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Policy Sequencing Towards Carbon Pricing

Empirical evidence from G20 economies and other major emitters

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Empirical evidence from G20 economies and other major emitters
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ABSTRACT: Carbon pricing is considered the most efficient policy to reduce greenhouse gas emissions but it has also been conjectured that other policies need to be implemented first to remove certain economic and political barriers to stringent climate policy. Here, we examine empirical evidence on the the sequence of policy adoption and climate policy portfolios of G20 economies and other major emitters that eventually implemented a national carbon price. We find that all countries adopted carbon pricing late in their instrument sequence after the adoption of (almost) all other instrument types. Furthermore, we find that countries that adopted carbon pricing in a given year had significantly larger climate policy portfolios than those that did not. In the last part of the paper, we examine heterogeneity among countries that eventually adopted a carbon price. We find large variation in the size of policy portfolios of adopters of carbon pricing, with more recent adopters appearing to have introduced carbon pricing with smaller portfolios. Furthermore, countries that adopted carbon pricing with larger policy portfolios tended to implement a higher carbon price. Overall, our results thus suggest that policy sequencing played an important role in climate policy, specifically the adoption of carbon pricing, over the last 20 years.

JEL Classification Numbers:	H23, Q48, Q54, Q58
Keywords:	carbon pricing, climate policies, policy sequencing, political economy

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1 Introduction

Carbon pricing has been suggested as an economically efficient instrument to reduce greenhouse gas emissions and a growing body of literature confirms its effectiveness[1] but many countries including some of the world's largest emitters appear reluctant to implement it. By the end of 2020, only about 40 countries had implemented either a carbon tax or a national emission trading scheme, leaving about 150 countries and about 85 percent of global greenhouse gas emissions without an explicit price on carbon ([World Bank], 2022). This slow progress in the adoption of carbon pricing has been associated with several barriers including concerns about high energy prices hurting households and reducing the industrial competitiveness of the economy (Klenert et al., 2018; Dolphin et al., 2019; Levi et al., 2020). Does the presence of these barriers suggest that countries need to give up on the idea of cabon pricing and instead need to resort to more feasible, yet second-best climate policies? A more optimistic view, based on a careful reading of the experiences of Germany and California, suggests that other climate policies can be used to lower or remove some or all of the barriers, thus paving the way for a subsequent adoption of carbon pricing (Meckling et al., 2015, 2017; Pahle et al., 2018).

This idea of policy sequencing suggests that climate policies can be used iteratively to address specific barriers to higher stringency. To this aim, government policies can address specific market failures, such as public good properties and asymmetric information. For example, positive externalities of green technological innovation can be addressed with public funding for research and development. This innovation can result in affordable alternatives to high-carbon goods and services lowering the impact of carbon pricing on household expenses, thereby making it both more effective and more acceptable. Likewise, asymmetric information is commonly addressed through support for education and labelling, which can in turn increase the market for less emission-intensive products and lead to positive returns to scale. Political opposition to stringent climate policies due to lobbying of powerful industry groups can be addressed, for example, through grants and subsidies that support the growth of a green sector, broadening the support base for additional policies. Furthermore, standards on environmental performance can provide long-term orientation and help coordinating private investments into the development of new innovative green technologies.

In this study, we present empirical evidence on sequencing of climate policies focusing on G20 economies and other large emitters that had adopted either a carbon tax or a national emission trading system (ETS) by the end of 2020. To our knowledge, we are the first to

[1] For example, Andersson (2019) examines the effectiveness of carbon pricing in Sweden; for a recent review, see Green (2021).

provide quantitative and international empirical evidence on how countries have built up their climate policy portfolios over time before eventually adopting a carbon tax or permit system. To this aim we combine a comprehensive dataset on carbon pricing (World Bank Carbon Pricing Dashboard) with a large international dataset on climate policies (den Elzen et al., 2019; Roelfsema et al., 2020; Fekete et al., 2021). For the purpose of our analysis, we aggregate 72 instrument categories to eight different instrument type and distinguish between six sectors. We then derive policy sequences based on pairwise conditional empirical frequencies. Furthermore, we use matching and linear regression to identify significant statistical associations between climate policy portfolios and the adoption and stringency of carbon pricing policies.

