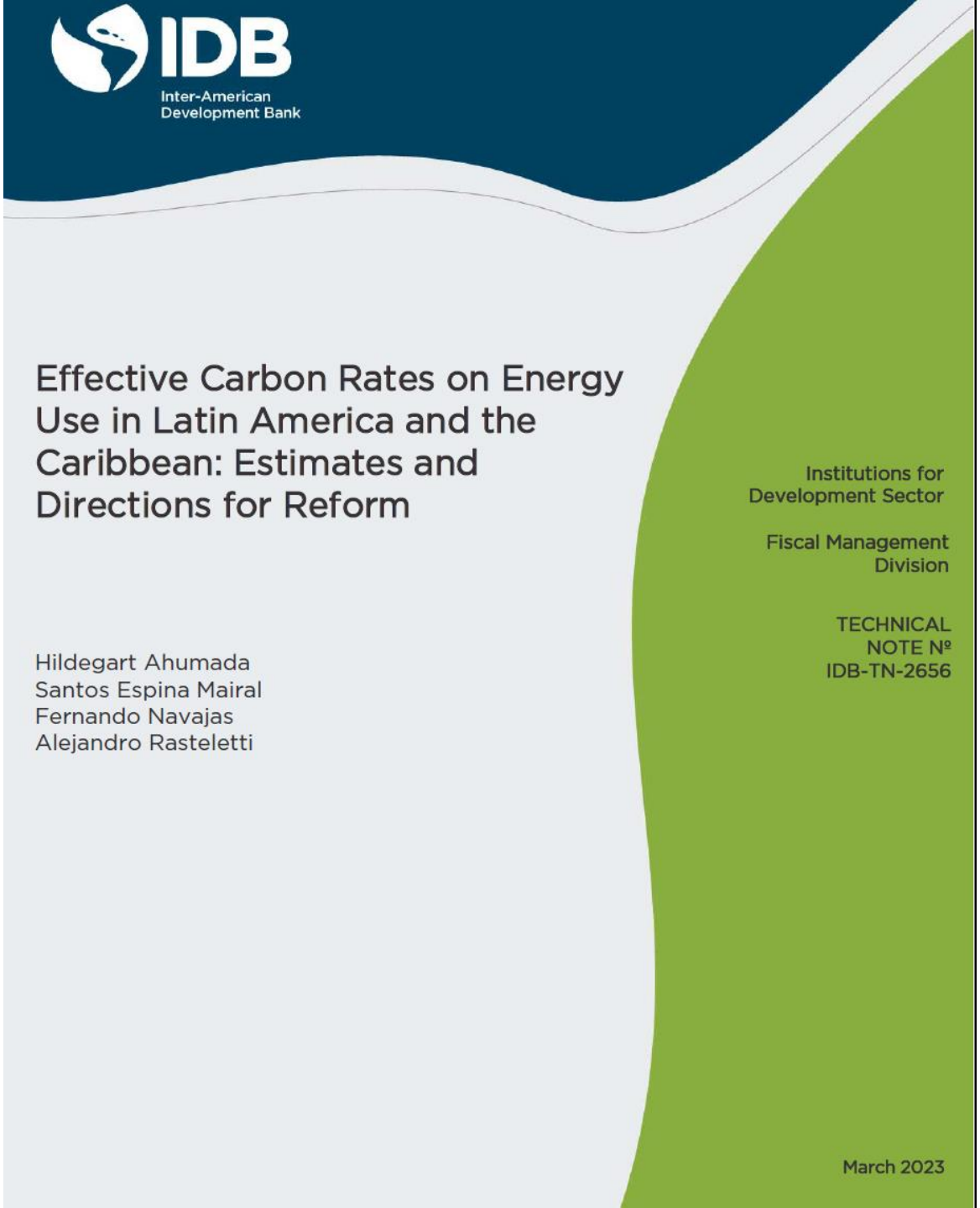


# Related literature

- OECD reports ECR (OECD-ECR, 2019, 2021) as well as papers using their data. We extend to LAC following IEA (2021) energy balances, emission conversion factors and adding bottom up sectoral energy use taxes for each country in LAC.
- OECD-ECR (2021) states the bias towards road transport in the measurement. We make this observation more accurate for LAC and prepare global sample to model determinants.
- Environmentally-related energy excise taxation (Barde and Bratheen, 2005; Navajas et al, 2012; Conte Grand et al, 2022). Excises here are one part, albeit important, of ECR.
- Models that explain observed tax structures in more positive terms and explain observed biases (in general terms, Becker, 1983 and Kanbur and Myles, 1992; applied to energy environmentally related taxes, Navajas *et al*, 2012; applied to fossil fuels taxes and subsides, Mahdavi *et al*, 2022).

# Related literature

- Papers on the structural determinants of carbon pricing in general (Carraro and Favero, 2009; Faure, 2020)
- Literature on the effects of energy subsidies on effective energy and carbon prices (Parry *et al*, 2021)
- Reports by OECD (OECD-ECR, 2021, chapter 2) and background academic papers (e.g. Sen and Vollebergh, 2018; Martin, Muûls and Wagner, 2016) on ECR and energy consumption and emissions
- Paper by Ahumada et al (2023) provides the database.


