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Assessing the authenticity of national carbon prices: A comparison of 31 countries

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ABSTRACT

Many countries have carbon pricing in place, in the form of a tax and/or market. Generally, this involves low price rates, incomplete emissions coverage, and price reductions for particular sectors. This raises the question whether the label "carbon price" – in the environmental-economics textbook sense – really applies. To answer it, we assess the authenticity of 31 national carbon prices, calculating average carbon prices and their gap with advertised prices, at both national and sector levels. The results indicate a poor level of authenticity. This means that the carbon prices published by sources such as the World Bank provide a misleading representation of the actual national policy pressure on emissions. Countries show considerable differences regarding the average carbon price level and the gap with advertised prices. Moreover, there is not a one-to-one relationship between advertised and average carbon prices, suggesting the former are not a good basis for international comparison of policy effectiveness. Across countries, the mean carbon price equals €7.90/ton of CO_2 while the mean price gap is 57.7%. Most noticeably, the highest advertised price for Sweden should be interpreted with care as it goes along with a price gap of almost €100 to the average price. In addition, Switzerland and Finland show relatively high price gaps. To illustrate the relevance and non-triviality of our indicators, note that Sweden occupies a 3rd position in terms of average carbon price (after Norway and Switzerland), 27th in terms of price gap, and 16th in terms of effective rate (i.e. sum of implicit and explicit carbon prices). We further find that implicit carbon prices dominate explicit ones for most countries, notably in road transport, whereas the reverse holds for industrial and electricity sectors. Combining our findings with recent empirical evidence for carbon-pricing effectiveness highlights the potential of the instrument to combat climate change, provided implementation is improved and internationally harmonized. Shifting the attention from advertised to average carbon prices might help in this regard.

1. Introduction

According to textbooks in environmental economics, a carbon price should be uniform across all polluters (Perman et al., 2011; Stern, 2007; Aldy et al., 2010; Cramton et al., 2017). The rationale behind such an approach is that the emission of any carbon-dioxide molecule at a certain time has the same impact on global warming and associated environmental, economic and health damages, regardless of where it is emitted. A uniform price thus results in effective emissions reduction against minimal costs or welfare losses. In addition, if price uniformity extends to all sectors and countries, carbon pricing will not cause unfair competition, in turn limiting carbon rebound and preventing carbon leakage (Baranzini et al., 2017).

The most common figure referenced with regards to the strength of pricing instruments is the upper most price rate implemented on emissions covered in a jurisdiction, before discounts are permitted. This is the nominal price used by the World Bank for their *carbon pricing dashboard* (World Bank, 2020) and is referred to by the OECD as the 'standard rate' (OECD, 2016). In this paper we call it the "advertised price", to distinguish it from an "average price" which we argue to provide a better basis for an aggregate-level comparison of countries. We will show that the advertised price can be highly misleading about the actual policy pressure on emissions. While the authors of carbon pricing databases and assessments (such as the World Bank's annual "State and

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Trends of Carbon Pricing") are probably aware of the incomplete picture provided by the nominal carbon prices they advertise, this is generally not clear to a wide group of social scientists, the media, political stakeholders and the broader public. Hence, our analysis fills a gap and contributes to better informed debate about actual implementations and comparisons of carbon pricing around the world. Note that Fig. 3 of World Bank (2020) (and Figure 2.3 of World Bank, 2021) – probably the most influential overview of carbon prices worldwide – plots advertised prices against emission coverage. But the report does not offer graphs with average prices and price gaps. As an illustration, this results in the World Bank information presenting Sweden as having the highest carbon price worldwide, while in terms of average carbon price we find it is only in third position (our Fig. 1), in price gap it is 27th (our Fig. 2), and in effective rate (sum of implicit and explicit carbon prices) it is 16th (our Fig. 5). This illustrates the relevance and non-triviality of our analysis.

We define a carbon price with total authenticity as one that applies uniformly, i.e. without any price differentiation, to 100% of the emissions within a jurisdiction. A smaller gap between advertised and average carbon price, and a higher average carbon price indicate more authenticity. Our study assesses the extent to which existing carbon prices – whether implemented through emissions trading systems (ETS), carbon taxes or a combination – differ from the authentic carbon price. Deviations from this authentic price are caused by low price rates, uncovered emissions, and price discounts or differentiation in the carbon price. Previous studies have documented existing carbon prices at the time, but not answered, nor asked, this critical question (Haites, 2018). We should note that OECD (2016, 2018) calculates average effective carbon rates, which differ from our average carbon prices as they include non-carbon energy taxes. Hence, these rates are comparable with the implicit carbon prices we plot in our Fig. 5. However, the essence and originality of our figure is that it offers a comparison between explicit and implicit average carbon price at a country level, which OECD does not do – it instead compares with the advertised carbon prices. Hence, we go a step further than OECD by comparing average implicit and explicit carbon prices. In addition, neither OECD nor World Bank calculate price gap indicators as we do. So while we recognize that OECD has done important groundwork in this respect, the topic has never received focused attention in concise and accessible form in the peer-reviewed literature.

In order to test for carbon-price authenticity, an economy-wide average price is calculated for each country. This is the average price paid per ton of CO_2 in an economy. It accounts for relevant price differentiation and incomplete coverage of total carbon emissions generated in that economy. In addition, a similar sector-level average price is calculated from carbon-pricing data for six sectors in each study country: 'road transport', 'other transport', 'industrial', 'agriculture & fishing', 'residential & commercial' and 'electricity'. From the advertised and average prices we derive a percentual price gap indicator which serves as an original, transparent indicator of the authenticity of carbon prices. Appendix A1 provides more details about the nature of these calculations.

