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Measuring Total Carbon Pricing

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Abstract

While countries increasingly commit to pricing greenhouse gases directly through carbon taxes or emissions trading systems, indirect forms of carbon pricing—such as fuel excise taxes and fuel subsidy reforms—remain important factors affecting the mitigation incentives in an economy. Taken together, how can policy makers think about the overall price signal for carbon emissions and the incentive it creates? This paper develops a methodology for calculating a total carbon price applied to carbon emissions in a sector, fuel, or the whole economy. It recognizes that rarely is a single carbon price applied across an economy; many direct carbon pricing instruments target specific sectors or even fuels, much like indirect taxes on fossil fuels; and carbon and fuel taxes can be substituted one for another. Tracking progress on carbon pricing thus requires following both kinds of price interventions, their coverage, and specific exemptions. This inclusive total carbon pricing measure can facilitate progress in discussions on minimum carbon price commitments and inform assessments of the pricing of carbon embodied in traded goods. Calculations across 142 countries from 1991 to 2021 indicate that although direct carbon pricing now covers roughly a quarter of global emissions, the global total carbon price is not that much higher than it was in 1994 when the United Nations Framework Convention on Climate Change entered into force. Indirect carbon pricing still comprises the lion's share of the global total carbon price, and it has stagnated. Taking these policy measures into account reveals that many developing countries—particularly net fuel importers—contribute substantially to global carbon pricing. Tackling fuel subsidy reform and pricing coal and natural gas emissions more fully would have a profound effect on aligning carbon prices across countries and sectors and with their climate costs.

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Produced by the Research Support Team

Measuring Total Carbon Pricing*

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Abstract

While countries increasingly commit to pricing greenhouse gases directly through carbon taxes or emissions trading systems, indirect forms of carbon pricing—such as fuel excise taxes and fuel subsidy reforms—remain important factors affecting the mitigation incentives in an economy. Taken together, how can policy makers think about the overall price signal for carbon emissions and the incentive it creates? This paper develops a methodology for calculating a total carbon price applied to carbon emissions in a sector, fuel, or the whole economy. It recognizes that rarely is a single carbon price applied across an economy; many direct carbon pricing instruments target specific sectors or even fuels, much like indirect taxes on fossil fuels; and carbon and fuel taxes can be substituted one for another. Tracking progress on carbon pricing thus requires following both kinds of price interventions, their coverage, and specific exemptions. This inclusive total carbon pricing measure can facilitate progress in discussions on minimum carbon price commitments and inform assessments of the pricing of carbon embodied in traded goods. Calculations across 142 countries from 1991 to 2021 indicate that although direct carbon pricing now covers roughly a quarter of global emissions, the global total carbon price is not that much higher than it was in 1994 when the United Nations Framework Convention on Climate Change entered into force. Indirect carbon pricing still comprises the lion's share of the global total carbon price, and it has stagnated. Taking these policy measures into account reveals that many developing countries—particularly net fuel importers—contribute substantially to global carbon pricing. Tackling fuel subsidy reform and pricing coal and natural gas emissions more fully would have a profound effect on aligning carbon prices across countries and sectors and with their climate costs.

Keywords: climate change, emissions trading, carbon tax, fiscal instruments, fuel subsidies

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1. Introduction

Carbon pricing is an essential policy for mitigating climate change (Stern et al. 2022). It signals to markets the societal cost of emitting greenhouse gases (GHGs), creating financial incentives to abate emissions, reduce fossil fuel consumption, and innovate low-carbon products and processes. Carbon pricing is fundamental toward implementing the polluter pays principle—the economic principle enshrined in Principle 16 of the Rio Declaration on Environment and Development of 1992 that the costs of pollution and its abatement should be borne by those emitting it. However, there is no single form of carbon pricing: designs differ significantly across space, reflecting jurisdiction-specific characteristics and policy objectives. This heterogeneity poses challenges for policy comparison and, therefore, requires comprehensive metrics for standardizing, aggregating, and contrasting carbon pricing efforts. To help overcome these challenges, this paper proposes a new methodology for calculating carbon prices, the Total Carbon Price (TCP), which can be used to understand the full policy-related price signal affecting the combustion of CO_2-emitting fuels.

To date, most of the focus on carbon pricing has followed a narrow set of policy instruments, namely carbon taxes and emissions trading systems (ETSs) (World Bank 2022, ICAP 2023). The TCP is designed to recognize the multiple building blocks for aligning the financial costs of fossil fuel combustion and carbon-intensive processes with their climate costs. These components include not only these well-tracked direct carbon pricing policies, but also indirect carbon pricing policies such as excise taxes on (and subsidies to) fossil fuels. Direct carbon pricing policies impose a cost expressed as a monetary unit per ton of carbon dioxide equivalent, CO_2e, which is then reflected in the relative prices of products and services. Their advantage is in sending a consistent price-per-ton signal across a broad range of market actors. Indirect carbon pricing policies impose a cost on specific carbon-containing energy sources; although not fully aligned with the carbon content across fuels, these interventions nonetheless influence the relative prices of products and services and contribute to the net price signal.[1] Both types of interventions can thus help implement the polluter pays principle in ways that non-pricing policies or abatement subsidies cannot. Recognizing that many direct carbon pricing policies are applied to a narrow set of sectors or fuels—limiting the extent to which carbon pricing is applied consistently throughout the economy—one quickly finds that the distinction between these direct and indirect building blocks becomes blurred.

Indeed, a growing body of work observes that carbon taxes and emissions trading are only a fraction of the carbon costs imposed on goods (Aldy and Pizer; Cahart et al., 2022; Dolphin et al., 2020; OECD 2021). Other policies, such as the net fuel tax burden, can provide the same incentive delivered by direct carbon pricing, and other energy tax reforms often accompany the introduction

[1] The framework proposed here uses the terms direct and indirect, as opposed to "explicit" and "implicit", because the latter has been used in the literature to refer to several different concepts affecting the clarity of the term. This includes shadow costs of regulation, indirect carbon pricing emerging from fuel taxes (as we do here), or to the carbon-price equivalents required to achieve the same reductions as renewable energy policies.

of carbon pricing. Focusing exclusively on direct carbon prices then provides an incomplete picture of the level and the change in the broader price incentives. Examples abound across all types of countries and levels of development. Indonesia announced in 2022 plans to introduce a carbon tax (World Bank, 2022b), yet in May 2022, the parliament approved an increase in energy subsidies (Reuters, 2022). In contrast, Mexico phased out consumption subsidies on gasoline and diesel and introduced fuel taxes and carbon taxes (Muñoz-Piña, Montes de Oca, and Rivera 2022). In 2022, global fossil fuel consumption subsidies doubled compared to 2021 levels and reached all-time highs, as governments sought to shield consumers and domestic prices from volatile international prices (IEA, 2023; Muta and Erdogan, 2023). Focusing only on direct pricing would underestimate the overall price signal in Mexico and overestimate it in Indonesia and in several European countries. Not infrequently, the fiscal carbon price burden is reallocated across instruments rather than altered; failing to account for indirect pricing policies can then result in misleading assessment of the effects of a direct carbon price. For example, when Sweden introduced its carbon tax in 1991, it simultaneously reduced fuel taxes. Similarly, when Uruguay introduced its carbon tax in 2022, it simultaneously reduced its fuel tax on gasoline (Administración Nacional de Combustibles 2021). A broader perspective on carbon pricing would deem this change neutral to total carbon pricing, while a narrow view would celebrate the new carbon tax.

The objective of the TCP is to provide a comprehensive picture of the extent to which economies price the social cost of GHG emissions across countries, sectors, and fuels. The metric will increase the informational base for the academic and policy discussions surrounding carbon pricing comparability, minimum carbon price commitments, and rules to understand the incentives under future carbon border adjustment mechanisms. To achieve these aims, the TCP needs to reflect not only prices or tax rates but also effective coverage, because many carbon pricing systems only cover emissions from specific energy-intensive industries[2] or installations above minimum emissions thresholds. The TCP should also reflect effective rates, net of special exemptions[3] and reduced rates, because special provisions for specific sectors may erode the price signal. Finally, the TCP should be transparent and easily verifiable, requiring using publicly available data and minimizing modeling, particularly where assumptions are not easily verifiable.

Different approaches have been taken in the literature to measure carbon pricing. Two main methodological choices can be highlighted: 1) the selection of the instruments to be incorporated in the metric, and 2) the method to calculate the prices. Selection can narrowly focus on direct carbon pricing instruments, broaden to integrate indirect carbon pricing, or even extend to a wider definition incorporating other instruments. Early trackers of carbon prices have focused on direct carbon pricing. For instance, every year since 2013, the World Bank State & Trends of Carbon

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[2] In the case of CO_2 and the industrial sectors, this includes oil refineries, steel works, iron production, aluminum, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids, and bulk organic chemicals.

[3] Note that while some exemptions fall under the coverage category, others act as free allocation affecting the average (instead of the marginal) carbon price; a last set of exemptions show up as reduced rates (when a share of a firms' emissions is exempt from the tax).

Pricing reports key metrics[4] for ETSs and carbon taxes. The World Carbon Pricing database (Dolphin et al., 2020, Dolphin, 2022) is another example of a direct carbon pricing metric complementing State & Trends by providing an average (emissions-weighted) carbon price metric both at the sector and economy-wide levels.

Other approaches have attempted to consider a much wider scope of policies, albeit at the risk of extending the meaning of carbon pricing beyond its logical scope. Cahart et al. (2022) propose a weighted average of incentives created by seven types of market-based policies, including renewable portfolio standards, feed-in-tariffs, and low-carbon fuel standards. Many of these additional policies influence the relative prices of clean energy sources. Still, renewable energy policies do not levy costs on or distinguish among polluting sources, weakening their contribution to a true carbon pricing signal. Another approach to calculating "implicit" carbon prices has been to divide expenditures associated with a policy by some estimate of avoided emissions, resulting in a measure of average costs (Marcantonini and Ellerman, 2014). Such studies point out that less comprehensive or direct climate policies (like those focused on renewable energy) result in higher prices due to higher costs, which should not be interpreted as greater ambition. IMF (2022), by contrast, propose to incorporate a variety of pricing and non-pricing policies by calculating the carbon price that would deliver the equivalent amount of reductions, but this method intends to calculate a measure of ambition rather than carbon cost alignment.

Incorporating an extensive set of instruments into a carbon pricing metric risks misrepresenting other policies as very expensive (or ambitious) vis-à-vis carbon pricing, which can be misleading as to their value, since many such policies primarily target other market failures (e.g., technology market failures or information barriers).[5] To focus on policies that more squarely implement the polluter pays principle for climate change, this paper proposes a taxonomy to identify the instruments delivering carbon pricing for inclusion in the TCP. The result is a broader view than the first metrics for direct carbon pricing, while avoiding expansion into non-pricing policies or policies that incentivize new technologies without disincentivizing polluting behavior.

A second methodological choice deals with the computation of the indirect carbon prices and it involves one of two approaches: bottom-up (via statutory review) or top-down (via inference from energy price data). The bottom-up or statutory approach requires collecting, reviewing, and processing tax data from reviews of official documents, including legislation and other government reports. The OECD's Effective Carbon Rates (ECR) takes this approach to estimate the total emissions price resulting from taxes (carbon and net fuel taxes) and emissions trading for 44 OECD and G20 countries. However, relying on statutory reviews, the data are available only for selected years (2018 and 2021) and a limited number of developing countries (OECD, 2021). Bottom-up reviews are onerous, and documentation is not readily available for many developing

[4] State & Trends key metrics relating to carbon taxes and ETSs include the carbon price in each jurisdiction, global carbon revenues collected, and the proportion of global GHG emissions covered by carbon taxes and ETSs.