IDB
Inter-American
Development Bank
Effective Carbon Rates on Energy Use in Latin America and the Caribbean: Estimates and Directions for Reform
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Fernando Navajas
Alejandro Rasteletti
Institutions for Development Sector
Fiscal Management Division
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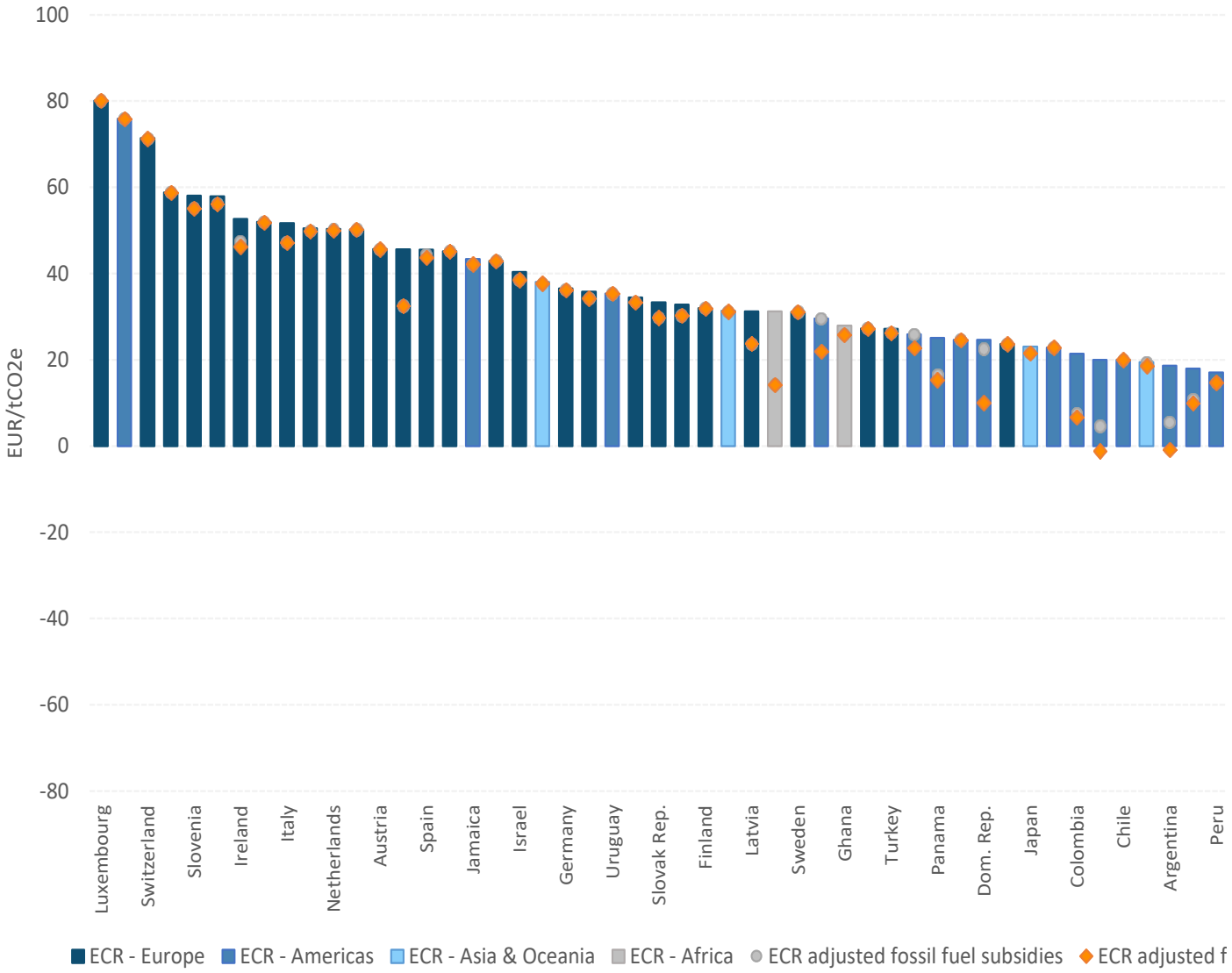
# ECR: Measurement and estimation

- *Energy balances*. An nxm matrix **B** ($b_{ij}$) expressing, in TJ, energy use of m products across n sectors.
- *Tax code*. An nxm matrix **T** ($t_{ij}$) expresing, in TJ, energy taxes including excises, carbon taxes and ETS prices and allowing for exemptions. Taxes are then expressend as EU/TJ
- *Conversion factors for emissions*. An nxm matrix **E** ($e_{ij}$) of CO2 emissions from energy use of m products across n sectors, expressed in TJ/t$CO_2$.
- By aggregation of the products and sectors we express effective carbon rates as a weighted sum across products $ECR_i = \sum_j w_{ij} b_{ij} e_{ij} t_{ij} \quad i = 1, \dots 6$ expressed in EU/t$CO_2$. Sectoral aggregation for OECD is 6 sectors.
- Each country has 6 sectoral ECR and an economywide value in our sample of 66 countries. Regional averages are unweighted.
  - Own estimates for 18 LAC countries, OECD sources for the rest