We find similar sequences of policy instruments across sectors and countries among countries that have adopted carbon pricing. Carbon pricing tends to be implemented last, after the adoption of all (or almost all) other instrument types. Examining the temporal evolution of countries' climate policy portfolios, we find that countries that adopted carbon pricing in a specific year tended to have larger policy portfolios than other countries. Furthermore, examining individual countries' policy portfolios in greater detail, we find large variation in the overall size of countries' policy portfolios at the time of adoption of carbon pricing, with possibly smaller portfolios among more recent adopters. We discuss several explanations for this finding including variation in institutional capacity but also increasing public support for climate policy, decreasing abatement costs, and policy diffusion between countries. Furthermore, our results suggest that countries with larger policy portfolios tended to implement carbon pricing policies with higher average carbon prices, consistent with the idea that earlier policies remove barriers to higher stringency.

Our analysis contributes to the debate about an optimal climate policy mix, including more normative work on the benefits of alternative instrument types (Peñasco et al., 2021), policy mixes (Bertram et al., 2015; van den Bergh et al., 2021), and second-best policies (Fischer et al., 2021). Our paper adds to this debate another layer of complexity, the temporal sequence of policy adoption. In principle, policies that might be considered second-best for a specific market failure, such as the negative externalities from GHG emissions, can also be considered as temporary remedies that facilitate a later adoption of the first-best policy (Pahle et al., 2018). This idea is generally consistent with the empirical evidence on the temporal sequence of policy adoption that we report in this paper. Indeed, our results suggest that earlier policies do not only facilitate the adoption of carbon pricing, but that they are also positively associated with its stringency, pointing to additional benefits of policy sequencing.

We also contribute to a growing debate about the determinants of political support for carbon pricing (for relatively recent empirical work see e.g. Anderson et al. (2021); Douenne and Fabre (2022); Mildenberger et al. (2022)). Our paper takes a macroscopic perspective and focuses on relatively long time scales over which early policies such as technology subsidies might in the past have slowly increased support for more stringent climate policies as they helped to transform the energy system, to reduce the emission-intensity of the economy, and to build pro-environmental interest groups. Indeed, our results suggest that it took countries on average between 5 - 18 years to move from other policies to carbon pricing. At the same, by reporting evidence consistent with the existence of substantial barriers to carbon pricing, we provide additional support for attempts to examine how the design of pricing policies can be used to increase political support and facilitate implementation (see, for example, Baranzini and Carattini (2017); Bechtel et al. (2020); Klenert et al. (2018); Kotchen et al. (2017)).

The paper is structured as follows. In Section 2, we explain our empirical framework, describe the dataset, and explain the statistical methods of the analysis. Results are presented in several steps in Section 3. Finally we discuss our main findings and conclude in Section 4.

2 Methods

2.1 Empirical framework

Building on prior work on climate policy sequencing we expect there to be barriers to the adoption of carbon pricing. Possible barriers include concerns about high mitigation costs for firms in energy-intensive industries who compete internationally, high costs for consumers and possibly a regressive distribution of these costs, political opposition to climate change policies, opposition to pricing policies, and concerns about the effect of a carbon price on employment in industries that rely on fossil fuels. Some of these barriers can generally be addressed with climate policies other than carbon pricing, such as technology subsidies, which can lower mitigation costs through technological innovation or more generally remove opposition to a pricing policy through a gradual transformation of the economy away from carbon-intensive activities.

We therefore expect there to be a positive statistical association between the number of climate policies other than carbon pricing, in the following referred to as the size of the climate policy portfolio, and the adoption and intensity of a pricing policy. This positive association can generally result from an ex-post effect, whereby earlier climate policies increase the probability of the subsequent adoption of a pricing policy, or from an ex-ante effect, whereby an anticipated later adoption of a pricing policy motivates the prior adoption of other policies (Figure 1). The latter direction of causation is especially plausible if high mitigation costs are a major concern, as those can reliably be reduced with other climate policies implemented prior to the planned adoption of carbon pricing. The larger those barriers to adoption, the stronger we expect the statistical association between the size of the policy portfolio and the adoption of the pricing policy to be.