[5] For example, policies supporting electric vehicles may imply an abatement cost of several hundred dollars per ton of CO_2. However, they can still be cost-effective if they properly address innovation market failures and barriers to adoption.

countries. The top-down or inference approach involves calculating the tax rates implied by the gap between supply costs and retail prices. This second approach enables a broader coverage for regions and periods, as data are more readily available; however, to the extent that prices are observed imperfectly, the approach can be less accurate. The TCP, as calculated in this paper, initially uses the top-down approach to cover as many countries as possible over a long period. However, as more information becomes available, the TCP will gradually move to a bottom-up implementation.

Following this methodology, the TCP offers a comprehensive metric (including direct, indirect, positive, and negative carbon prices) that can be computed at the global, country, sector, and fuel level for over 140 countries from 1991 to 2021. Several important findings can be highlighted.

First, only limited progress has been made since international climate negotiations began 30 years ago, which should be a wakeup call to scale-up carbon pricing (as a key element of a policy mix) if the world is to reduce emissions between one-quarter to one-half over the next decade in line with the goals of the Paris Agreement. Second, while the number of direct carbon pricing instruments has increased steadily over the last decade (World Bank, 2022), the direct component continues to be a small share of total carbon pricing to date. By contrast, indirect forms of carbon pricing are widespread across all continents, cover an important share of global emissions, and at significant rates per content of CO_2; however, they have not been rising noticeably. Third, indirect carbon pricing is not evenly spread across fossil fuels: rates are highest and most pervasive among transportation fuels, while TCPs for industry and especially the power sectors remain remarkably low. Nor is indirect carbon pricing evenly spread across countries. Higher-income countries rely more heavily on indirect fuel taxes than lower-income countries, and net indirect carbon pricing is weakest among fuel exporters, indicating that energy subsidies still play an important role in weakening carbon pricing incentives.

By revealing the dominant role of indirect carbon pricing measures, the analysis underscores that the evolution of carbon pricing incentives cannot be assessed without them. An exclusive focus on direct carbon pricing instruments overlooks large contributions by net fuel taxes toward pricing carbon, particularly in non-industrial sectors, and contributions made by many developing countries, which are less likely to have direct instruments but may have high levels of indirect carbon pricing. Tracking indirect pricing is also important to avoid overstating the effect of direct carbon prices, because carbon taxes applied to fuels are commonly introduced in conjunction with broader energy tax reform that features offsetting tax reductions—and on occasion they have simply replaced existing fuel excise taxes. Finally, we conclude that policy considerations unrelated to climate change are driving total carbon pricing levels: TCPs have been positive since before climate change was an international priority. Taking pre-existing indirect taxes into account, we do not observe a greater increase in carbon pricing among higher income countries than lower income countries during the period of climate negotiations, as one might expect in the spirit of common but differentiated responsibilities.

2. Climate policy instruments and total carbon pricing

Identifying the instruments delivering carbon pricing is an essential first step in measuring total carbon pricing. This section proposes a framework to understand and categorize such instruments, elaborating on Pryor et al. (2023). We start by distinguishing pricing from non-pricing policies and then further categorize by target or motive (see Table 1).

Pricing policies are instruments providing a continuous financial incentive—not otherwise included in the market price—for targeted behavior, including taxes, tradable permits, and subsidies. Non-pricing instruments fall into a broader category, comprising pollution control mandates, non-tradable standards, efficiency standards, public infrastructure investment, mandates for the use or phase-out of specific technologies, and policies addressing informational market failures, such as product labeling and information disclosure. Such non-pricing policies are naturally out of for the scope of building a carbon pricing metric. However, it should be underscored that non-carbon-pricing policies can be desired *in addition to* carbon pricing,[6] as they can address other market failures that carbon pricing is unable to tackle directly (Fischer et al., 2012; Fischer and Newell, 2008).[7] Even where these policies may be asked to substitute for pricing policies, categorizing them as tantamount to carbon pricing would both misrepresent incentives and undervalue their primary role as complementary policies to help decarbonize economies.

Policies can also be categorized based on the market failure they are primarily geared for targeting, such as (i) unpriced climate and other environmental externalities[8]; (ii) information, behavioral, and financial barriers; and (iii) technology market failures. We include among "carbon pricing policies" those primarily addressing the unpriced carbon externality by accounting for the social costs (or benefits) of emissions associated with the production or consumption of a good, irrespective of the stated objective of the policy. We further distinguish between *direct* carbon pricing—where payments are directly linked to actual emissions—and *indirect* carbon pricing, which is applied to carbon-intensive inputs via fuel excise taxes and subsidies affecting final energy consumers.[9] The result from this approach is shown in Table 1.

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[6] Yet, in a second-best world of underpriced emissions, these policies are implemented as substitutes in many countries, which comes at an efficiency cost.

[7] While carbon pricing also creates incentives to adopt greener technologies, it is less able to directly address behavioral and financial barriers or deeper technology market failures.

[8] Energy taxes may be introduced to address other environmental externalities such as those resulting from underpricing for local air pollution, congestion and road accidents. Similarly, energy taxes may be introduced for other revenue raising considerations, including to finance other government priorities (e.g., in the 1980s Chile introduced fuel taxes to finance reconstruction (incl. of roads) after the devastating earthquake).

[9] We acknowledge that some carbon taxes are implemented as indirect taxes but included as direct carbon pricing instruments in the State and Trends of Carbon Pricing (WB 2022b, 2023b) because they are called carbon taxes. Where these taxes are calculated in proportion to carbon content and applied across multiple fuels and sectors, they fall into the spirit of direct carbon pricing in this taxonomy. Others are more analogous to indirect carbon pricing as we describe it, which is why a total carbon pricing metric is so important.

Table 1. Taxonomy of climate instruments

Climate policies	Policy type		Type of market failure	Policy instrument	Estimating contribution to total carbon pricing
Pricing Policies	Carbon pricing	Direct carbon pricing	Unpriced carbon externalities	Carbon taxes	Straightforward but depends on coverage
				Emission Trading Systems	
				Carbon crediting mechanisms	Design-dependent, baseline considerations
				Tradeable Performance Standards	Straightforward if trading price data is transparent; depends on coverage
		Indirect carbon pricing		Fuel (excise) taxes	Depends on alignment between carbon content and tax rates across fuels
				Fuel subsidies (consumption)	
				VAT deviations: VAT differential on fuels	
				Fuel subsidies (production)	Unclear to what extent the removal affects national prices. Data limitations.
	Technology and production incentives	Renewable support	Technology market failures	Feed-in tariffs, technology deployment subsidies	Improve relative costs of renewables but no marginal emissions reduction or fuel-switching incentive
		Other taxes and tradable standards	Technology market failures & Information, behavioral and financial barriers	Clean energy standards, tradable renewable portfolio standards, energy efficiency tax credits, VAT differential on machinery, vehicle taxes	Correcting relative costs across multiple sources, but no marginal emissions reduction incentive
Non pricing policies	Standards (non-tradable) and other regulations			Technology mandates, air pollution standards, fertilizer regulations, fuel efficiency, energy efficiency building codes.	----
	Public investment			Public transportation infrastructure, other infrastructure for innovation.	
	Information policies		Information, behavioral and financial barriers	Certification, product labeling and rating, information disclosure policies	
	Other policies			Other EV policies	

Direct carbon pricing includes carbon taxes and emission trading systems (ETSs), which may include cap-and-trade schemes (mass-based trading) or tradable performance standards (TPSs) (rate-based trading),[17] as well as certain carbon crediting mechanisms. These mechanisms all levy a cost directly on emissions or in proportion to the carbon content of a product, typically emission-intensive inputs. By applying a consistent price per ton of carbon dioxide equivalent (CO_2e) across multiple sources, direct carbon pricing contributes to equalizing marginal abatement costs across emissions sources, which minimizes the total costs of climate change mitigation. Incorporating the marginal carbon prices arising from carbon taxes and ETSs into the TCP is straightforward but depends on coverage. If an ETS or carbon tax covers only a small share of a country's emissions, weighting by coverage translates this nominal price into a low TCP figure. Other direct carbon pricing instruments can be more challenging to include in the TCP. For example, carbon crediting mechanisms typically involve voluntary transactions, and relevant coverage and price data are not available, so they are excluded.[18] With a TPS (or even a CAT with 100% grandparenting), all credits are allocated rather than auctioned and trades can remain private; without public trading on secondary markets or a binding price floor or ceiling, the market prices may not be clearly revealed. These ETSs are included with the best available pricing information in the State and Trends of Carbon Pricing (WB 2023b).[19]

Indirect Carbon Pricing includes fuel excise taxes, fuel subsidies, and value-added tax (VAT) deviations (arising if VAT rates on fuels are below the standard VAT rate). These policy instruments play a part in pricing carbon because they affect how market prices of fuels align with their social costs, including their environmental damages. However, since the tax or subsidy rates are typically fuel-specific and set according to a variety of motives,[20] their degree of alignment with climate costs is typically limited and less efficient than broad-based direct carbon pricing. Fuel mixes also vary significantly by sector, so the implications for carbon pricing incentives are also sector specific.

In the case of fuel excise taxes, the price signal arises via a flat monetary amount per physical unit of the good (e.g., USD/liter), which can be effortlessly translated into a carbon rate (e.g., USD/tCO_2) using the carbon content of the fuel. While fuel excise taxes send a positive indirect carbon price signal, fuel subsidies constitute negative carbon pricing. Since the TCP measures

[17] A TPS allocates emission allowances in proportion to output using a performance benchmark and is a form of emissions trading functionally equivalent to combining a carbon price with an output-based rebate (Fischer 2001, Fischer 2019, Parry 2014).
[18] Carbon crediting mechanisms are a subsidy for climate change mitigation activities rather than a price on emissions.
[19] Examples include Output-Based Pricing Systems in Canada or China's ETS.
[20] Examples include revenue raising, energy security, road user fees, and political or distributional aims.

carbon pricing for domestic emissions, only subsidies for fuel consumption (as opposed to production) are included.[21]

Value-added taxes themselves are not part of the TCP; as across-the-board consumption taxes, they do not affect relative prices. However, in some countries, value-added taxes are not applied at the same rate to fuels as they are applied to other goods, creating a form of subsidy (indicated as VAT deviations henceforth). Because this practice reduces fuel consumption prices and influences relative prices, VAT deviations are considered a form of (negative) indirect carbon pricing.

Due to the ease of conversion between fuel units and carbon content, including indirect carbon pricing estimates is possible with no complex modeling activities required. The main challenge is that, because excise taxes can vary by sector or consumer type, specific information is needed for tracking their impact downstream. However, as is discussed next, these same techniques are required for tracking direct carbon pricing impacts up- or downstream.

Differences and similarities between direct and indirect carbon pricing. The core theoretical difference between direct and indirect carbon prices relates to whether the price is consistent across emission sources, although this difference is much less stark in practice compared to what they are in theory. At one end of the spectrum, a direct carbon pricing system treats all emissions equally (i.e., with a uniform carbon price) across the entire economy. At the other end would be a set of fuel taxation systems that price fuels or activities at different rates (e.g., combustion of fuel used for road transportation compared to industrial applications). Most jurisdictions with carbon prices sit in the middle of this spectrum. Many direct carbon pricing policies apply nonuniformly across sectors or groups in the economy, such as in terms of coverage (e.g., by targeting only certain sectors or exempting certain activities) or the applied carbon price (e.g., through different carbon tax rates or trading system features). For example, the EU ETS covers only power and industrial sectors, with a separate partially linked system for aviation. Argentina and Mexico have introduced carbon taxes with varying carbon tax rates across fuels, independent of the carbon content of each fuel. While governments may call these policies "carbon taxes," they are closer to the definition of indirect carbon pricing, as the overall carbon price is not directly proportional to emissions. This spectrum of how policies are designed and implemented underscores the need to include both direct and indirect pricing in a comprehensive framework, as discussed in the introduction.