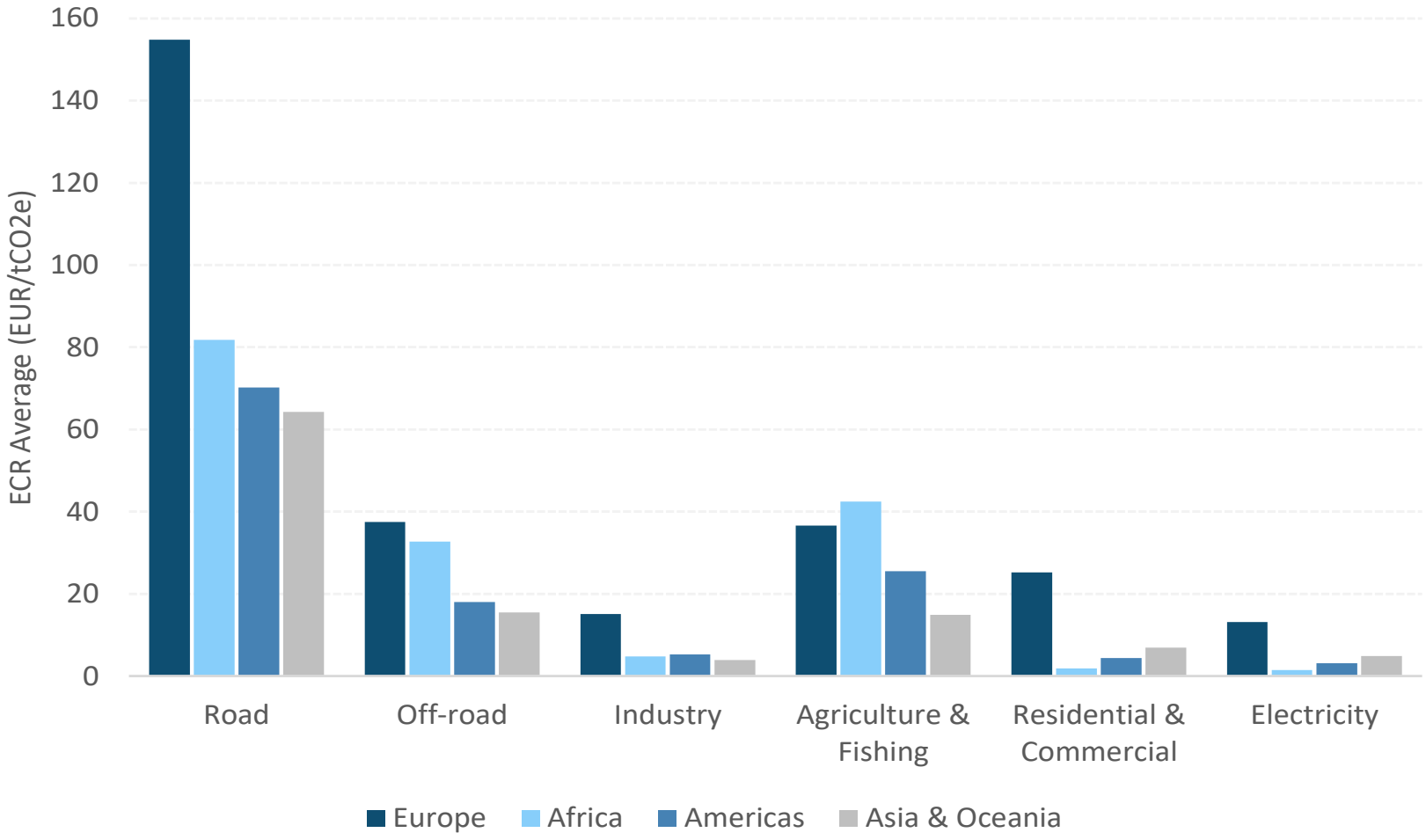
# Economy wide estimates of ECR

**Figure 1: Effective Carbon Rates, 2018**



# Sectoral differences

**Figure 2: Effective Carbon Rates in Regions, by Sector**



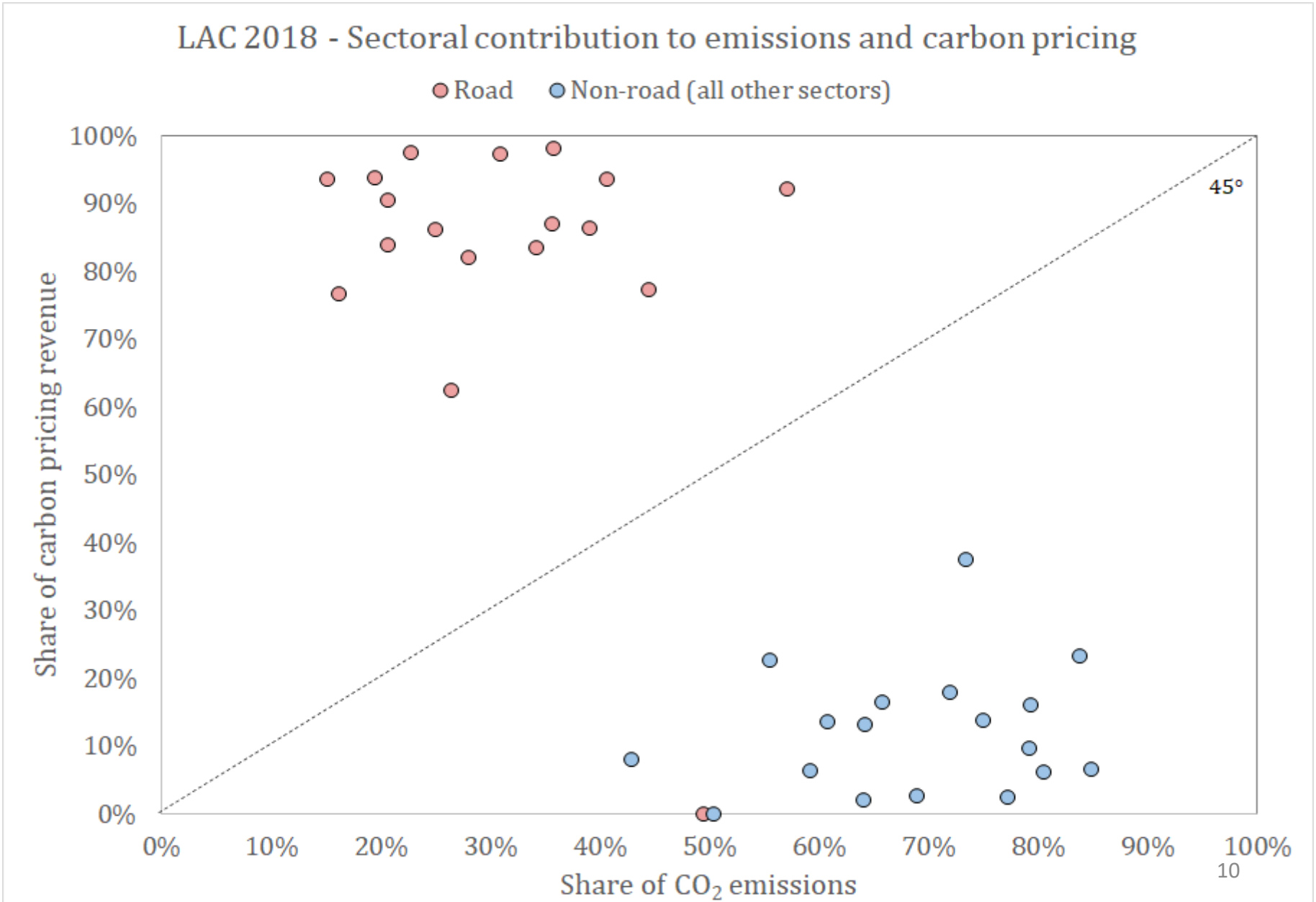

Source: Authors' estimations for LAC countries. For other countries, see OECD (2021a, 2021b).