The remainder of this article is organized as follows. Section 2 compares economy-wide advertised and average carbon prices between 31 countries. Section 3 examines the price-gap performance of economy-wide carbon prices, relating it to the average price rate. Both sections show clear differences between three groups of countries, with carbon tax, ETS and a combination of the two. Section 4 then contrasts sector-level average and advertised carbon prices. Section 5 broadens the scope by comparing (explicit) carbon pricing with implicit carbon prices, at both country and sector levels. Section 6 concludes and draws policy conclusions.

2. Comparing average and advertised carbon price rates

The authenticity of a carbon price will be based on two criteria. The first is the *average price* paid per ton of CO_2 in an economy, which takes into account all price and emission-coverage levels used. It thus accounts for the total charge of carbon price rates implemented to the total carbon emissions generated in that economy, giving the average charge per unit of emissions. The higher the average price rate, the greater the emissions reduction capability of the carbon price. The second criterion measures the difference between average and advertised carbon prices, referred to as the *price gap*. This captures the combined effect of partial emissions coverage by an instrument and the use of price discounts in certain sectors. A lower price gap indicates that the advertised carbon price is associated with a higher level of emissions coverage and price uniformity. A smaller gap between advertised and average carbon price, and a higher average carbon price indicate more authenticity. Appendix A2 provides more details about these criteria and their motivation, and Appendix A3 about the sample of countries and data.

The advantage of an average carbon price is that it accounts for all the information about the advertised price, emissions coverage within and between sectors, and price differentiation or discounts. This provides a reasonable measure of the average regulatory pressure to reduce emissions in the country (or sector, if applied to a specific sector). Indeed, if in some (sub)sector prices are high and in another low, then in the first emissions reduction will be high and in the second low, so moderate overall – which an average price that is also moderate in this case would reflect well.[1]

Fig. 1 shows the drastic difference between the average carbon prices measured in this study and the advertised rates, demonstrated by the grey section of the bar. The difference is particularly significant for countries operating a combination of carbon tax and ETS pricing. It means that advertised prices are providing a misleading representation of the actual price rates implemented. Sweden demonstrates a price gap of almost €100, indicating that its high advertised price (€127.04) should be interpreted with care. In addition, Switzerland and Finland, and to a lesser extent Norway and France, show considerable price gaps.

The reason for the observed price gaps in Fig. 1 differs between instruments, i.e. carbon tax or ETS. Regarding the first, countries tend to charge multiple rates in the implementation of the tax, often associated with specific sectors. In sources such as the *World Bank Carbon pricing dashboard* it is suggested that the advertised price represents the average carbon price charged on emissions covered by the tax. However, we find that this does not hold true for any of the countries with a carbon tax.

The price rate charged through ETS pricing is far more transparent, because each permit has a single price governed through a market system. But as Fig. 1 shows, while the price charged per ton of CO_2 is the same in all EU countries, the average price outcome varies greatly between each country. For example, Luxembourg displays the lowest average rate of €1.95, while Greece's average rate is at €8.40. This is due to a number of factors, such as free allocation of permits and differences in the number of large emitters (and sector structure) required to pay for permits under the EU-ETS.

3. Economy-wide carbon pricing

The results for the average price and price gap criteria show that the carbon pricing implemented around the world today is not very authentic. Of the two criteria, the average price rates are particularly poor across all countries. Fig. 2 shows that most countries have low average prices. The majority is even below the €10 and the highest of Norway is still below €40. Countries operating combined pricing

[1] One commentator suggested that only concrete prices provide incentives, questioning the usefulness of average prices. Apart from this questioning the general usefulness of statistical aggregation and analysis in scientific research, one should realize that advertised prices are not generally applied because of exceptions (price differentiation and uncovered emissions), and hence cannot be seen as concrete prices either.