This point raises another topic of debate: should the focus of the TCP be on levels or changes? The question is important, given the dominance of excise taxes on transportation fuels and widespread reliance on them for raising revenues and funding road infrastructure since before

[21] Production subsides affect marginal domestic carbon pricing if the subsidized fuel is a commodity traded in a global market and the market share of the subsidizing country is large in the global market. A production subsidy to a locally traded fuel will affect the marginal price in that market. In the case of globally traded fuels, a price-taker country subsidizing a globally traded fuel will have no impact on (international) marginal prices and, therefore, total output. This is reflected in Table 1, where fuel subsidy reform in the production sector is classified as having either an indirect or no carbon pricing signal. However, there is an ambition to incorporate and extend the scope of the indirect carbon pricing metric as more data becomes available.

climate change became an urgent issue. An argument can be made that some portion of these taxes are road user fees or internalizing other externalities—such as congestion, local air pollution, or energy security concerns—to which the cost of carbon should be additional (Parry et al., 2014). The TCP measure allows for the analysis of both perspectives.

3. Total carbon pricing indicator

To operationalize the concept of a total carbon price, metrics are needed to reflect the full (direct and indirect) net (positive minus negative) carbon price signal affecting emissions or the consumption of emissions- intensive fuels at a specific level of analysis, e.g., in a sector, in a country or globally. The formulas for the TCP indicators are presented in Appendix B. While this analysis focuses on emissions from carbon-intensive fuels, potential extensions to the TCP and alternative weighting strategies are discussed in Section 7.

Conceptually, the TCP can be grounded on the incentives faced by a firm that uses fuel and non-fuel inputs of production and is subject to paying a carbon price for its direct emissions. A profit-maximizing firm would equalize its marginal benefits and costs of additional fuel and non-fuel inputs (See Appendix B); when the costs of using emission-intensive inputs rise, the firm is incentivized to economize on them. For the firm, the marginal costs of each input are influenced by the intermediate (fuel) input costs and the direct emissions costs. When a firm is subject to direct carbon pricing, the direct CO_2 pricing influences the relative costs of inputs in proportion to their incremental emissions. On the other hand, indirect CO_2 pricing affects input costs via the price to the firm, which includes the upstream supply cost and a net tax wedge corresponding to the fuel taxes net of subsidies per unit of fuel paid by the firm. The accumulated net tax wedges, weighted by the firm's use of fuels and their CO_2 intensity, represent the *indirect* component of the TCP.

A sector-specific TCP measures the cumulative *downstream* weight of carbon pricing policies for a given sector. Ideally, the computation of a sector-specific TCP requires knowledge of the level of direct carbon prices, direct emissions coverage, differential treatment within a sector,[22] and the sector-specific indirect carbon taxes, including many arising upstream. In this paper, for each country and year, we calculate a sector-specific TCP as the sum of two components: the average price applied to direct emissions (accounting for coverage as described in Appendix B) and the indirect tax payments per unit of fuel-related emissions, which relies on the net tax wedge as described above (See Appendix B).[23] When aggregating across fuels to compute the value for a

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[22] For example, many ETS systems have minimum thresholds for coverage; in these cases, ETS-covered firms may then be exempt from fuel charges that are imposed on smaller firms outside the ETS.

[23] The calculation intends to capture the average price paid by *incremental* emissions. The carbon price applied on average to embodied emissions would need to reflect free allocation and rebates that depend on factors like output or production capacity.

specific sector, the TCP can point out differences in the level of carbon pricing across sectors of the economy, perhaps reflecting other policy priorities or concerns related to international competitiveness and affordability.

A fuel-specific TCP aggregates the net effect of carbon pricing *upstream* to the fuel level. Calculating it involves summing two components: a weighted average of indirect (net) tax burden and a downstream fuel-related direct emissions payment (See Appendix B). Calculating the first component can be relatively straightforward, since indirect taxes are fuel-specific, although sector-specific exemptions and deviations must be accounted for.[24] Further, CO_2 emissions from fossil fuel combustion are mainly determined by the fuel's chemical properties, so the emissions rates tend to be stable across consumption levels. In this case, the distinction between marginal and average emissions rates is likely to be small. One exception is that some fuel consumed may not be combusted, as with natural gas as an input to fertilizer.[25] A country-level TCP can be calculated by aggregating either across sectors or across fuels. Aggregating across fuels involves weighting the carbon pricing interventions according to the fuel-related emissions shares, using energy consumption and emissions factor information. Finally, following a similar logic, TCP estimates from the country level can be used to create aggregates at regional (e.g., country income group) or global levels, using relevant emissions shares as weights. Section 6 shows examples of global, country, sector, and fuel-level estimations of the TCP.

4. Data and current total carbon price (TCP) implementation

Computation of the TCP requires data related to nominal rates of the fiscal instruments and policies, as well as the amount of emissions each rate is applied to. The empirical applications of the TCP discussed in this paper are focused on CO_2 emissions from combustion processes, rather than total greenhouse gas emissions, due to data availability and ease of quantification. The dataset used in this study includes information on carbon taxes and emissions trading systems, fuel excise taxes, energy consumption subsidies and VAT deviations for coal, diesel, gasoline, kerosene, LPG, natural gas, and other oil products consumed in the industrial, power, residential, public administration and services, and transport sectors. The dataset includes 142 countries, with observations ranging between 1991 and 2021 although data are available for a shorter range in some cases. As we implement a comparison of the TCP across levels of per-capita income and fossil fuel trading status, we also need data on these two variables. This dataset allows us to compute the TCP at the global and national levels and for specific sectors and fuels to assess how the fiscal burden is allocated across these two dimensions. Fiscal instruments applied to electricity

[24] For example, taxes on final energy consumption may differ from those for energy used in producing intermediate goods.

[25] Fossil fuels consumed for non-energy uses are however not included in the implementation of the total carbon price in sections 5 and 6.

consumption are not included for consistency and data limitations reasons.[26] Finally as we compare the finding from the TCP to those from the net effective carbon rates, data on these metrics for 2021 are taken from OECD (2022).

4.1. Fuel consumption and emissions data

Data from energy balances published in IEA (2022) as employed in World Bank (henceforth WB) (2023a) are used to determine the amount of fuel affected by each carbon pricing instrument. From this dataset, we source consumption of fossil fuels across each sector: 1) industrial,[27] 2) power, 3) residential; 4) services and public administration; and 5) transport sectors.[28] It is important to mention that the sum of these five sectors does not cover all fossil fuel combusted in the whole economy. For example, emissions from aviation are not incorporated in the transport sector. In particular, the IEA dataset provides information about the fuel consumption in each sector for the following fuels: 1) coal; 2) diesel, 3) gasoline; 4) kerosene; 5) LPG; and 6) natural gas[29] (IEA, 2022). CO_2 emissions factors used to compute emissions from fuel consumption are obtained from WB (2023a). Data for net imports and exports of fossil fuels have been sourced from IEA (2022).[30] This energy and emissions data allows calculating the TCP for each country and year at the national, sector, and fuel levels.

4.2. Direct carbon pricing data

Data for direct carbon prices are taken from WB (2022a), which contains nominal rates and coverage for each carbon tax and emissions trading scheme at the jurisdiction level. However, it does not provide quantitative estimates for support measures, such as free allocation of allowances

[26] First, an electricity tax incentivizes conservation but does not distinguish among fuel sources with respect to their carbon intensity; therefore, it is more appropriately considered to address behavioral or technology market failures related to energy efficiency. Furthermore, electricity price data is not readily available across all countries and determining a reference supply cost is problematic due to a host of other factors, such as tariff-setting regulations, market structure, interventions from the government and positive externalities arising from electricity access and wider electrification. Finally, as electricity is a generated form of energy rather than a primary fuel source, the carbon price equivalent of a given electricity tax would differ depending on the countries' average carbon intensities, which differ in ways that are more complicated to calculate.

[27] The industrial sector includes subsectors related to: 1) cement; 2) construction; 3) food and forestry, 4) iron and steel; 5) machinery; 6) mining and chemicals; 7) non-ferrous metals; and 8) other manufacturing sectors. It excludes consumption related to energy transformation encompassing the following IEA flows: 1) transformation processes; 2) transfers, including pipelines; 3) energy industry own use; 4) distributional losses, and 5) a statistical difference (WB 2023a).

[28] The transport sector includes three subsectors: 1) domestic shipping; 2) railways, and 3) roads. Each category includes consumption related to both freight and passenger traffic.

[29] Detailed information on IEA flows incorporated in each item of the fuel taxonomy used here can be found in WB (2023a). Consumption data are expressed in thousand Tons of Oil Equivalent (kTOE).

[30] This variable is measured by the flows "Crude oil and NGL imports" and "Crude oil and NGL exports" so that a measure of net exports (exports net of imports) can be easily computed.

in ETSs.[31] As WB (2022a) only provides coverage estimates at the jurisdiction level, the proportion of a country's emissions from each sector and fuel covered by each ETS and carbon tax were estimated based on instrument-specific coverage policies (see Appendix A).

4.3. Indirect carbon pricing data

As data on statutory nominal rates for fuel excise taxes and subsidies, as used by OECD (2021), are not easily accessible for all countries included in the TCP, much less on an annual basis, a proxy for net fuel taxes is computed for each specific fuel-sector combination following the price-gap approach (Kosmo, 1987, Larsen and Shah, 1992: Coady et al., 2019). The method calculates the net fuel tax by comparing data for supply costs, and retail prices net of VAT and upstream carbon prices that are reflected in the retail price as follows:

$$\textit{net fuel tax} = \textit{retail price} - \textit{supply cost} - \textit{VAT payments} - \textit{upstream carbon price}$$

The source data are drawn from an updated version of the dataset in Parry et al., (2021) and WB (2023a), which includes information, disaggregated by fuel and by sector, on:

- The **retail price**, an average end-user price paid by final users in the corresponding sector or for the whole economy, which incorporates all applicable taxes and subsidies, including VAT payments. For example, this is the average price for gasoline 'at the pump'.
- **Supply cost**, an average cost including all production, transformation, transportation and distribution costs and profits but excluding taxes, as discussed below. It includes producer subsidies to the extent to which they are reflected in the supply cost by producers.
- **VAT rates,** including the standard VAT rate in each country and the reduced rates granted to specific fuels for a limited set of end-uses. The effective VAT rate on energy consumed in the industrial, power generation, and service sectors is zero because these users reclaim paid VAT. The output of these sectors, e.g., the electricity produced by the power sector, carries VAT when consumed by households.

Retail prices

Annual average retail prices are widely available for coal, natural gas, and electricity at an economywide level, as well as disaggregated by main end-user—industrial, residential, and power generation. However, for other fuels (e.g., gasoline and diesel) only economywide annual average retail prices are available (Parry et al, 2021). The dataset from Parry et al., (2021) does not include spatially specific fuel prices. Accordingly, retail prices for some fuels are taken from IMF and World Bank country desk datasets. For cases where such data was not available, they use a simple average across various third-party sources, including Eurostat, IEA, World Bank Doing Business Indicators, Global Petrol Prices Retail Energy Price Data, and Enerdata Global Energy & CO2

[31] When different carbon tax rates are applied in the sector they cover, this paper uses the highest rate in the computation of the TCP as WB (2022a) does not provide quantitative estimates of emissions covered by each specific tax rate.