# Level and structure of ECR for LAC, 2018

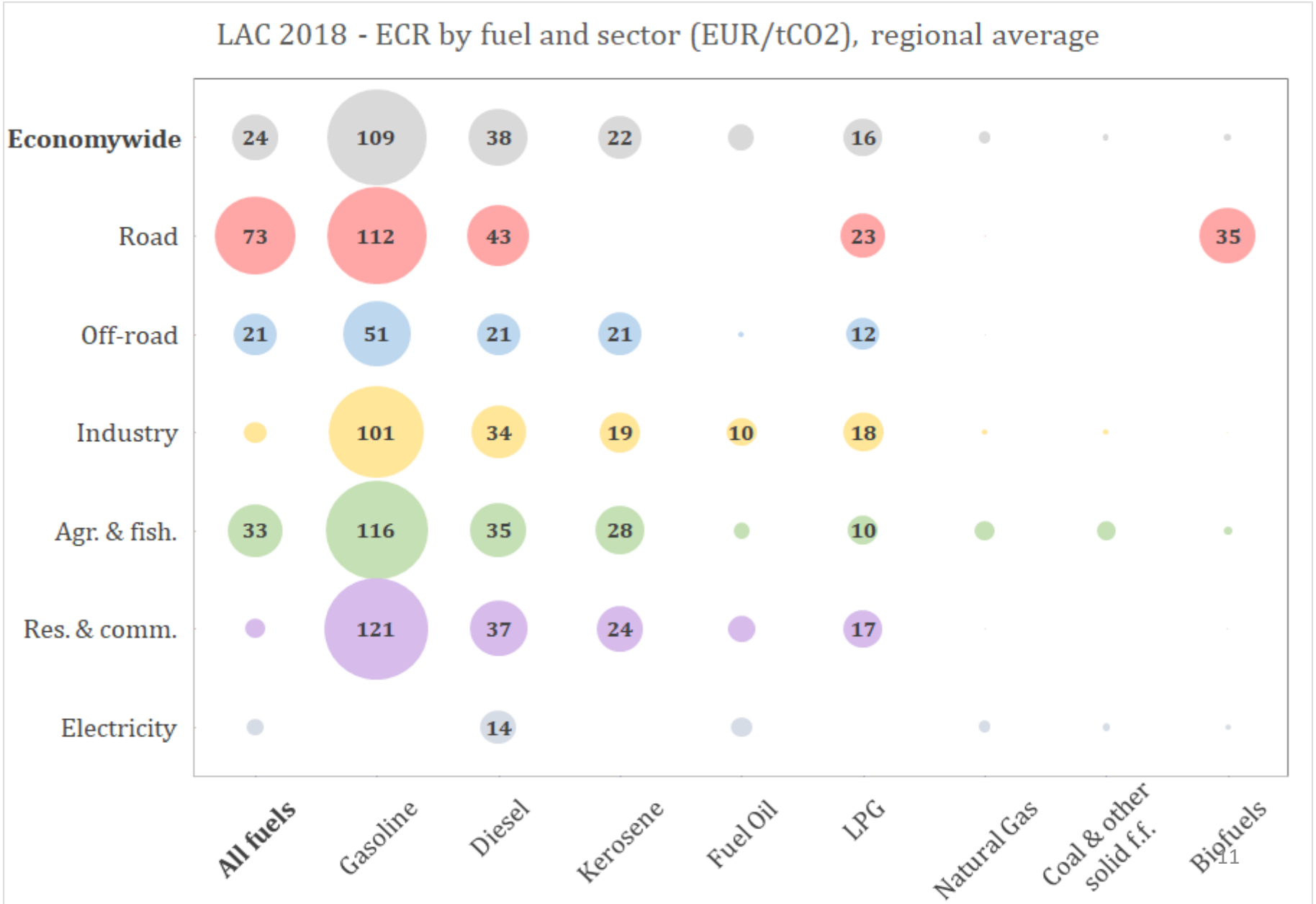
| country | Fuel Excise Tax | Carbon Tax | **Effective Carbon Rate** | *Electricity Excise Tax* |
|---|---|---|---|---|
| Argentina | 17.18 | 1.46 | **18.64** | *4.39* |
| Bolivia | 20.02 | 0.00 | **20.02** | *4.95* |
| Brazil | 16.24 | 0.00 | **16.24** | *5.26* |
| Chile | 18.77 | 1.24 | **20.01** | *0.00* |
| Colombia | 19.68 | 1.72 | **21.39** | *0.00* |
| Costa Rica | 75.93 | 0.00 | **75.93** | *7.66* |
| Dom. Rep. | 24.61 | 0.00 | **24.61** | *0.00* |
| Ecuador | 0.00 | 0.00 | **0.00** | *12.59* |
| El Salvador | 17.95 | 0.00 | **17.95** | *0.00* |
| Guatemala | 6.86 | 0.00 | **6.86** | *3.75* |