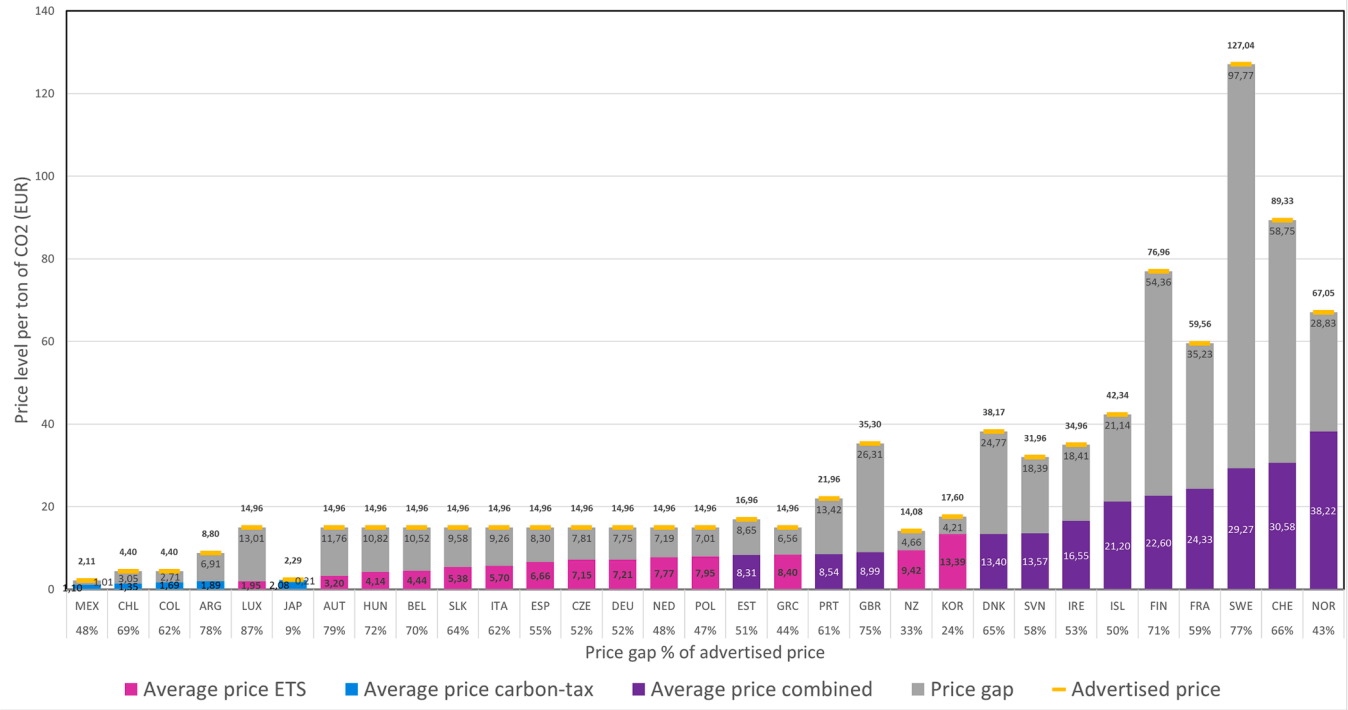

Fig. 1. Comparison between economy-wide advertised and average carbon prices per ton of CO_2.

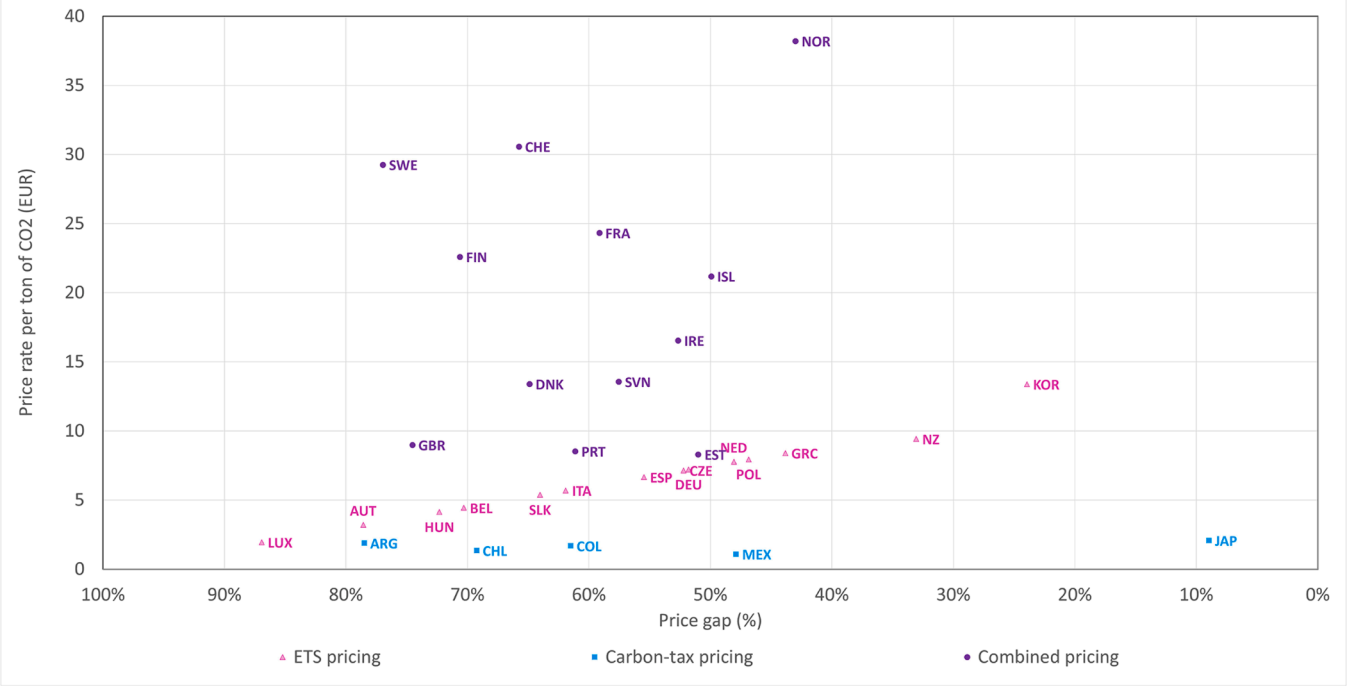

Fig. 2. Average price rate and price-gap performance of economy-wide carbon prices.

generally have a higher price than countries operating a single instrument, which may seem obvious but is not a necessary outcome as a single instrument might be relatively ambitious. The high combined price is likely due to a high level of commitment to carbon pricing amongst these countries, reflected by next to participating in EU-ETS also implementing a national carbon tax.

The price gap indicator shows that many countries implement a price with poor emissions coverage and price uniformity, with the majority of countries demonstrating a price gap of 50% to 70% between their average and advertised price. The highest price gaps are found in Luxembourg, Austria and Argentina, while the by far best performing countries for this indicator are New Zealand, Korea and Japan. It cannot be concluded that utilising ETS, carbon tax or combined pricing led to countries having a lower price gap as the variation in each group is fairly large.