Data, as discussed in Annex B of Parry et al., (2021). Missing data for natural gas and coal used in the power generation sector were filled by using prices in the industrial sector, and vice versa. Where data are missing for both sectors, Parry et al., (2021) assume the retail fuel price is equal to the supply cost plus any known taxes, including import duties (weighted by the share of the imported fuel) and pre-retail taxes (such as an upstream carbon tax).[32]

Supply costs

To represent supply costs, the database relies heavily on import price information, supplemented by estimates or assumptions of appropriate markups. Supply price includes mark-ups for within-country transportation, distribution, marketing, and margins, with higher margins for residential users than for industrial power generation (following US EIA, 2021 and European Commission, 2018). In the case of finished petroleum products, supply costs consist of the port (or hub) prices from IEA (2021), with countries mapped to either the United States, Northwestern Europe, or Singapore. Parry et al., (2021) price LPG at a 30% discount to gasoline, taking as a reference the difference between gasoline and LPG pre-tax prices for unsubsidized European markets. It is important to highlight that LPG prices may vary considerably within countries due to the size of the cylinders, local market conditions, and local delivery arrangements. Kojima (2021) notes that selling LPG in small quantities makes the fuel more affordable – in terms of expenditure per purchase – but is costlier for each kg sold. The author points out that markets with no price controls have settled on cylinders larger than 10kg, to strike a balance between affordability and supply cost. Parry et al., (2021) also discusses the shipping and distribution margins applied for all countries, namely $0.15-$0.22 per liter – based on the average of unsubsidized OECD countries. An additional $0.10 per liter is added to land-locked and small-island developing countries. In the case of natural gas, supply costs are based on hub, import or net-back export prices with upward adjustments for transportation and distribution. Domestic natural gas prices were available for large natural gas markets (e.g., most European and South and East Asian countries),[33] while countries with missing domestic prices were mapped to a specific regional hub price (either the US, Netherlands TTF, or Northeast Asian LNG). In the case of coal, Parry et al., (2021) document the methods used to infer the export or import-parity price with mark-ups for transportation, processing, and distribution reflecting the type of user (power, industrial, and residential sector) and extent of domestic production. For electricity, supply costs were provided by IMF country desks or calculated using the CPAT model (WB 2023a).

VAT deviations

The VAT component is assessed by sourcing the VAT (in price per unit of energy) applied to a specific fuel (contained in the IMF database). Like in the case of retail price and supply costs, the

[32] This scenario is fairly common, occurring in about 50% of cases for coal, 40% for gas, 10% for gasoline and diesel, and 30% for LPG and kerosene.

[33] In the case of LNG exporters without a well-functioning domestic natural gas market, a country-specific liquefaction and shipping fee was deducted to net-back prices from delivery abroad (Parry et al., 2021).

dataset used in this study does not include within country VAT receipts, therefore not taking into account that the same fuel can be subject to different rates across administrative units and locations of a country. This is particularly relevant in countries with prices varying greatly across sub-national jurisdictions. VAT rates from the IMF database are also used to compute VAT deviations, as the difference between the overall VAT rate and the VAT rate applying to a specific fuel.

4.4. Exchange rate data

Countries implement carbon pricing in their local currencies and, to allow comparability across jurisdictions, carbon prices are often converted to their USD equivalents by using market exchange rates (MER) (World Bank, 2022). An alternative to using MERs using purchasing power parities (PPP). For carbon pricing, the choice between MER and PPP can be informed by the aim of the comparison. When the aim is to examine the burden on households and firms PPPs are more propriate, as they allow to incorporate differences in purchasing power and real living standards (Aldy and Pizer, 2016, Blanchet, 2017). When the aim is to understand how level the playing field is in the context of traded goods (e.g., embodied carbon), MER are more appropriate (Aldy and Pizer, 2016). This paper first presents estimates in using MER, but also uses PPP for sensitivity analysis in Section 7. A conversion factor from constant MER U.S. dollars to international dollars is obtained by dividing GDP data expressed in international dollars (series NY.GDP.MKTP.PP.KD in the World Bank World Development Indicators (WDI)) by GDP data expressed constant U.S. dollars (series NY.GDP.MKTP.KD in the World Bank WDI).

5. Trends in total carbon pricing

Aggregate TCP data can be used to evaluate the status of and trends in carbon pricing worldwide, across country types, sectors, and fuels. The following results point at several lessons: First, TCP has shown limited progress since the early international climate negotiations of 30 years ago. Second, despite progress, direct carbon pricing remains a small share of total carbon pricing. More emissions are covered at higher rates by indirect forms of carbon pricing. Third, indirect carbon pricing is dominated by transportation fuel taxes (and subsidies); carbon pricing for industry and especially the power sector remains remarkably low. Fourth, net indirect carbon pricing is weakest among fuel exporters. Finally, while higher-income countries have higher indirect (and thereby total) carbon pricing levels than lower-income countries, their TCPs have not increased noticeably more compared to countries in lower income categories.

5.1. Global trends

Figure 1 presents the global aggregate TCP, its components, and their variation across countries to understand how different circumstances have influenced carbon pricing. We follow Vagliasindi (2012), who points out that structural and economic country characteristics correlate with countries' levels of energy tax or subsidy policies. Accordingly, we split the countries based on

1. the level of economic development: Low-income and Lower-middle-income, indicated as "LLMICs" and Upper-middle-income and High-income countries, indicated as "UMHICs"; and
2. the access to national energy sources: net exporters and net importers of oil and natural gas.

We therefore end up with four groups: LLMICs that are net exporters over the time range, LLMICs that are net importers, UMHICs that are mainly net importers, and UMHICs that are net importers. Country contributions to cross-country TCP aggregations are weighted by emissions. The largest emitters, China and the US, as well as most EU member states, both fall into the UMHIC category. (Full classifications are given in Appendix C).

Globally, we observe slow progress on total carbon pricing over the last 30 years. The use of direct carbon pricing instruments has grown over time, but they still cover only a quarter of global emissions and apply relatively low rates, resulting in a small contribution to the TCP. By contrast, in 2021, 87% of the TCP stemmed from the indirect pricing component, which shows a small upward trend, albeit with a downturn in 2021.

The lower panel of Figure 1 reveals striking differences among the four country categories. LLMICs have negligible direct carbon pricing and lower indirect carbon prices than UMHICs. Net energy exporters in both categories have significantly lower indirect carbon prices than their net-importing peers. In particular, net exporting LLMICs have on average been net subsidizers of fossil-fuel emissions at the rate of USD 25/tCO_2 in the last five years. For the other groups, the TCP is positive in the last 5 years of the sample, with an average of USD 10/tCO_2 in importing LLMICs, USD 25/tCO_2 in exporting UMHICs, and USD 42/tCO_2 in importing UMHICs. The lower levels of energy taxation in LLMICs may result from constraints in the institutional and taxation capacity (including the ability to minimize tax evasions) rather than being a deliberate policy choice. In all cases, the level and pattern of the TCP is closely associated with the pattern of energy taxation, although direct carbon pricing becomes noticeable among the UMHICs.

Figure 1. Global TCP and its components in 2021 dollars. Only the ICP is shown when it identically overlaps with the TCP. The list of countries belonging to each of the four groups is shown in Appendix C.

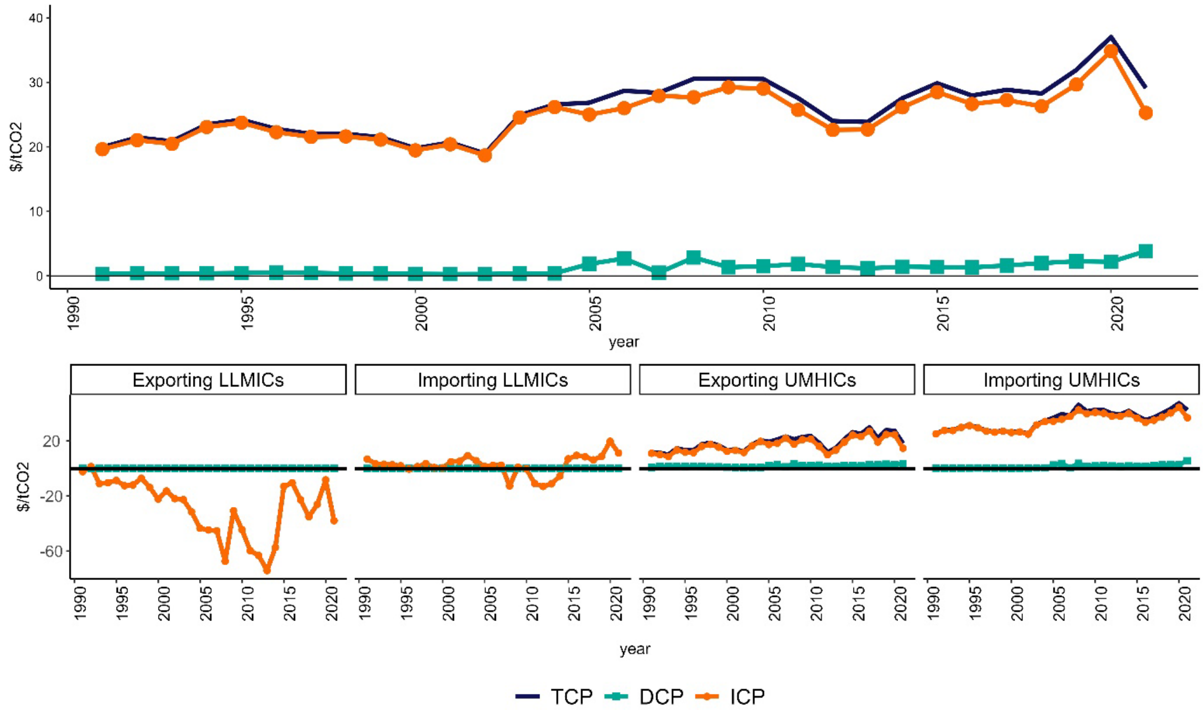
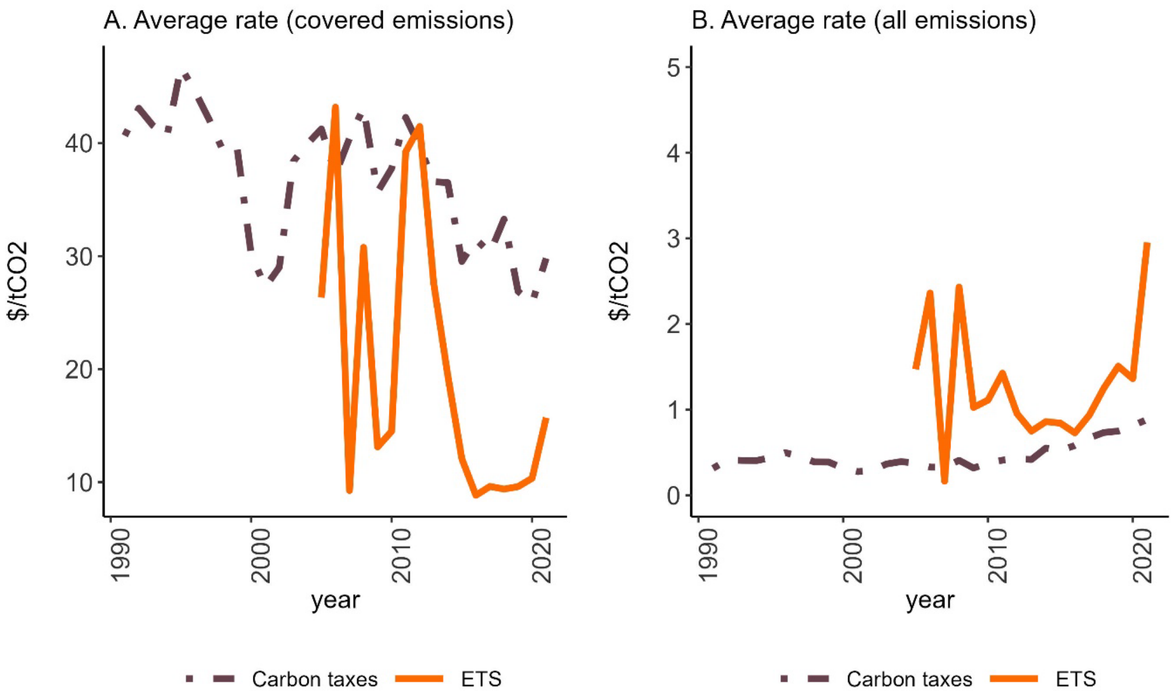