| Honduras | 25.91 | 0.00 | **25.91** | *2.83* |
| Jamaica | 43.34 | 0.00 | **43.34** | *0.00* |
| Mexico | 28.28 | 1.28 | **29.57** | *0.00* |
| Nicaragua | 14.28 | 0.00 | **14.28** | *3.06* |
| Panama | 25.07 | 0.00 | **25.07** | *0.00* |
| Paraguay | 22.83 | 0.00 | **22.83** | *0.00* |
| Peru | 17.09 | 0.00 | **17.09** | *4.14* |
| Uruguay | 35.35 | 0.00 | **35.35** | *0.00* |
| *LAC simple average* | *23.85* | *0.32* | ***24.17*** | *2.70* |

*Source: own estimation based on country-level legislation and tax codes, and EIA World Energy Balances.*

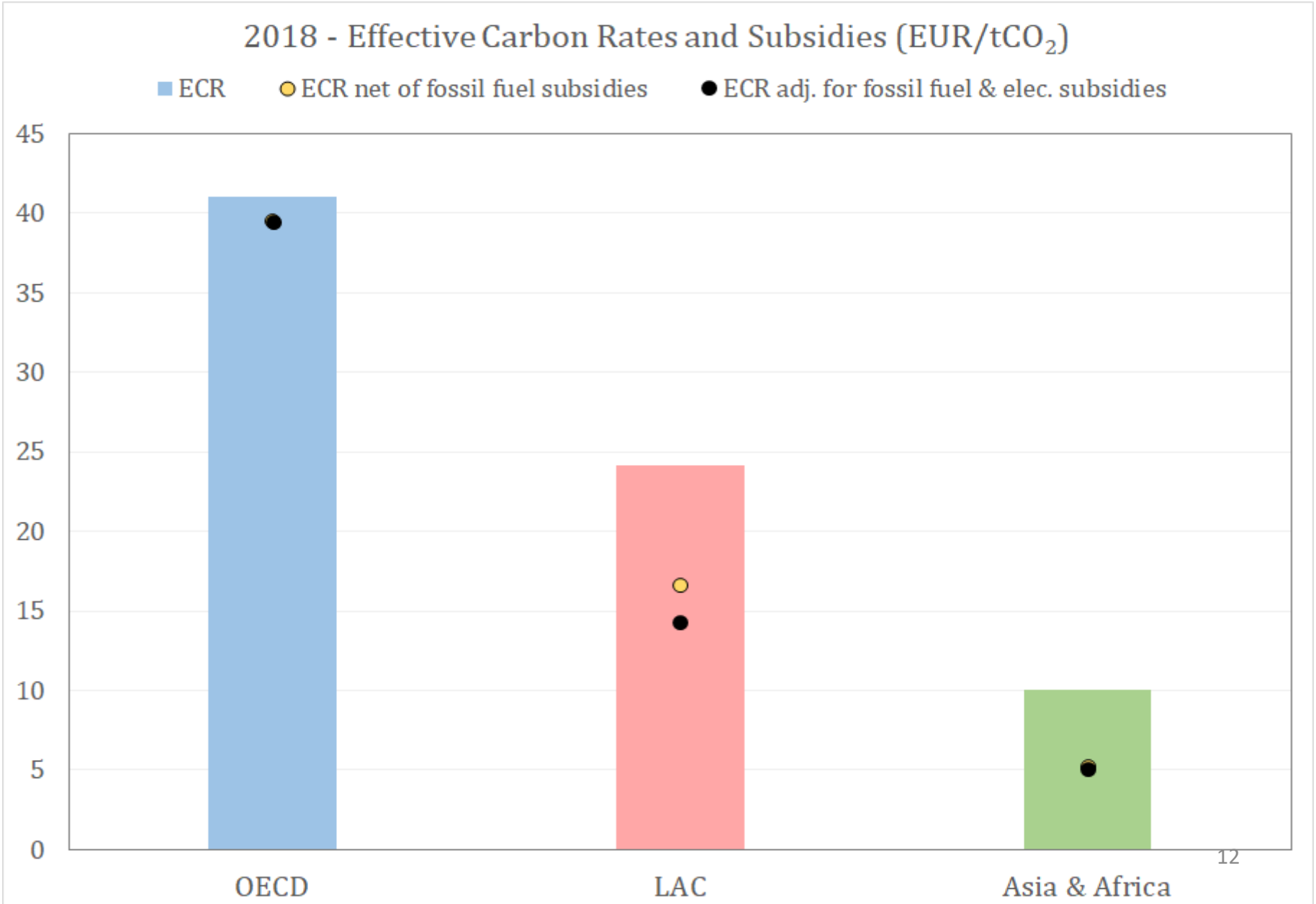
# Sectoral bias of ECR: Road Transport vs Others