Across all countries, the mean economy-wide price per ton of CO_2

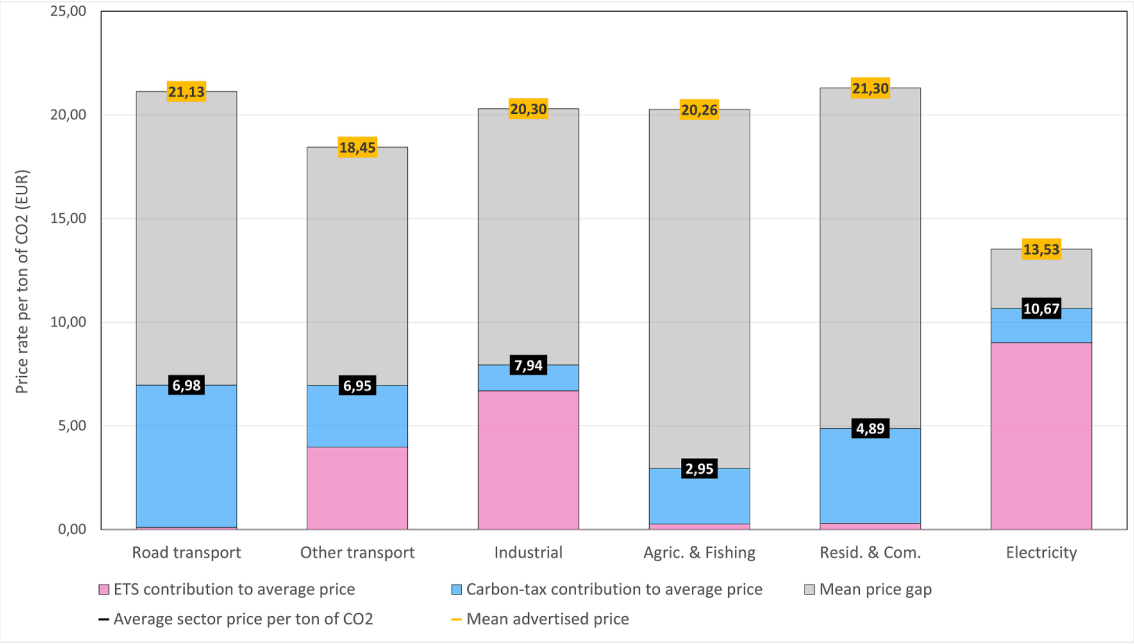

Fig. 3. Sector-level average and advertised carbon prices per ton of CO_2. *Mean value across countries weighted for emission levels.

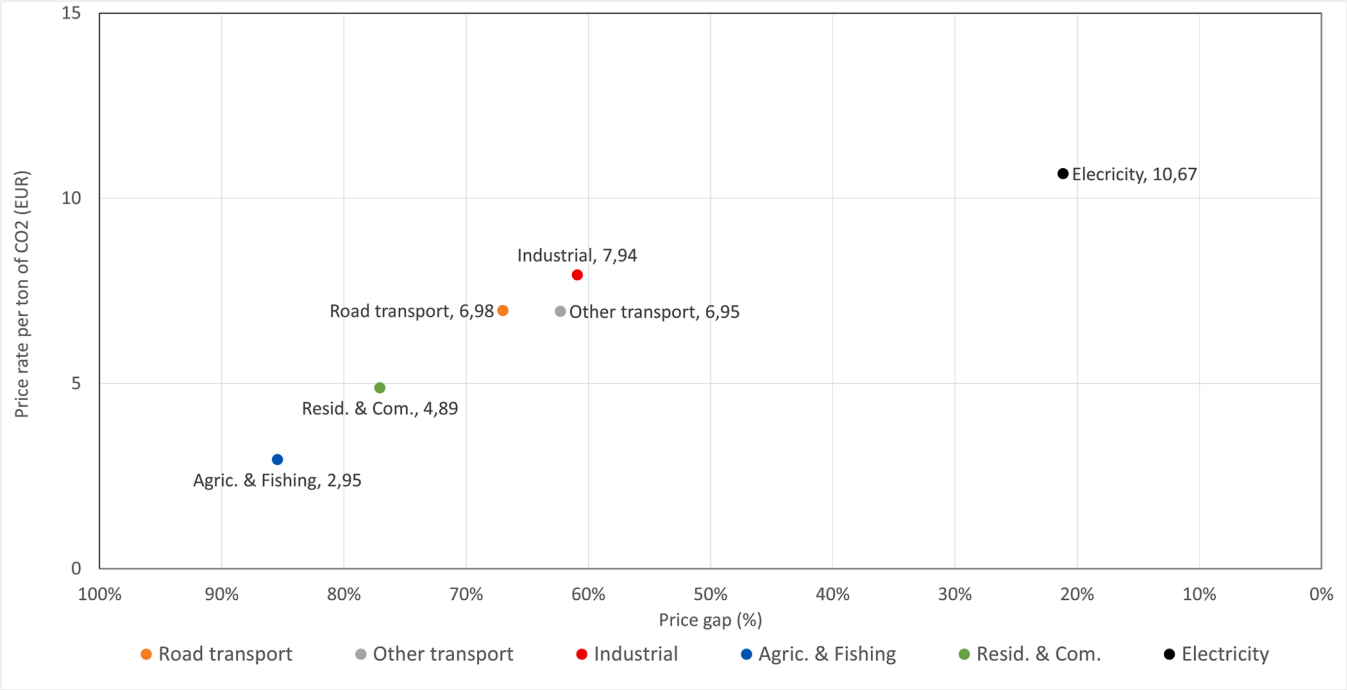

Fig. 4. Average price rate and price-gap performance of sector-level carbon prices.

equals €7.90, which is considerably lower than the mean advertised price of €18.68. Hence, the mean price gap is €10.78 or 57.7% of the mean advertised price.

4. Sector-level carbon pricing

Fig. 3 shows that sector-level average prices across countries are all below €22. However, while all sectors are categorised in the same threshold, there is a clear difference between pricing in the 'electricity' sector compared to all others.