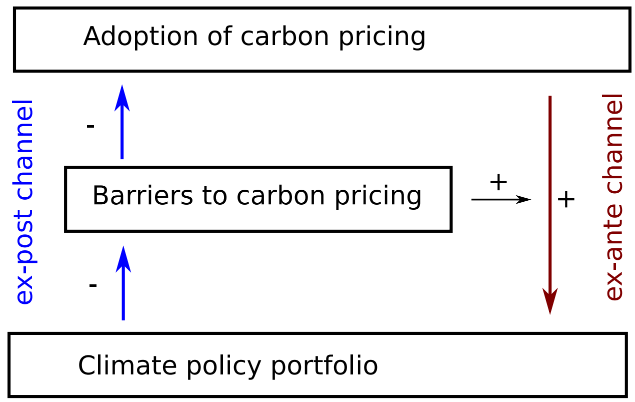

Figure 1. **Causal diagram**. The arrows represent possible causal relationships between the adoption of a carbon pricing policies, (unobserved) barriers to carbon pricing, and the climate policy portfolio.

In the first part of the analysis, we examine the sequence of policies to identify the temporal order in which climate policies with different instruments types tend to be adopted. We then briefly descripe the temporal evolution of climate policy portfolios. After this more descriptive analysis, we use a matching methodology to establish whether countries that adopted carbon pricing in a given year had larger policy portfolios than those that did not. We find that adopters indeed had larger portfolios. To address concerns about possibly confounding country characteristics (Figure A1 in the Appendix) we use a linear regression in which we include a few such characteristics. Furthermore, we use the regression analysis to examine the association between the size of the policy portfolio and the level of the pricing policy at the time of implementation.

2.2 Data

We use data on climate policies from the website `climatepolicydatabase.org`, which provides to our knowledge the most comprehensive international dataset on climate policies. The dataset has been gradually composed over the recent years (Nascimento et al., 2021) and been analysed in a number of academic publications (den Elzen et al., 2019; Roelfsema et al., 2020; Fekete et al., 2021; Yao and Zhao, 2022). The dataset is based on other international datasets, reports, and country specific documents, and incorporates a variety of other popular datasets on climate (or in some cases more broadly environmental) policies such as the Climate Change Laws of the World (Eskander and Fankhauser, 2020) and OCED policy instruments database[2].

Despite the variety of sources used for the construction of the dataset it can generally not be expected to include all climate policies of every country. Information on data comprehensiveness for individual countries was obtained from the NewClimate Institute. The dataset can generally be considered comprehensive for G20 economies (including EU member countries that are individual members of the G20, but not other EU members) and 18 additional countries to which we loosely refer as other major emitters. These additional countries are mostly advanced and emerging economies in Europe, Asia and Latin-America but also encompass some less developed countries and two countries in Africa (Figure 2). For all these countries, climate policies have been collected with the aim of completeness and the dataset has gone through a validation with national stakeholders and experts. For all other countries, the data can generally not be considered comprehensive. We hence drop all those countries from our sample. This includes some of the early pioneers of carbon pricing (Norway, Sweden, Finland, Poland, Denmark) (see Tables A4 and A5 in the Appendix for a detailed list of countries).

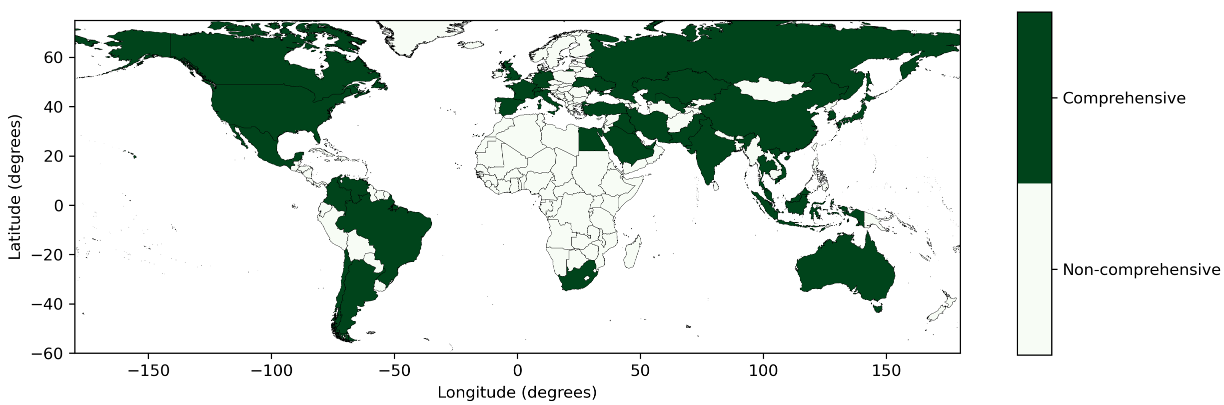

Figure 2. **Sample of countries included in the analysis.** Map shows whether the data on climate policies can be considered comprehensive. See also Table A4 in the Appendix.