Figure 2 illustrates key trends in direct carbon pricing, distinguishing between policy prices (the average of the prices applied to emissions weighted by the emission covered by each instrument) and effective prices (the average rate of direct carbon pricing of all emissions). The left panel of Figure 2 shows that where instruments are in place, carbon policy prices have ranged from USD 10 to 45 per tCO_2. The number of carbon taxes has steadily increased since the 1990s, yet the average carbon tax rates have consistently been between USD 30 and 45 per tCO_2. The fluctuations occurred as new carbon taxes emerged with low rates, while long-standing carbon taxes increased their high rates. The ETS rates show much more variability, initially due to the relatively small number of schemes and the more volatile nature of emissions markets. The spike in 2021 is due to the introduction of a few schemes. China's national ETS, launched in 2021, increased global emissions coverage by 7.4%. Additionally, a few carbon pricing initiatives with relatively high carbon prices emerged in that year, such as Germany's national ETS for heating and transport fuels, where allowances sold for about USD 30/tCO_2.

When plotting the effective rates in the right pane of Figure 2, a different message emerges: Global direct carbon prices remain low due to limited coverage, although they have been rising as that coverage has expanded, reaching USD 3/tCO_2 in 2021. For example, ETSs cover just 16% of global emissions in 2021, with 8% covered just by China's national ETS.

Figure 2. Policy prices (left panel) and effective (right panel) global rate of direct carbon pricing in 2021 dollars.

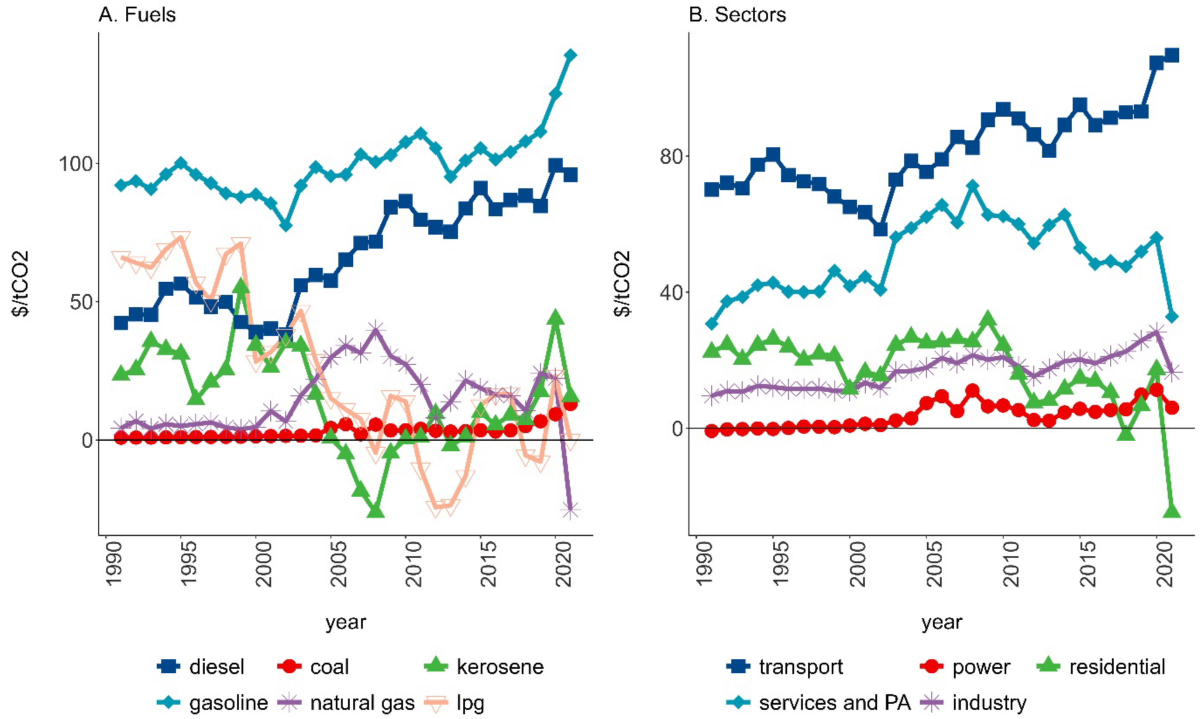


The right panel of Figure 2 highlights that direct carbon pricing instruments are unlikely, on their own, to deliver the ambitious targets of the Paris Agreement. Our analysis, therefore, supports the decision at COP26 on "accelerating efforts towards the […] phase-out of inefficient fossil fuel subsidies", the first negotiated references to ending fossil fuel subsidies in the UNFCCC's 26-year history (UN Climate Change Conference UK 2021). Similarly, fuel taxation has a clear role to help limit GHG emissions as discussed next, as well as for other policies in the policy mix.

5.2. TCP across fuels and sectors

Figure 3 illustrates how the TCP varies across fuels and sectors. It shows that liquid fuels (diesel and gasoline) have the highest prices on embodied carbon, thanks to high indirect taxes; as a result, the transport sector has the highest TCP, followed by services, where transportation fuels comprise a large share of their energy consumption. The low carbon price on coal largely arises from direct carbon pricing instruments applied to the power sector; although they have been increasing, that sector is also subject to indirect fuel taxes on natural gas, which rise and fall in the sample. Industry and residential consumers use a broader mix of fuels, and their TCPs reflect the underlying trends. These divergences reveal potential opportunities to broaden the application and increase the stringency of carbon pricing instruments to access lower cost abatement, particularly in non-transport sectors.

Figure 3. Trends in global TCP by sector and fuel.

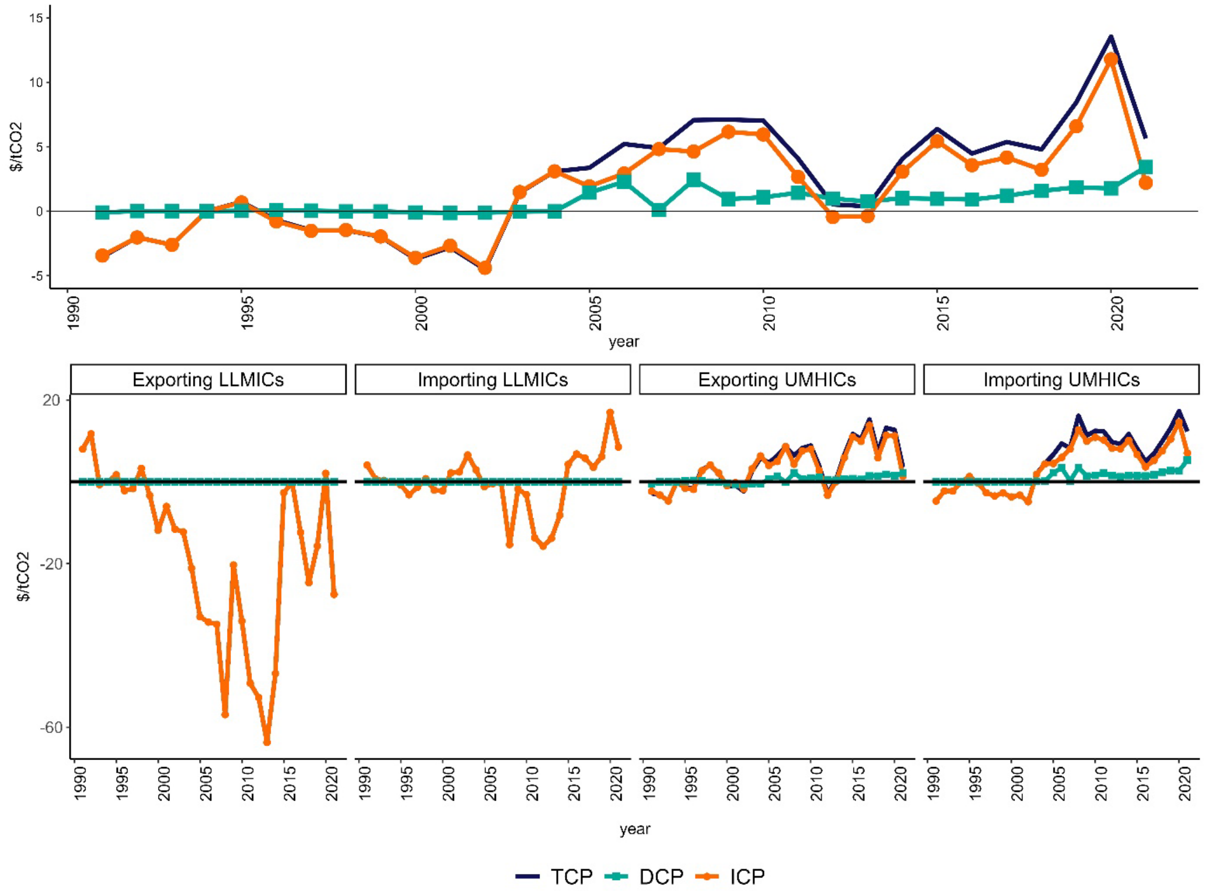


5.3. How far have we come since the Framework Convention?

The United Nations Framework Convention on Climate Change entered into force in 1994. From this point forward, there was a global agreement to take climate change seriously. At that point, aside from a handful of policies in Nordic countries, direct carbon pricing had yet to develop. However, substantial indirect taxation of carbon-emitting fuels was already in place. These taxes were motivated by many factors, including general revenue collection, earmarked funding for building roads or transmission networks (user fees), or energy security.

Figure 4 takes stock of how total carbon pricing has changed compared to 1994. We see limited but overall positive progress globally, and that the magnitude of changes in indirect carbon pricing has not been that different from that in direct carbon pricing (although it has been more variable). When we compare across country types, excepting LLMIC exporters, we now see little difference in the evolution of the TCP between developing and developed countries, particularly in recent years. In other words, UMHICs have not raised their TCPs noticeably more than LLMIC importers. While UMHIC exporters had overall lower TCP levels than UMHIC importers (Figure 4), here we see little difference between them in the change in TCP since the Framework Convention. However, among LLMIC exporters a deterioration in the TCP is noticeable (though highly volatile).

Figure 4. Changes in global TCP and its components compared to the levels in 1994.