The average price in the 'electricity' sector (€10.67) is far greater than in any other and is implemented with a much smaller price gap (€2.86). This is less than one fourth of the price gaps measured for the other sectors (ranging between €14.15 and €17.31). The smaller price gap represents the strong emissions coverage and price uniformity in the 'electricity' sector, as well as its lower advertised price rate. This is the result of a small proportion of emissions coming from countries with combined pricing, as these tend to be the nations with the highest advertised rates. In this sector they are only responsible for 10.5% of emissions, compared to contributions ranging from 19.6% to 24.6% in all other sectors.

Fig. 3 also suggests that ETSs and carbon taxes tend to price sectors

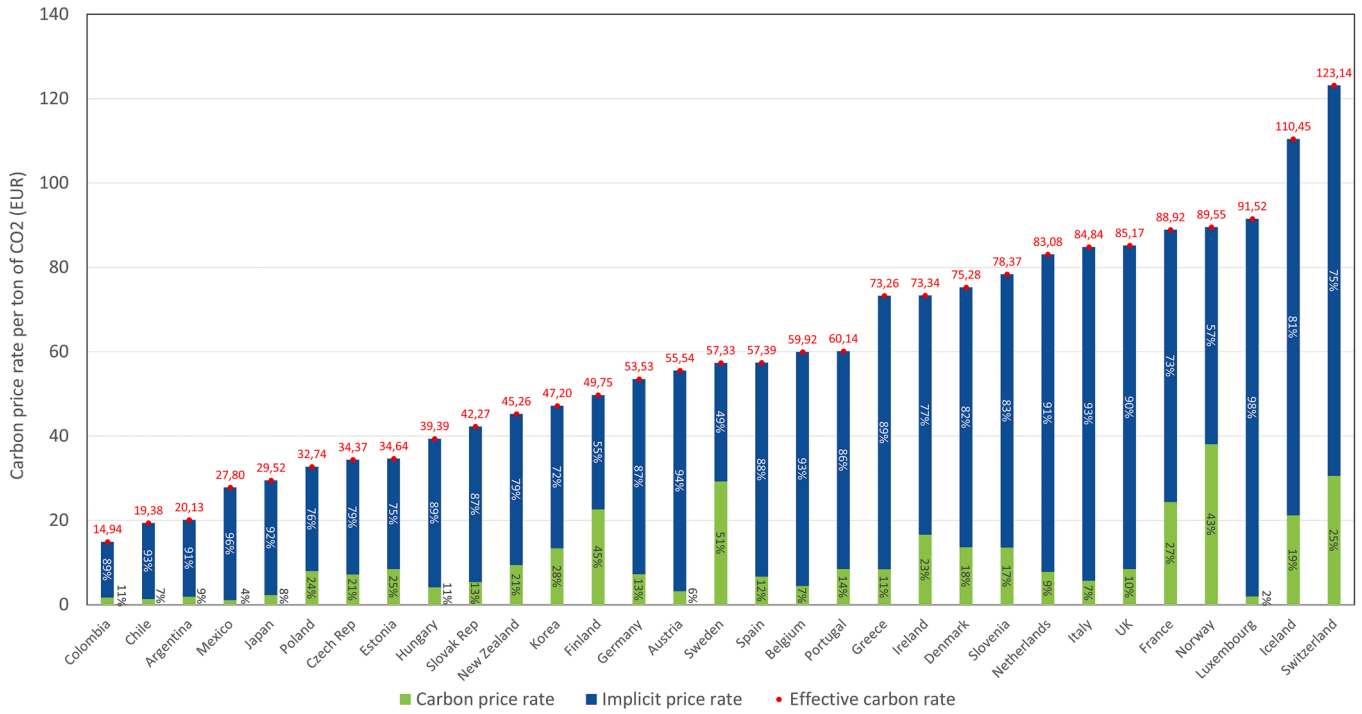

Fig. 5. Average explicit carbon prices and implicit carbon prices in each country.

differently. ETSs are shown to have an extremely low contribution to pricing in the 'road transport', 'agriculture & fishing' and 'residential & commercial' sectors, where carbon taxes are most prevalent. Conversely, for the 'industrial' and 'electricity' sectors, where the ETS contribution is greatest, the carbon tax contribution is far lower. The 'other transport' sector is unique in that there are similar levels of contribution from both instruments. This reflects that ETSs and carbon taxes are implemented in a complementary fashion between sectors.

The results from the average price and price-gap criteria show that sector-level pricing averaged among emissions across all countries is inauthentic. The average price rate in each sector is very low: Fig. 4 shows that all sectors have a price which is near or below €10. As has been highlighted already in this section, by far the highest authenticity is found in the electricity sector, where the average price is almost €3 higher and the price gap at least three times lower than in any other sector.

5. Comparing carbon pricing with implicit carbon prices

It is not only carbon pricing which influences emission levels in an economy. Other energy taxes indirectly price emissions. The sum of explicit and implicit prices results in a so-called effective carbon rate, which is the total charge per ton of CO_2 (OECD, 2016). Although both types of pricing are capable of incentivising carbon emissions reduction, it is important to distinguish between them because their accuracy of incentivizing such reduction differs. Unlike carbon pricing, general energy taxes provide an imprecise incentive for carbon emissions reduction because their tax levels are not set in proportion to the carbon content of associated energy sources. In fact, under general energy taxes fuels with a high carbon intensity can be taxed at lower rates than low-intensity alternatives. This translates then into a relative advantage for the carbon-intensive option, which goes against the idea of carbon pricing.[2] (Lachapelle, 2011). Nevertheless, a full perspective on the implications of carbon prices requires that implicit prices are accounted for as well. Another reason to assess the sum of the two is that it makes a difference whether countries substitute implicit by explicit carbon prices or instead add the second type to the first. Because in the latter case, the regulatory effect will be stronger.