Every policy in the dataset carries information on policy objectives, administrative level, instrument types, targeted sectors, and more. To prepare the data for our analysis, we focus only on policies that have climate change mitigation as one of their objectives. Furthermore, we neglect any policies at the subnational level and apply all EU policies to the member countries' portfolio. If a country became member after the policy was decided in the EU, we use the year of joining the EU as the date of policy adoption.

[2] https://www.oecd.org/env/indicators-modelling-outlooks/policy-instrument-database/

The dataset distinguishes 72 instrument categories, which we aggregate to seven different instrument types based on the instrument typology of the IEA. Furthermore, we distinguish between five sectors based on the sector definition of the IPCC AR5 WGIII (Electricity and heat production; Transport; Buildings; Industry; Agriculture, forestry, and other land use) and one additional sector General for policies that do not target specific sectors. We combine the final climate policy dataset with data from the Carbon Pricing Dashboard of the World Bank to consistently distinguish an additional instrument type carbon pricing, which can otherwise also be considered a subtype of financial incentives. The final eight instrument types are: Regulatory instruments; Grants, subsidies, and other financial incentives; Information and education; Policy support; Research, development, and deployment; Voluntary agreements; Procurement and investment; and Carbon pricing. A list of the corresponding instrument categories together with their frequency in the dataset is shown in Table A6 in the Appendix.

We find that every instrument type has been used in every sector in at least one country (Figure A3 in the Appendix). The number of times we observe a specific instrument-sector combination in our database ranges from 18 (Research, development and deployment in Agriculture, forestry, and other land use) to 1902 (Policy support introduced without targeting a specific sector).[3] The latter pattern includes national climate change strategies and emission reduction targets including the NDC. Other frequent combinations are also well known from the climate change mitigation policy research and practice. This includes a frequent use of financial incentives in the energy sector (e.g. feed-in-tariffs, emission permits), and frequent use of regulatory instruments in the buildings and transport sector (e.g. efficiency standards for household appliances, energy efficiency standards for buildings, and emission standards for road transport vehicles).

We complement the climate policy data with country characteristics that we obtain from several sources. This includes GDP per capita data in purchasing power parity from the World Bank, an index of education from the Human Development Indicators provided by the United Nations Development Program, an index of the control of corruption from the World Governance Indicators of the World Bank, and information on fossil fuel reserves from the US Energy Information Administration. Descriptive statistics are provided in Table A1 in the Appendix.

2.3 Statistical methods

In the first part of the analysis, we identify policy sequences in terms of their instrument type. The eight instrument types result in 40320 possible sequences. To identify these

[3]In total, we observe 14,540 instrument-sector combinations.

sequences, we first consider all possible pairs of instrument types. For each of these 28 pairs, we examine which of the two instrument types tends to be adopted first across sectors and countries. We then use the relative timing of these pairs to construct the overall sequence.

Formally, we consider the adoption of two instrument types as events X and Y respectively. Using this terminology, we examine the conditional frequency that event X is preceded by event Y across countries and sectors. In mathematical terms, we examine the conditional frequency $f(Y_{t-1}|X_t)$ whereby X_t and Y_{t-1} are binary variables indicating whether the two policies have been decided up to the year t and $t-1$ respectively:

$$f(Y_{t-1}|X_t) = \frac{n(Y_{t-1} \wedge X_t)}{n(X_t)} \tag{1}$$

with the number of times an event is observed in the data denoted as $n(.)$. We then derive the relative order of all possible pairs of instrument types by comparing $f(Y_{t-1}|X_t)$ and $f(X_{t-1}|Y_t)$. Because we are interested in existing policies at the time of decision of a new policy, we exclude all observations after an event is observed for the first time (i.e. after the first time a specific instrument is adoped in a specific sector in a specific country).