# Sectoral and products bias of ECR



# Adjusted ERC, for energy subsidies



# Econometric modelling of ECR determinants

- Separate 3 models: Economy wide, Road Transport and Rest of sectors. First two models are cross section n=66, third is a panel of n=5x66.
- ECR and adjusted (for subsidies) as explained variable against a set of structural, economic and institutional variables. To handle many potential variables, an automatic algorithm (Autometrics, see Doornik, 2009 and Hendry and Doornik, 2014) helped us select the relevant determinants.
  - Uses a tree search to discard paths rejected as reductions of the initial unrestricted model based on ordered squared t-statistics, given a p-value provided by the researcher and providing misspecifications tests.
  - Allows obtaining more robust estimations by selecting the observations that are outliers among all the observations in the sample (given a p-value). That is, by using impulse dummy saturation we can find countries that can be treated as outliers in the cross-country regressions, apart from testing the regional (OECD and LAC) effects

# Data and variables definition

• Broad group of candidate explanatory variables was compiled from various sources. These include standard income-level measures as GDP per capita (*gdp*), and indicators that intend to proxy fiscal revenue needs. Among them a proxy of the marginal cost of public funds (*mcf*) defined from optimal indirect taxation formulae (Navajas *et al*, 2012) :

$$mcf = \frac{1 + VAT}{1 + 0.1\,VAT} \qquad (2)$$

• Three blocks of explanatory variables related to governance and institutions; infrastructure quality indicators and geographical indicators

# Data and variables definition

| Variable group | Variable name | Description |
|---|---|---|
| *Carbon pricing variables* | **ecr** | Effective Carbon Rate (EUR/tCO2) in 2018. ECR includes fuel excises, carbon tax, and marginal permit price for ETS systems, in case these instruments are operative. Data drawn from ECR 2021 was replaced from TEU 2019 uniquely for the Road sector in the particular cases where the sectoral ECR saturated the 120 benchmark. |
| | **ets** | Dummy variable coded =1 if Emission Trading System was operative in 2018, excluding subnational systems (as for the case of USA, Canada, Japan, China). |
| | **carbon** | Dummy variable coded =1 if Carbon Tax was operative in 2018, excluding subnational systems (USA). |
| | **subsidy_fuel** | Fossil fuel subsidies (EUR/tCO2) in 2018. LAC country data is from FIEL (2020). TEU SD countries have fuel subsidy data from OECD TEU SD, but do not have electricity subsidy data, so the latter are filled with zero-values. The remainder of the countries in the document have fuel subsidy data from OECD Inventory of Support Measures for Fossil Fuels, taking into acount uniquely Budgetary Transfers, because Tax Expenditures should already be accounted for under TEU methodology. Electricity-based support measures are taken as Electricity subsidies (see below). |
| | **subsidy_elec** | Electricity subsidies (EUR/tCO2) in 2018. Same sources as above. |
| | **adj_ecr** | Effective Carbon Rate net of Fuel Subsidies (EUR/tCO2) |
| | **adj_ecr_elec** | Effective Carbon Rate net of Fuel Subsidies and adjusted for Electricity subsidies (EUR/tCO2). This estimate is done assuming a cost structure where 90% are explained by variable costs, and considering that subsidies on electricity increase the demand for fossil fuels to the extent that electricity generation is fossil-fuel based. Thus, ECR net of fossil fuel subsidies is hereby adjusted by substracting **subsidy_elec** multiplied by 0.9 and by the share of electricity generated using fossil fuels (**1-renew_elec**). |