With this in mind, Fig. 5 shows the average effective carbon rates in each of our study countries and compares these with the explicit average carbon prices (so the difference is the implicit average carbon price). The implicit rates are measured using fuel excise tax rates in each economy. The key takeaway from this figure is that the implicit prices tends to dominate the explicit ones in most countries. A similar conclusion was drawn by the OECD (2016) but based on advertised instead of average carbon prices. South Korea, Finland, Sweden, France and Norway are the only countries where carbon price rates are greater than 25% of effective carbon rates. The figure shows that there is no clear correlation between the explicit carbon price and the overall effective carbon rate, i.e. countries with high explicit carbon prices do not necessarily have high effective rates. For example, whereas Luxembourg has one of the lowest average explicit prices, its average effective rate is the third highest in the sample. Conversely, Sweden has one of the highest average explicit price rates, but its average effective rate is mid-range relative to other countries in the dataset. Such tendencies may indicate that countries such as Sweden are transforming implicit carbon prices to explicit prices. However, it is also possible that the large gap for Sweden is due to tax base erosion, i.e. past effectiveness

[2] To illustrate, diesel produces more CO_2 per litre than gasoline when combusted, which means that its carbon tax should be higher. But in many countries the energy tax per litre of diesel is in fact lower (of course, fuel taxes may have other motivations, such as tax revenues or local particulate contamination). To further complicate, since the fuel efficiency of diesel is considerably higher than of gasoline, diesel cars tend to emit less CO_2 per km than comparable gasoline cars.

of the high carbon tax in terms of emissions reduction in sectors where it applied. This would represent a positive step forward for carbon pricing in securing consistency and accuracy in national carbon prices, as well as contributing to a harmonisation of carbon prices at an international level. But it also means that the stringency of a country's climate policy can be easily overestimated.

Undertaking a similar analysis at a sector level, Fig. 6 shows that implicit prices are implemented unevenly across sectors. It is centred in the road transport sector, contributing 96% of the effective carbon rate of €177.02 in this sector. This explains the low reactivity of carbon emissions in this sector to explicit carbon pricing efforts, as its influence is so much lower than that of implicit charges (Tvinnereim and Mehling, 2018). The second highest effective rate is as low as €28.89, for the agriculture & fishing sector.

Although implicit prices are not so high in the 'other transport', 'agriculture & fishing' and 'residential & commercial sectors', they are still dominant over explicit prices in the composition of the effective rate, contributing 72%, 90% and 80%, respectively. Meanwhile, the low implicit prices in the 'industrial' and 'electricity' sectors mean that these are the only ones where explicit pricing is dominant, but they also have the lowest effective carbon rates, €12.19 and €13.38, respectively. In these cases, it is likely that carbon prices have a clearer impact on emissions reduction relative to other sectors.

This section has shown that taking into account implicit prices both nuances and complicates the understanding of overall carbon-pricing performance of countries and sectors.

6. Conclusion and policy implications

Our study shines a fresh light on carbon prices worldwide and can help to improve the quality of the debate about what has been achieved so far, and what are the most important areas requiring improvement. We proposed the average carbon price charged across total emissions in the economy as a clear and fair approach to summarize implemented carbon prices. In fact, this average carbon price could serve as a standardised way of publicising carbon prices as it succinctly identifies the average strength of the price incentive for emissions reduction and allows for a direct comparison between countries or sectors.

Our analysis finds that carbon pricing implemented around the world is not very authentic. The key problems for almost all countries is that the average price level is low and the price gap with the advertised price large. Indeed, across all countries, the mean economy-wide price per ton of CO_2 is only €7.90, while the price gap is more than half (57.7%) of the mean advertised price. Two key insights of our analysis are as follows. First, advertised prices should be interpreted with caution as they tend to exaggerate the carbon price pressure on economic activities. Instead, average carbon prices are a more reliable measure as they account for emissions coverage and price differentiation. Second, countries show considerable differences with respect to the average carbon price level as well as to the gap between advertised and average carbon prices. Moreover, these differences do not have a one-to-one relation with diversity in advertised carbon prices. Hence, if one wants to compare effectiveness among countries, the advertised prices form a unreliable basis, and one would do better to use the average prices for international comparison of policy effectiveness.

Similar issues were found at a sector level too. Average sector prices measured across all countries were well below the Paris' €35 benchmark with the 'agriculture & fishing' and 'residential & commercial' sectors demonstrating particularly high price gaps. Only pricing in the 'electricity' sector was found to be far superior to any other sector, with a price gap of only 21%, indicating strong emissions coverage and price uniformity.

The previous section put the average pricing calculations in the context of implicit carbon price rates in each country and sector analysed. A general dominance of implicit over explicit carbon pricing was found in most countries. However, the sectoral analysis demonstrated that the majority of implicit prices is focused in the 'road transport' sector, where rates are six or more times higher than in any other sector. In contrast, implicit prices were shown to be much lower in the 'industrial' and 'electricity' sectors, where explicit carbon prices dominate implicit ones.