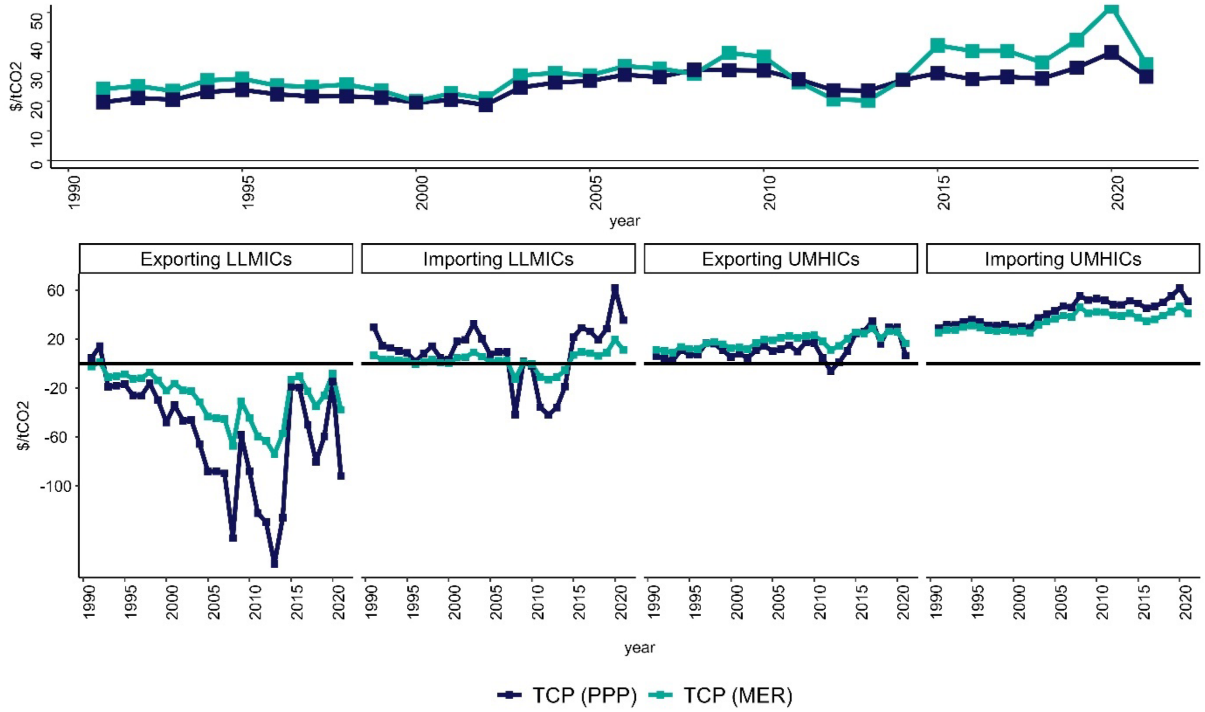


6. Sensitivity to assumptions and directions for improvement

6.1. Exchange rates

As discussed in section 4, the appropriate choice of the exchange rate to convert carbon prices denominated in local currency to US dollars depends on the aim of the comparison. MER are appropriate in the context of traded goods and when the purpose is to understand how level the playing field is; by contrast, PPPs are recommended when examining the burden on households and firms. This paper uses MER as a default for all plots. However, the main differences and consequences of both approaches merit discussion. An estimation of the TCP using PPPs will adjust for purchasing parity, amplifying carbon prices imposed in lower-income countries. One might expect the PPP method to increase the overall assessment of carbon pricing relative to using MER. However, in the aggregate, the TCP calculated via PPPs gives lower prices than the one calculated using MER, as seen in the top graph of Figure 5. The intuition is that PPP amplifies not only carbon prices but also fuel subsidies, as seen in the bottom half of Figure 5, where the PPP approach tends to increase the TCP among net fuel importers but decrease it among fuel exporters.

Figure 5. Comparison of TCP with purchasing power parity (PPP) versus market exchange rates (MER)



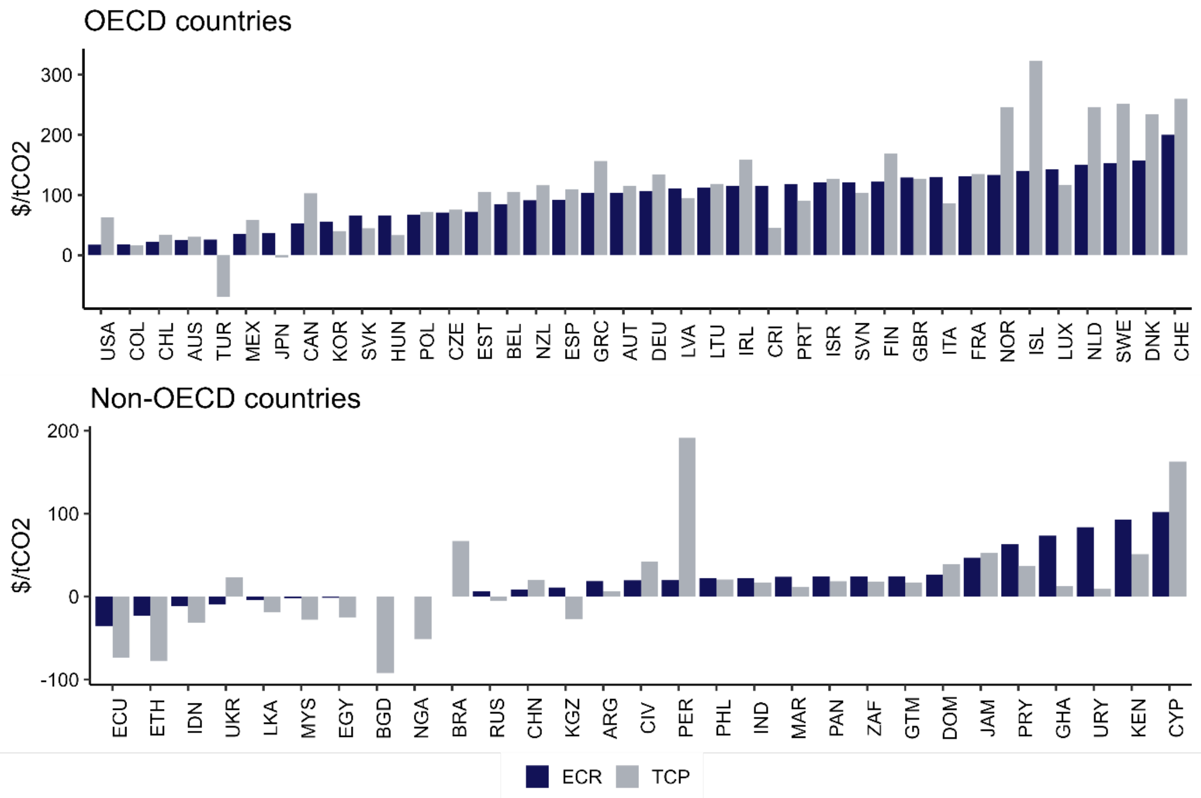
6.2. Data limitations and trade-offs

As discussed in Section 4.2, the price-gap approach to calculating indirect emissions pricing has benefits in terms of energy data availability but challenges for interpreting estimated gaps as accurate measures of government fiscal interventions. Kojima and Koplow (2015) point out that calculating adjusted reference prices may require dedicated studies taking into account diversity within a country, especially large countries such as Brazil or China, in terms of location-specific costs of transportation, storage, distribution, and retailing, but also exemptions and thresholds which can be granted to specific users or uses of a certain fuel. It is also true that policies boosting domestic prices, such as market price support, would here be interpreted as equivalent to a tax on energy if they lead to an increase in retail price (Kojima and Koplow 2015). A final point is related to the fact that retail prices of fossil fuels are affected by competition in the market: producers with market power will tend to have higher markups over their supply costs. When using the price gap methodology, higher markups in concentrated markets will be misinterpreted as higher indirect taxes, even though the higher retail price is not due to the imposition of any policy instrument.

The following figure compares the TCP results using the present price-gap methodology for indirect carbon pricing with the OECD (2022) effective carbon rate (ECR) methodology, which relied on desk reviews of fuel excise taxes and consumption subsidies. The ECR study covers a narrower set of countries, but a good number of non-OECD countries is available for 2021. For OECD countries, the results seem generally well aligned, but with some important variations. In more cases, the TCP seems to overstate the contribution of indirect carbon pricing, relative to what can be documented by policy review. However, for some countries—particularly the less affluent members—the TCP estimates are well below the ECR, even changing signs. For non-OECD countries, the signs correlate well (there are few cases with a positive ECR and negative TCP, or vice-versa), but the levels are highly variable.

For these reasons, we hesitate to compare results for individual countries. A concerted and coordinated data collection effort using comparable methodologies would be valuable for consistent comparisons across a wide range of countries and for improving the calibration and use of price-gap methods.

Figure 6. Comparison between the net Effective Carbon Rate (ECR) and the TCP.



6.3. Pricing marginal versus average carbon

The TCP estimated in this paper reflects the marginal carbon price—the effective price paid by an additional ton of CO2 combusted. A natural extension would be to estimate a total average carbon price—the total carbon payments per ton of emissions. Both measures take emissions coverage into account, but an average carbon price would also account for the free allocation of emission allowances, inframarginal tax exemptions, and output-based rebates or benchmarks. These provisions drive a wedge between marginal and average emissions prices, because emitters' net carbon payments reflect only a share of the value of their total emissions. Such measures are commonly used in direct carbon pricing schemes, in particular for industrial emitters that are highly trade exposed, as a way to relieve competitive pressures (Fischer and Fox 2012), or to limit consumer price increases (Fischer and Pizer 2019). However, freely allocated allowances can reduce the effectiveness of the marginal carbon price. If the full embodied carbon costs are not passed on, consumers lack incentives to engage in conservation or to purchase alternative low-carbon products. Free allocation can also create windfall profits and reduce the cost pressures that drive firms to invest in clean technologies (Flues and Van Dender, 2017; OECD, 2021). Average carbon pricing is thus an important indicator for understanding full carbon cost alignment. It will also be essential for the implementation of border carbon adjustment policies, which seek to ensure that all carbon embodied in covered goods is priced at the same level domestically. In other words, average and not marginal emissions are adjusted at the border, meaning that credits for carbon pricing in other jurisdictions will be based on average and not marginal carbon prices (Cosbey et al. 2019).

6.4. Effectiveness-weighted total carbon pricing

The TCP measures the (price) incentive, but it is not necessarily a good indicator of the triggered mitigation outcomes. The TCP, as implemented in this article, uses a simple weighting system of emissions shares to understand the average (marginal) price faced by emissions in an economy, sector, or fuel. The current generation of carbon pricing measures —such as the World Carbon Pricing (Dolphin, 2022) database, the Effective Carbon Rates (OECD, 2021), and the measure presented here — are focused on producing a descriptive measure of the carbon price rather than on the more difficult endeavor of assessing the decarbonization impacts of the carbon. If the goal is an indicator of the environmental effectiveness of carbon pricing, alternative weighting of fuel- and sector-specific carbon pricing can be used to better predict the impact on emissions. Mitigation elasticity[34] – the percentage change in CO_2 emissions as a response to a percentage change in the CO_2 price – is likely to differ across instruments, countries, sectors, and fuels. Factors thought to influence the size of mitigation elasticity include the level, variance and uncertainty of the CO_2 price, [35] the saliency and transparency of the instrument used to deliver carbon pricing, [36] the instrument's fuel and sector coverage, the availability of substitutes to the fuel affected by carbon pricing, and the size of the abatement costs. For example, the response to changes in carbon taxes or excise duties may differ from changes in fuel prices. Upon future data availability, weighting could be implemented by instrument-sector, or instrument-sector-fuel.

[34] If the size of mitigation elasticity is not constant, lower carbon prices associated with higher elasticities might deliver larger CO2 savings than higher carbon prices associated with activities that have limited mitigation actions (and therefore lower elasticities). An alternative weighting system could consider fuel or sector-specific response elasticities to calculate an indicator, although some consideration would have to be given to short- versus long-run effects.