| Variable group | Variable name | Description |
|---|---|---|
| *Control variables* | **gdp** | GDP per capita, 2018, PPP (constant 2017 international $) |
| | **emission** | CO2 emissions, 2018 (kg per PPP $ of GDP) |
| | **emission_transport** | Transport sector share in CO2 emissions from enery use. Keep in mind this sectoral definition encompasses Road and Off-Road transport, and takes into account emissions excluding biofuel combustion, and thus is not directly comparable with our approach. |
| | **oil** | Oil rents, 2018 (% of GDP) |
| | **net_exporter** | Dummy coded =1 if country is a net energy exporter |
| | **renew_energy** | Renewable energy consumption, 2018 (% of total final energy consumption) |
| | **renew_elec** | Renewable electricity output, 2015 (% of total electricity output) |
| | **energy_use** | Energy use (kg of oil equivalent) per $1000 GDP, 2014 (constant 2017 PPP). |
| | **dist_loss** | Electric power transmission and distribution losses (% of output), 2014 |
| | **polity** | Polity Index, 2018 (10 is full democracy, -10 full autocracy) |
| | **regqual** | Normalized estimate based on a standard distribution (ranges from aprox -2.5 to 2.5). Reflects perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development. 2018. |
| | **mcf** | Marginal Cost of public Funds, proxied as (1+VAT)/(1+0.1*VAT). VAT data was sourced from PWC. For USA, State-level Sales & Use tax rates were weighted by total energy consumption shares for 2018 from EIA. |
| | **debt** | Gross Government Debt (% of GDP), 2018 |
| | **deficit_prim_5** | General government primary net lending/borrowing (% of GDP), 2014-2018 avg |
| | **pop_density** | Population density, 2018 (people per sq. km of land area) |
| | **latitude** | Latitude value of capital city |
| | **elevation_span** | Elevation span (distance in m from lowest to highest point) |
| | **road_quality** | Road quality index, 2017-2018 edition (1 = extremely underdeveloped—among the worst in the world; 7 = extensive and efficient—among the best in the world]) |
| | **road_density** | km of road per sq. km |
| | **road_paved** | Percentage of roads paved (%) |
| | **transport_infr** | Logistics performance index: Quality of trade and transport-related infrastructure (1=low to 5=high). Nicaragua was completed due to missing data using the OLS best fit prediction based on its road_quality value, given that the correlation coefficient between both variables is 0.77. |
| | **vehicles** | Motor vehicles per 1000 people (2014) |

# Summary of econometric results

- A simple automatic selection of explanatory variables lead to a simplified picture: ECR main determinants selected at the economy-wide level are basically three, GDP, marginal cost of funds and the presence of ETS.
  - The first two come (as expected) from ECR determinants in the road transport sector while the third (ETS) come from its effects in the rest of sectors.
- Other structural and institutional elements play an auxiliary or secondary role, while most physical or geography variables in our large dataset are not selected.
- The effect of ETS on economy wide ECR is significant (7%). Absence of a similar effect from carbon taxes show that they are probably associated with compensatory effects in excises.
- LAC as a region is not captured as having a different model nor does it interact with individual variable effects. The only test for differences in LAC versus OECD is shown in the role of ETS, since these are not operative in LAC.

**Table 1. Regression results for selected economywide models**

| Explanatory variables \ Dependent variable | ECR | ECR-F | ECR-F-E |
|---|---|---|---|
| Log (GDP per capita) | 6.08** | 6.80** | 6.28** |
| | (2.08) | (2.01) | (2.14) |
| ETS | 11.0** | 12.5** | 16.1*** |
| | (4.09) | (3.94) | (4.21) |
| MCPF | 104** | 87.3* | 73.8* |
| | (35.08) | (33.81) | (36.14) |
| CRI | 57.2*** | 59.9*** | 62.4*** |
| | (10.04) | (9.65) | (10.31) |
| SWIT + LUX | 37.8*** | 37.7*** | 37.2*** |
| | (7.81) | (7.50) | (8.02) |
| JAM | | 29.8** | 32.1** |
| | | (9.61) | (10.27) |
| EGYP | | -35.9*** | -33.7** |
| | | (9.60) | (10.26) |
| ECU | | -84.0*** | -82.0*** |
| | | (9.63) | (10.29) |
| Constant | -157*** | -149** | -131** |
| | (45.02) | (43.46) | (46.45) |
| **Adjusted $R^2$** | 0.726 | 0.839 | 0.827 |
| **Observations** | 66 | 66 | 66 |

Note: ECR stands for the standard effective carbon rate, ECR-F corresponds to ECR adjusted for fuel subsidies, and ECR-F-E corresponds to ECR adjusted for both fuel and electricity subsidies. Standard errors are shown in parenthesis. * means p-value <0.05, ** p-value <0.01, and *** p-value <0.001.

**Table 2. Regression results for road transport**

| Explanatory variables \ Dependent variable | ECR |
|---|---|
| Log (GDP per capita) | 19.0** |
| | (6.33) |
| Oil | -6.24* |
| | (2.51) |
| Elevation Span | -0.005* |
| | (0.003) |
| MCPF | 559*** |
| | (125.90) |
| Population Density | 0.147*** |
| | (0.04) |
| Constant | -725*** |
| | (147.40) |
| **Adjusted $R^2$** | 0.571 |
| **Observations** | 66 |

Note: ECR stands for the standard effective carbon rate for the road-transport sector. Standard errors are shown in parenthesis. * means p-value <0.05, ** p-value <0.01, and *** p-value <0.001.