While we find low average carbon prices, recent empirical studies indicate these have already been quite effective in reducing emissions or curtailing emissions growth. One study estimated for OECD countries that one € increase in energy taxes reduces carbon emissions from fossil fuel consumption by 0.73% in the long run (Sen and Vollebergh, 2018). Another uses data for 142 countries over two decades, 43 of which had a carbon price in place by the end of the study period (Best et al., 2020). It finds that the average annual growth rate of CO_2 emissions from fossil-fuel combustion has been around 2% lower in countries with a carbon price, and that an additional € per tonne of CO_2 reduces annual emissions growth by about 0.3%. A third study concluded that the EU-ETS,

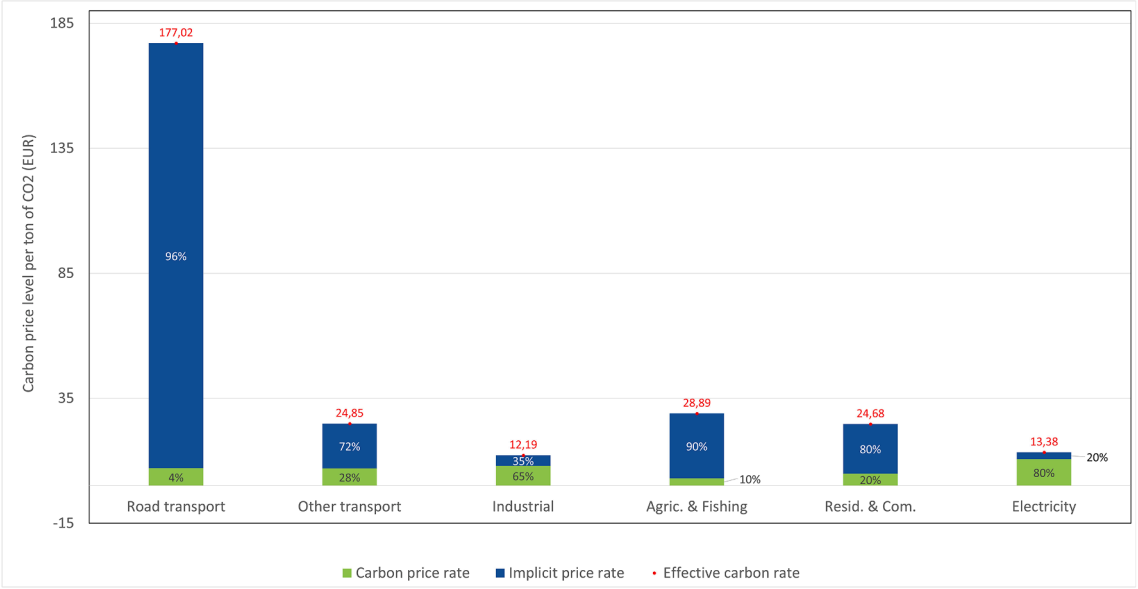

Fig. 6. Average explicit carbon prices and implicit carbon prices in each sector.

developed to meet the Kyoto Protocol, reduced covered emissions by 7.5%. This is equivalent to 3.8% of total EU-wide emissions, representing about half of the EU's Kyoto aim (Bayer and Aklin, 2020). Since all these results are for rather weak carbon prices as assessed in our study, one should expect considerable emissions reduction with higher carbon prices.

Currently low carbon prices are due to climate policy being predominantly unilateral in nature, despite the Paris Agreement. Indeed, the latter focuses on voluntary emission targets and did not achieve an inter-country coordination of climate policies and their strength. Harmonizing explicit carbon prices among countries, such as is already happening through ETS systems, will encourage substitution of widespread non-carbon energy taxes by carbon taxes, facilitating an international comparison through explicit carbon prices. This in turn will allow for a gradual transition to coordination or even harmonization of effective carbon prices around the world, notably if aided by expanding coalitions and border carbon tariffs as contemplated by the EU (Al Khourdajie and Finus, 2020; van den Bergh et al., 2020). In turn, this could support rising carbon price rates necessary to achieve sufficient global emissions reduction.

In addition, if the advertised or visible prices would be replaced by the lower average prices one would expect less resistance. While there are cases of resistance which have been repeatedly mentioned in popular and even academic writings (such as the yellow vest protests in France or the Washington state referenda), the truth is much more balanced, namely there are many carbon prices implemented (most extensively the EU-ETS in 30 countries). Moreover, many public survey studies show quite some public support for carbon pricing and provide lessons for design, notably revenue use, to maximize support (Carattini et al., 2019; Maestre-Andrés et al., 2021). Shifting the discussion from advertised to lower equivalent average carbon prices, as confirmed by our findings, can make it easier to garner support for higher prices and thus more emissions reduction.

Finally, future research could give more attention to three issues. First, an intertemporal analysis along the lines of our approach would be useful to see if average carbon prices and gap with advertised prices follow a trend and whether differences among countries become smaller over time. In addition, this could test if gaps get smaller over time due to erosion of the carbon-tax base. This might, for instance, explain why Sweden has such a large gap. Second, the statistical comparison of difference between carbon pricing by countries, as undertaken here, could be usefully complemented by historical information obtained from case studies about institutional and policy processes. This could clarify public support for, and political feasibility of, carbon pricing and other climate policies in the various countries. This is an immense task given the 31 countries involved, which merits a separate study. Third, broadening the average-price and price-gap indicators to capture the implicit prices of non-price instruments could result in a metric allowing the comparison of overall climate policy among jurisdictions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendices.

A1. Calculation of average carbon prices

In this section we demonstrate how to calculate the average price of a carbon pricing instrument. The formula can be used for both ETSs and carbon taxes. For countries only operating one instrument, their carbon price will be equal to the average price of the pricing instrument they use. For countries using two instruments, the average price of both instruments will be summed to derive the overall carbon price in the economy.

The sector-level average price per country is then calculated as follows:

$$P_s^c = X_s^{ets} \hat{A} \cdot C_s^{ets} + X_s^{ctax} \hat{A} \cdot C_s^{ctax}$$

Here:

X_s^{ets} = Average implemented prices applied in a sector (s) by an ETS.
X_s^{ctax} = Average implemented prices applied in a sector (s) by a carbon tax.
C_s^{ets} = Emissions coverage applied in a sector (s) by an ETS.
C_s^{ctax} = Emissions coverage applied in a sector (s) by a carbon tax.
P_s^c = Average carbon price in a sector (s) implemented by a single country (c).