[35] High price variance may systematically affect abatement decisions and firm investment decisions. Price variance and uncertainty are generally higher under emissions trading than under carbon taxes. Aldy and Armitage (2022) show that cost-effectiveness is affected by ETS allowance price uncertainty and firm-specific forecast errors.

[36] Chetty et al. (2009) find that economic agents underreact to taxes (in general) that are not salient due to inattention and imperfect optimization, while Bernard and Kichian (2018) find empirical evidence of the carbon tax's saliency effect on British Columbia's diesel demand. More generally, the response to changes in carbon taxes or excise duties may differ from changes in fuel prices (Andersson, 2019; Davis and Killian 2011; Rivers and Schaufele, 2015).

6.5. Other greenhouse gas emissions

This paper estimates the TCP on CO_2 emissions from the combustion of fossil fuels. Extensions of this work will consider the role of other GHG emissions in setting a TCP. The current estimation does not include other GHG emissions, including methane, nitrous oxide from agriculture, fugitive emissions from mining activities, waste and industrial processes, and non-fuel combustion from industrial processes.

Emissions from land use change and forestry (LUCF) emissions also a play a prominent role in many jurisdictions. The TCP could thus be extended to cover any direct pricing of LUCF emissions —such as through REDD+ credit trading—as well as indirect fiscal incentives for deforestation-driving commodities. Unsustainable agricultural production is responsible for CO_2 emissions associated with deforestation and forest degradation. Moreover, 40% of global deforestation is commodity-driven (Global Forest Watch, 2023; Honosuma et al., 2022).[37] Fiscal incentives to deforestation-driving commodities can place an indirect price on CO_2 emissions. For instance, input agricultural (coupled) subsidies can generate a perverse incentive to increase deforestation and CO_2 emissions (Barbier and Burgees, 1994; Leruth, Paris and Ruzicka, 2001) and, for this reason, may be categorized as negative indirect carbon pricing. In contrast, commodity taxes that vary according to the sustainability of the production generate the right incentives for sustainable practices and indirectly set a positive indirect carbon price on the emissions associated with the commodity's production (Heine, Hayde and Faure, 2021). Calculating the indirect carbon pricing emerging from pricing incentives applied to deforestation-driving commodities could be a crucial extension to the measurement of the TCP.

6.6. Other pricing instruments

The current TCP reflects carbon pricing on emissions released in a given country. However, interest is growing in the pricing of the consumption of emissions embodied in traded goods. The European Union is in the process of implementing a carbon border adjustment mechanism (CBAM) to impose ETS-aligned prices on the emissions associated with imports from covered sectors. While the CBAM aims to adjust for average direct carbon prices, interest is growing in leveraging trade policy more generally to reflect the carbon costs of traded goods. Currently, the structure of tariffs and non-tariff barriers (NTB) leads them to fall more heavily on products from relatively clean industries than on carbon-intensive goods (Shapiro, 2021). This trade policy bias can be interpreted as an underpricing of CO_2 that reaches $500-800 billion dollars each year (ibid). Better consideration of the pricing of carbon embodied in trade is thus an exciting avenue for potential extensions to total carbon pricing indicators.

[37] Growing data availability allows for CO2 emissions from deforestation to be mapped to specific commodities (Escobar et al., 2020; Pendril et al. 2019, McFarland, et al., 2015). For instance, cattle meat and oilseed products generated more than 600 Mt CO2e in 2010-2014.

7. Conclusions

Measuring carbon pricing is necessary to understand all economic actors' incentives to reduce GHG emissions. An increasing number of contributions in the literature highlight that carbon pricing is implemented in various forms, both directly through ETS or carbon taxes and indirectly through pricing instruments such as fuel taxes and fossil fuel subsidy reform. The TCP proposed in this paper summarizes a comprehensive carbon price signal affecting the consumption of fossil fuels via direct and indirect carbon prices.

While identifying and obtaining data on direct carbon pricing is relatively straightforward, defining and measuring an indirect carbon price is more complex. This paper lays out a framework guiding the definition of indirect carbon pricing. Policies that provide a pricing incentive that addresses the unpriced carbon externality can be translated into a carbon price, even when they are primarily adopted for other socio-economic objectives. Therefore, indirect carbon pricing consists of instruments that change the price of carbon-intensive goods in ways that change both the absolute and relative prices of those goods. Although indirect carbon pricing instruments are not designed to align prices with carbon contents across fuels, meaning they may vary across covered sources of GHGs, many direct carbon pricing instruments are also applied narrowly, missing opportunities to equalize marginal abatement costs across sectors and fuels. Understanding the cumulative weight of both direct and indirect carbon pricing is thus necessary to judge progress.

To measure indirect carbon pricing, including fossil fuel subsidies, this paper leverages energy price, consumption, and supply cost data with global coverage. Combining direct and indirect carbon pricing data and weighting by emissions, a comprehensive carbon pricing metric—the TCP— is calculated at the global level and for 142 countries yearly from 1991 to 2021. Estimates are presented for groups of countries from different levels of economic development and energy exporting status as well as by fuel and sector. The findings highlight limited global progress in carbon pricing over the last three decades since the Framework Convention entered into force. While the number of direct carbon pricing instruments has increased steadily over the last decade, indirect carbon pricing of CO_2 emissions from fuel combustion shows close to no progress over this period, with the global average of carbon rates in 2021 not far from those in the 1990s.

Indirect carbon price instruments cover a significant share of global emissions and are priced at higher rates than their direct counterparts. Therefore, indirect carbon pricing represents over 85% of total carbon pricing. On the other hand, while progress on direct carbon pricing continues (in terms of uptake and price levels), it covers a relatively small share of total global emissions and at lower rates than indirect carbon pricing.

Transport emissions are priced the highest among all sectors, with rates reaching roughly USD 110 tCO_2 in 2021, followed by the service sector at USD 32 tCO_2, the next largest user of highly taxed transportation fuels. By contrast, indirect carbon pricing on natural gas and carbon-intensive coal—and direct carbon pricing for their industrial users—remain low. These insights highlight opportunities for future carbon pricing reforms and alignment. The results confirm previous results for OECD countries and some major economies (OECD, 2021) and bring new insights about the roles played by developing countries in carbon pricing.

The urgency of focusing on a comprehensive measure of carbon pricing like the TCP is heightened by the recent surge in fossil fuel subsidies, which would not be considered by indicators focusing on direct carbon pricing. Prior to 2021, energy subsidies had been, somewhat unsteadily, declining. In 2020, low crude oil prices and lower consumption delivered record low fossil fuel subsidies. However, tight supply conditions in the energy market after the COVID-19 pandemic and the subsequent Ukrainian war caused international energy prices to rise and subsidies along with them, as governments in developed and developing countries sought to shield consumers by artificially keeping domestic prices low (instead of or in addition to directly supporting purchasing power via price-decoupled income support) (IEA, 2023). From about $150 billion in 2020, energy subsidies more than doubled in 2021, and in 2022 more than doubled again to about $700 billion, according to the most recent estimates (IEA, 2023). Our analysis reflects only the increase in energy subsidies occurring in 2021, as evidenced by the global TCP value decreasing in that year (see Figure 1), so the most recent surge in energy subsidies in not incorporated in our analysis. If computed based on the indirect and direct carbon prices prevailing in 2022, the value of the TCP would be significantly watered down by the doubling of the subsidies taking place in that year, further eliminating any progress made in the carbon pricing arena in the last 20 years.

Acknowledging the stagnation of carbon pricing globally can be a first step toward redoubling efforts to align market incentives with climate realities. The findings stress the urgent need of intensifying efforts for an elevated carbon pricing uptake and at levels that are sufficient to align with the social cost of carbon. They also underscore the need for increasing the emissions coverage of total carbon pricing and aligning carbon rates across sectors within an economy. Moreover, to avoid that progress on direct carbon pricing is undone by backtracking in indirect carbon pricing, indirect pricing may require more attention in global climate policy efforts. Further recognizing the importance and multiplicity of motives for indirect carbon pricing instruments suggests that advisory programs on carbon pricing would benefit from also highlighting non-climate reasons to support change (Heine and Black, 2019).

The proposed metrics represent one possible approach indicating the status and developments of carbon pricing incentives, and several dimensions for extensions and improvements, also with data collection, are highlighted. These indicators provide valuable insights for judging progress on carbon cost alignment, a key component for driving private investment and climate-cognizant decision making; however, total carbon pricing metrics should not be viewed as measures of ambition or mitigation effort across jurisdictions. Meeting the climate challenge involves a range of activities and interventions, addressing market, behavioral, informational, and technical barriers to produce transformational change. A broader view, including but not limited to pricing metrics, is needed to understand how effectively countries are responding to the climate mitigation challenge.

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Appendix A. Methodology

A1. Estimating emissions coverage of policies by fuel and sector

Step 1: Assign basic percentage coverage (BP) ***and point of regulation by IEA fuel and/or economic subsector***

Based on stated emissions coverage subject to each Carbon Pricing Instrument (CPI), we assign coverage for every subsector and every fuel: generally, 100% or 0%, depending on the characteristics of the CPI. This approach allows the computation of final coverage to reflect both fuel and sector attributes. If coverage under a CPI is predominantly determined by fuel but some sectors are exempt, then we assign covered fuels 100% and any exempt sector 0%. Any sectors not explicitly exempt are assigned 100%. The same happens in the reverse situation—if coverage is predominately determined by sector but with some fuel exemptions, we generally assign 100% of the sectors as covered, any exempt fuels are assigned 0%, and other fuels 100%. However, in some cases a CPI is described as covering some activities in a subsector but not others (e.g., where domestic aviation is covered but not domestic shipping, both within 'Domestic navigation'). The relative size of activities within subsectors will vary substantially between countries, so for simplicity we assign 50% for partial coverage. It is noted that this 'basic coverage' is the starting point, which is adjusted to account for other factors, including overlap and total national GHG coverage (see below).

Step 2: Calculate basic emissions coverage (BE) ***for every fuel-subsector-instrument***

For each economic subsector *s* fuel *f* and CPI *p,* basic emissions coverage of each fuel in each subsector (BE_{sf}) is determined for each CPI:

$$BE_{sfp} = e_{sfc} \times BP_{sfp} \text{ and } BP_{sfp} = BP_{sp} \times BP_{fp}$$

where BP is a basic percentage coverage, BE indicates related basic emissions volume in t CO_2 and *e* is the actual emissions volume associated with a given fuel *f* in sector *s* based on IEA data for a given country *c*.

Step 3: Adjust basic coverage for any exempt overlap

In those instances where a subset of emissions from covered sectors or fuels are exempted when subject to another CPI (as is often the case where ETS installations can claim back any carbon tax levied) these are subtracted to find the adjusted emissions coverage (AE):

$$AE_{sfp} = BE_{sfp} - FE_{sfq}$$

where FE_{sfq} is the final covered emissions volume (in t CO_2) for sector *s* and fuel *f* under instrument *q* which attracts the exemption, and AE_{sfp} is the adjusted emissions volume coverage (in t CO_2) for sector *s* and fuel *f* and instrument *p*. If under instrument *i* there are no exemptions for emissions covered by a different CPI, $AE_{sfp} = BE_{sfp}$.

Step 4: Scale coverage down to meet known economywide coverage

If the proportion of a country's total emissions covered by the sum of a mechanism's adjusted coverage for each sector and fuel is higher than the proportion of a country's total emissions known to be covered by that mechanism (KP_p), the adjusted coverage for each fuel *f* and sector *s* is scaled down accordingly to determine the final emissions volume coverage figure:

$$FE_{sfp} = AE_{sfp} \times KP_p / (\Sigma_s \Sigma_f AE_{sfp} / e_c)$$

If the sum of adjusted coverage is below the known economywide coverage, then individual adjusted coverage is used: i.e., if $(\Sigma_s \Sigma_f AE_{sfp} / e_c) < KP_p$ then $FE_{sfp} = AE_{sfp}$.