**Table 3. Regression results for pooling of other sectors**

| Explanatory variables \ Dependent variable | ECR |
|---|---|
| Agriculture & Fishing Sector | -349*** |
| | (71.44) |
| ETS | 7.15** |
| | (2.41) |
| ETS * Agriculture & Fishing Sector | -23.5** |
| | (8.48) |
| MCPF * Agriculture & Fishing Sector | 327*** |
| | (65.64) |
| Baltic * Off-Road Sector | 90.7*** |
| | (1.93) |
| Latitude | 0.100** |
| | (0.035) |
| SWI * Off-Road Sector | 91.1*** |
| | (1.55) |
| CRI * Agriculture & Fishing Sector | 64.9*** |
| | (4.62) |
| Constant | 7.09*** |
| | (1.26) |
| **Adjusted $R^2$** | 0.419 |
| **Observations** | 330 |

Note: ECR stands for the standard effective carbon rate for the road-transport sector. Baltic dummy includes Estonia, Latvia and Lithuania. Robust standard errors are shown in parenthesis. * means p-value <0.05, ** p-value <0.01, and *** p-value <0.001.

**Table 4. Regression results for cross section of other sectors**

Note: ECR stands for the standard effective carbon rate for the road-transport sector. Baltic dummy includes Estonia, Latvia and Lithuania. Standard errors are shown in parenthesis. * means p-value <0.05, ** p-value <0.01, and ** p-value <0.001.

| Sector | Off-road | Industry | Agriculture & fisheries | Residential & commercial | Electricity |
|---|---|---|---|---|---|
| Dependent variable / Explanatory variables | ECR | ECR | ECR | ECR | ECR |
| ETS | 9.41 | 7.37*** | | 16.7*** | 10.4*** |
| | (5.15) | (1.56) | | (2.84) | (0.72) |
| MCPF | | | 257*** | | |
| | | | (59.57) | | |
| latitude | | 0.054* | | | |
| | | (0.03) | | | |
| Baltic | 85.2*** | | | | |
| | (12.02) | | | | |
| SWIT | 84.6*** | | | 46.5*** | |
| | (20.05) | | | (11.34) | |
| JAM+UGA | 78.4*** | | | | |
| | (14.30) | | | | |
| DMK | | 16.9*** | | | |
| | | (4.68) | | | |
| NOR | | 24.0*** | | | |
| | | (4.69) | | | |
| SLOV | | 20.2*** | | | |
| | | (4.67) | | | |
| JAM | | 18.6*** | 82.3*** | | |
| | | (4.66) | (21.54) | | |
| CRI | | | 72.1** | | |
| | | | (21.62) | | |
| UGA | | | 91.1*** | | |
| | | | (21.51) | | |
| TUR | | | 85.8*** | | |
| | | | (21.51) | | |
| NETH | | | | 84.7*** | |
| | | | | (11.34) | |
| ISR | | | | 48.3*** | |
| | | | | (11.29) | |
| ICE+KOR+SWIT+ UK+CRI+JAM | | | | | 17.0*** |
| | | | | | (1.24) |
| Constant | 16.0*** | 3.36*** | -271*** | 3.27 | 1.33*** |
| | 3.32 | 0.79 | 68.71 | 1.86 | 0.48 |
| **Adjusted $R^2$** | 0.612 | 0.721 | 0.510 | 0.678 | 0.877 |
| **Observations** | 66 | 66 | 66 | 66 | 66 |

# Final comments

- Economy-wide ECR across countries are explained by GDP, the marginal cost of public funds and the existence or not of an ETS mechanism.
  - The first two variables drive the equation for road transport ECR while ETS significance comes from the panel estimate for the (poorly taxed) rest of sectors.
- The quantitative contribution of ETS to economy-wide ECR is significant (countries with ETS have on average 7% higher ECR) and shows that the introduction of ETS does not carry a compensatory adjustment of other components of ECR, mainly excises.
  - The result that there is no "carbon pricing crowding out" (if we are allowed to use the term) after the introduction of ETS is a significant result.
- The same cannot be said in the case of carbon taxes, according to our results, probably do to the fact that carbon pricing results may come with compensatory adjustments in excises in road transport fuels.

# Final comments

- Three main explanatory variables, from a very large list of potential determinants, as consistent determinants of ECR. These are GDP per capita, the marginal cost of public funds, and having a nationwide ETS in operation.
  - The first two variables lead to an increase in the economywide ECR through their effects on the road transport sector.
- The significance of having a nationwide ETS in operation comes from the electricity, industry and commercial and residential sector.
  - The quantitative contribution of having an ETS to the economywide ECR is significant in magnitude, suggesting that the introduction of an ETS does not carry a compensatory adjustment of other components of ECR (e.g. excises taxes), that nullifies its effects on carbon pricing.
- This contrasts with the effect of having carbon taxes, which is not selected as a ECR determinant, probably due to policy substitution or design deficiencies.
- Policy implications on the direction of reform from 3 margins: Instruments, energy products and sectors. Country specific: It depends on energy structure and institutions.