Where the super-index *ctax* denotes "carbon tax" and *ets* denotes "emission trading system".

The economy-wide average price is calculated as follows:

$$P_c = \sum_{s=1}^{n} P_s^c \hat{A} \cdot E_s^c / E_c$$

Here:

E_s^c = The sector emissions (s) in a country (c).
E_c = Total emissions in a country (c).
P_c = Average price implemented in a country (c).

The percentual price gap for the economy-wide carbon prices is calculated as follows:

$$G_c = \left(\frac{A_c - P_c}{A_c} \right) \hat{A} \cdot 100$$

Here:

A_c = Advertised price in a country (c).
G_c = Percentual price gap in a country (c).
The sector-level average price for emissions generated across all countries is calculated as follows:

$$P_s^a = \sum_{c=1}^{n} P_s^c \hat{A} \cdot E_s^c / E_s^a$$

Here:
E_s^a = The total sector emissions (s) in all countries studied (a).
P_s^a = The sector-level average price (s) for all countries studied (a).
The percentual price gap for the sector-level carbon prices is calculated as follows:

$$G_s^a = \left(\frac{A_s^a - P_s^a}{A_s^a}\right) \hat{A} \cdot 100$$

Here:
A_s^a = Mean of advertised prices for all countries studied (a), weighted for sector-level emission levels (s) in each country.
G_s^a = The sector-level percentual price gap (s) for all countries studied (a).

A2. Procedure to assess the authenticity of carbon prices

There are three factors which govern the strength of a carbon price in an economy. The first is the average price implemented in relation to 100% of the emissions in the economy, not just the emissions covered by the pricing instrument(s). The second is the percentage of emissions covered in an economy, which ideally should be 100% of emissions. The third is the price uniformity (or differentiation) of the actual price levels implemented in an economy, relative to the advertised price. In the perfect scenario all prices implemented should be equal to the advertised price, as such there should be no price reductions permitted. We have designed two criteria which we will use to assess these three factors for each carbon price.

(1) Average carbon price level:

Calculation of the average carbon price is designed as an indicator of the influence carbon prices have on emission levels in the national economy. The greater the average price level implemented, the greater the emissions reduction capability of the carbon price.

(2) Percentual price gap:

The second criterion measures the difference between the average price and advertised price and is referred to as the price gap. This indicator combines information relating to the emissions coverage and price uniformity of the carbon price. The reason for combining the factors is threefold: it is difficult to accurately separate this information when two pricing instruments are in operation; deviation from carbon price uniformity is only relevant to carbon taxation, not to ETS pricing; and it simplifies graphical representation. The assumption for this indicator is that the lower the price gap, the higher level of emissions covered and the closer the uniformity of the prices implemented with the advertised rate.

Now a smaller gap between advertised and average carbon price, and a higher average carbon price indicate more authenticity, meaning that the associated policy pressure on emissions reduction will be more consistent and stronger.

A3. Data

The data for the composition of the carbon price calculations were taken from recent OECD research projects. The data on emissions, emissions coverage and advertised prices for carbon taxation was extracted from OECD (2019) and for ETS from OECD (2018) and Postic and Métivier (2019). There are slight variations in the emissions data between the two datasets, but this has a minimal effect on the average price calculations that form the core of the analysis.

The OECD datasets use the most up to date carbon emissions statistics collected by the International Energy Agency in 2016 (IEA, 2018). In comparison, emissions data used in World Bank carbon pricing dashboard dates to 2012. A further benefit of the OECD reports is that they provide in-depth sectoral information for each carbon price. Emissions and pricing levels are available for six sectors: road transport, other transport (aviation, rail, shipping), industrial, agriculture & fishing, residential & commercial, and electricity.

In selecting the countries for study, our goal was to include as many national carbon pricing instruments operating around the world. The reports do not include information for countries outside of the OECD which claim to have carbon prices, such as Kazakhstan, Indonesia and Taiwan as we could not guarantee that their data are consistent with the OECD data. We also omitted countries with regional carbon pricing instruments that were included in the OECD reports, notably China, Canada and the US. This was because our focus is on national instruments and we found that analysing regional pricing based on national emissions statistics distorted results. We were also unable to find supplementary data of equal quality to the OECD reports in order to include these countries and regions into our study.

For eight countries participating in EU-ETS we could not find consistent data. These are countries, and generally small emitters, who do not fall within the remit of the OECD and include: Cyprus, Lithuania, Latvia, Liechtenstein, Romania, Bulgaria, Malta, Croatia.

Following these choices, we obtained a strong and consistent sample of 14 countries using only ETS, 5 countries using only carbon taxes and 12 countries using both. These countries are as follows (abbreviations appear in the figures in the main text):

- *Countries with an ETS:* Austria (AUT), Belgium (BEL), Czech Republic (CZE), Germany (DEU), Greece (GRC), Hungary (HUN), Italy (ITA), South Korea (KOR), Luxembourg (LUX), Netherlands (NED), New Zealand (NZ), Poland (POL), Slovak Republic (SLK) and Spain (ESP).
- *Countries with a carbon tax:* Argentina (ARG), Chile (CHL), Mexico (MEX), Colombia (COL) and Japan (JAP).
- *Countries with combined carbon pricing:* Denmark (DNK), Estonia (EST), Finland (FIN), France (FRA), Iceland (ISL), Ireland (IRE), Norway (NOR), Portugal (PRT), Slovenia (SVN), Sweden (SWE), Switzerland (CHE) and UK (GBR).

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