The 'known coverage' figure is taken from existing sources (generally the World Bank's *State and Trends of Carbon Pricing*, where possible accounting only for CO_2 emissions to align with the IEA dataset used for this analysis.

Note: This differs from the OECD approach, which determines coverage by sectors (where possible using a bottom-up approach) and applies a constant % coverage to each fuel within the sector.

Step 5: Convert emissions coverage into a coverage factor

The final emissions coverage volume figures is converted back to a coverage factor *v* for each fuel and sector, for use in the calculations described in Section 4 of this paper:

$$v_{fp} = \Sigma_f FE_{sfp} / \Sigma_f e_{sfc}$$

or

$$v_{sp} = \Sigma_s FE_{sfp} / \Sigma_s e_{sfc}$$

A2. Determine the point of regulation for each fuel-subsector-mechanism

Each fuel-subsector-mechanism is allocated a point of regulation relative to the point of combustion based on the characteristics of the CPI using the following three categories:

- **Upstream:** if charged before emissions are released to the atmosphere, e.g., paid by distributors and importers of fuels.
- **Point source**: if charged at the point of combustion, e.g., applied to power plants.
- **Downstream**: if charged after emissions are released to the atmosphere, e.g., paid by importers of finished products with covered embedded emissions.

This is generally determined based on fuel or sector, similar to assigning basic percentage coverage. Where there is an inconsistency between the point of regulation for a fuel and subsector, additional research is undertaken to establish the specific point of regulation for that sector-fuel-instrument.

Appendix B. Analytical representation

B1. Total carbon price (TCP) and firm incentives

To ground our calculations of the TCP, we start by considering the incentives of a competitive firm making decisions based on the prevailing market prices and policy interventions. Firm *i* has output q_i, which is a function of its non-fuel production inputs (vector $\mathbf{X}_i$) and its consumption of different fuels (vector $\mathbf{FC}_i$). It receives price P_i for its good, and pays price p_i^x for its non-fuel production input of type *x*, X_i^x, and for its consumption of fuel type *f*, FC_i^f, it has unit input costs of c_i^f, inclusive of any policy interventions. The firm has direct emissions $e_{ist}(\mathbf{FC}_{ist}, \mathbf{X}_{ist})$, also a function of its input choices, and it is subject to pay a direct carbon price τ_i per tCO_2 on the covered share v_i of its emissions. It may also receive free allocations that are grand-parented (*G*) and fixed or rebated in proportion to its output equal with a unit value $\tau_i b_i$, where b_i is often a benchmark emissions allocation. The resulting profits π_i are

$$\pi_i = \underbrace{P_i q_i(\mathbf{FC}_i, \mathbf{X}_i)}_{\text{revenues}} - \underbrace{\sum\nolimits_x p_i^x X_i^x}_{\text{non-fuel input costs}} - \underbrace{\sum\nolimits_f c_i^f FC_i^f}_{\text{fuel input costs}} - \underbrace{\tau_i \left(v_i e_i(\mathbf{FC}_i, \mathbf{X}_i) - G_i - b_i q_i(\mathbf{FC}_i, \mathbf{X}_i) \right)}_{\text{direct emissions costs net of free allocation}} \qquad (1)$$

A profit-maximizing firm would equalize its marginal benefits and costs of additional fuel and non-fuel inputs:

$$\begin{aligned} (P_i + \tau_i b_i) \frac{\partial q_i}{\partial FC_i^f} &= c_i^f + \tau_i v_i \frac{\partial e_i}{\partial FC_i^f}; \\ (P_i + \tau_i b_i) \frac{\partial q_i}{\partial X_i^x} &= p_i^x + \tau_i v_i \frac{\partial e_i}{\partial X_i^x}. \end{aligned} \qquad (2)$$

The right-hand sides reflect the *marginal costs* of each input, which are influenced both by the intermediate input costs and the direct emissions costs. Direct CO_2 pricing influences the relative costs of inputs in proportion to their incremental emissions contribution. Indirect CO_2 pricing affects input costs via c_i^f, the price to the firm, which can include the relevant upstream supply cost, SC_i^f, and the net tax wedge Δ_i^f, corresponding to the fuel taxes net of subsidies per unit of fuel paid by the firm or passed down from upstream vendor liabilities. It will be this net tax wedge Δ_i^f that we will attempt to calculate from both a sector- and fuel-specific standpoint for each country.

From a product pricing perspective, the value of the output-based allocation or rebate raises the value of marginal product to the firm (as seen on the left-hand side), but it does not distort the relative marginal costs of inputs. Fixed allocations do not influence marginal decisions.

The firm perspective is also useful for considering the effect of policies on average operating costs to the firm, which must be passed along through higher product prices for the consumer in the long run. These average carbon pricing costs (ACP) are

$$ACP_i = \sum_f \Delta_i^f \frac{FC_i^f}{q_i(\mathbf{FC}_i, \mathbf{X}_i)} + \tau_i \left(v_i \frac{e_i(\mathbf{FC}_i, \mathbf{X}_i)}{q_i(\mathbf{FC}_i, \mathbf{X}_i)} - b_i \right) \tag{3}$$

that is, the sum of the indirect tax burden of fossil fuel consumption per unit of output, plus the direct tax on covered emissions over the benchmark allocation per unit of output. This *ACP* is thus a measure of average *embodied* carbon costs in a product, which is the primary indicator of competitiveness effects of climate policies.

For our aggregate measures of total carbon pricing, however, we are interested in the extent of carbon pricing *per unit of emissions* on the margin, which is the primary driver of incentives to reduce emissions. These measures must be constructed without firm-level data, and so will rely on sector- or fuel-specific averages for the marginal emissions factors and policy information.

B2. Sector-specific total carbon price (TCP)

A sector-specific TCP measures the cumulative *downstream* weight of carbon pricing policies for a given sector. For each country *c* and year *t*, we calculate a sector-specific TCP that can be represented as

$$TCP^s = \underbrace{\tau_s v_s}_{\text{average price for direct emissions}} + \underbrace{\frac{\sum_f \Delta_s^f FC_s^f}{\sum_f \mu_s^f FC_s^f}}_{\text{indirect tax payments per unit of fuel-related emissions}} \tag{4}$$

where Δ_s^f is the price gap (calculated net fuel tax burden) for fuel *f* in sector *s*, μ_s^f is the fuel's emissions factor; *FC* is its consumption of fuel type *f*, and v_s is the coverage factor for direct emissions pricing regulation.[38]

B3. Fuel-specific total carbon price (TCP)

A fuel-specific *total carbon price* aggregates the net effect of carbon pricing *upstream* to the fuel level. A fuel-specific TCP can thus be represented as

[38] Note that the second term for the indirect tax burden is equivalent of the weighted sum of the fuel-specific tax per unit of emissions per unit of fuel, where the weights are the fuel's emissions shares for the sector: $\sum_f \Delta_s^f / \mu_s^f \frac{\mu_s^f FC_s^f}{\sum_j \mu_s^j FC_s^j} = \frac{\sum_f \Delta_s^f FC_s^f}{\sum_f \mu_s^f FC_s^f}$.

$$TCP^f = \underbrace{\frac{\sum_s \Delta_s^f FC_s^f}{\sum_s \mu_s^f FC_s^f}}_{\substack{\text{indirect tax payments}\\ \text{per unit of total fuel-}\\ \text{specific emissions}}} + \underbrace{\frac{\sum_s \tau_s v_s \mu_s^f FC_s^f}{\sum_s \mu_s^f FC_s^f}}_{\substack{\text{downstream fuel-related}\\ \text{direct emissions payments}\\ \text{per unit of emissions}}} \tag{5}$$

where Δ_s^f is the price gap (calculated net fuel tax burden) for fuel *f* in sector *s,* μ_s^f is the fuel's emissions factor; and v_s is the coverage factor.

B4. Country-level total carbon price (TCP)

Calculating a country-level TCP, we can either aggregate across sectors or across fuels. Aggregating across fuels, involves weighting carbon pricing measures according to the fuel-related emissions shares as follows:

$$TCP_c = \underbrace{\frac{\sum_f \sum_s \Delta_s^f FC_s^f}{\sum_f \sum_s \mu_s^f FC_s^f}}_{\substack{\text{indirect tax payments}\\ \text{per unit of total fuel-}\\ \text{specific emissions}}} + \underbrace{\frac{\sum_f \sum_s \tau_s v_s \mu_s^f FC_s^f}{\sum_f \sum_s \mu_s^f FC_s^f}}_{\substack{\text{downstream direct emissions}\\ \text{payments per unit}}} \tag{6}$$

A sector-based aggregation—weighted by emissions shares—may be more reliable:

$$TCP_c = \underbrace{\frac{\sum_s \tau_s v_s e_s}{\sum_s e_s}}_{\substack{\text{total direct tax payments}\\ \text{per unit of emissions}}} + \underbrace{\frac{\sum_s \sum_f \Delta_s^f FC_s^f}{\sum_s e_s}}_{\substack{\text{total indirect tax payments}\\ \text{per unit of emissions}}} \tag{7}$$

where e_s is total emissions for the sector.

Appendix C. Grouping of economies by type

EXPORTING LLMICS	Morocco	Moldova	Hungary
Angola	Myanmar	Mexico	Ireland
Benin	Nicaragua	Malaysia	Iceland
Bolivia	Nepal	Norway	Israel
Cameroon	Pakistan	Oman	Italy
Congo, Dem. Rep.	Philippines	Qatar	Jamaica
Congo, Rep.	Korea, Dem. People's Rep.	Suriname	Jordan
Algeria	Senegal	Turkmenistan	Japan
Egypt, Arab Rep.	El Salvador	**IMPORTING UMHICS**	Korea, Rep.
Ghana	Togo	Armenia	Lebanon
Indonesia	Tanzania	Australia	Lithuania
Iran, Islamic Rep.	Ukraine	Austria	Luxembourg
Mongolia	Uzbekistan	Belgium	Latvia
Mozambique	Zambia	Bulgaria	Malta
Nigeria	Zimbabwe	Bahrain	Montenegro
Sudan	**EXPORTING UMHICS**	Bosnia and Herzegovina	Namibia
South Sudan	Albania	Belarus	Netherlands
Syrian Arab Republic	United Arab Emirates	Botswana	New Zealand
Tajikistan	Argentina	Switzerland	Panama
Tunisia	Azerbaijan	Chile	Peru
Venezuela, RB	Brazil	China	Poland
Vietnam	Brunei Darussalam	Costa Rica	Portugal
Yemen, Rep.	Canada	Cuba	Paraguay
IMPORTING LLMICS	Colombia	Cyprus	Romania
Bangladesh	Denmark	Czechia	Singapore
Côte d'Ivoire	Ecuador	Germany	Serbia
Eritrea	Estonia	Dominican Republic	Slovak Republic
Ethiopia	Gabon	Spain	Slovenia
Honduras	United Kingdom	Finland	Sweden
Haiti	Guatemala	France	Thailand
India	Iraq	Georgia	Trinidad and Tobago
Kenya	Kazakhstan	Gibraltar	Türkiye
Kyrgyz Republic	Kuwait	Greece	Taiwan, China
Cambodia	Libya	Guyana	Uruguay
Lao PDR	Russian Federation	Hong Kong SAR, China	United States
Sri Lanka	Saudi Arabia	Croatia	South Africa