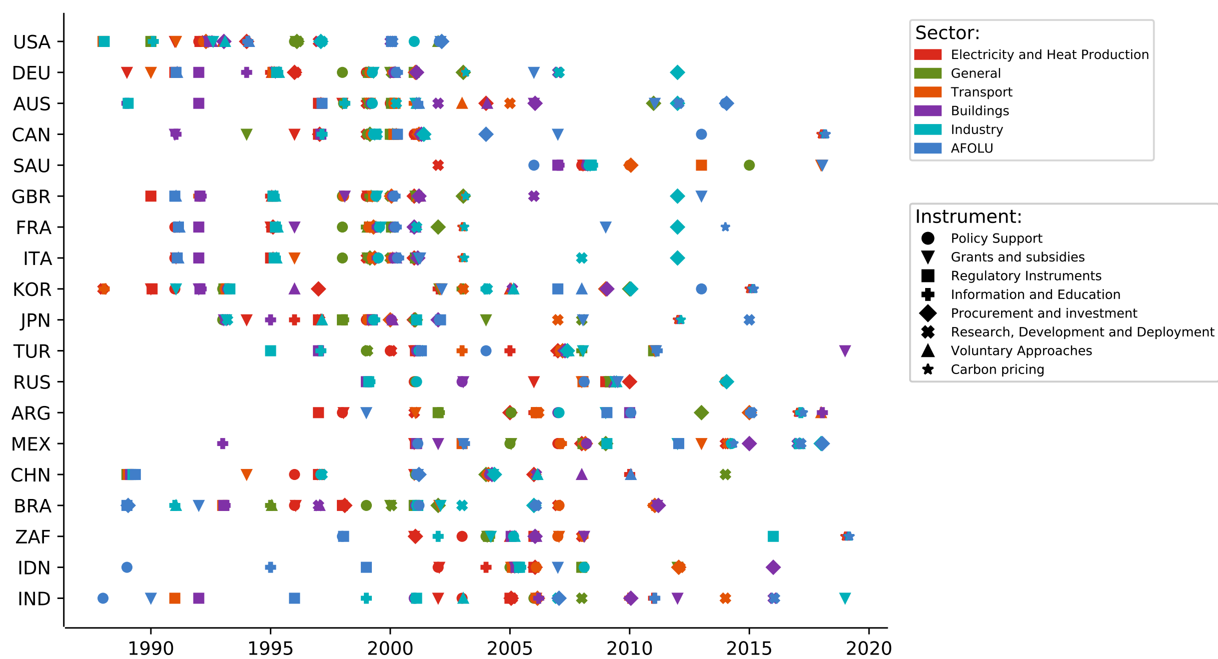

Figure 3. **Adoption of policies with different instrument types and sectors over time in different countries.** Shown are only policies that are the first of their kind in terms of their country, instrument type, and sector combination. The figure illustrates all information used for the derivation of policy sequences. See text for explanation and an example.

The data used for the identification of policy sequences is illustrated in Figure 3. For example, we find that in the USA regulatory instruments X precede voluntary approaches Y in three out of six sectors. In the remaining three sectors, both instrument types are implemented for the first time in the same year. This yields $f(X_{t-1}|Y_t) = 0.5 > 0 = f(Y_{t-1}|X_t)$. For the USA, we hence consider regulatory instruments as preceding voluntary approaches.

In the second part of the paper, we examine differences in the adoption of carbon pricing and in policy sequencing across countries. To this aim, we quantify the size of countries' climate policy portfolios. We do so by counting how many of the eight instrument types have already been implemented in the six sectors mentioned above. This yields a score between 0 and 48 for every country and every year. We complement this information with a range of control variables: GDP per capita, education, control of corruption, political globalisation, and the prevalence of fossil fuels in a country. The choice of explanatory variables is informed by the results of comprehensive international analysis of the factors that determine the adoption of pricing policies (Dolphin et al., 2019; Best and Zhang, 2020; Levi et al., 2020).

We first examine the statistical association between the size of countries' climate policy portfolios and whether countries adopted carbon pricing in a given year. To this aim, we compare the climate policy portfolios of countries that adopted a national carbon price in a given year with the portfolios of countries that did not adopt a carbon price neither earlier nor in the same year. We refer to the first group of countries as treated countries and to the second group as control countries. For the statistical analysis, we match every treated country with one control country. To this aim, we assign every treated country a randomly chosen control country. We iterate this random assignment 1000 times and then compare the average size of the policy portfolios of treated countries with the average size of portfolios of the control countries. For inference, we calculate bootstrapped confidence intervals. In addition, we estimate a logit model with the adoption of carbon pricing as binary dependent variable, which allows us to include certain country characteristics as control variables.

We next focus on heterogeneity among countries that eventually adopted a national carbon price (treated countries). We first examine the size of policy portfolios at the time of adoption of carbon pricing. To this aim, we estimate a linear regression model with the size of the policy portfolio at the time of adoption as dependent variable and the same control variables as above. To examine trends over time we also include the year of adoption as an explanatory variable. Because the number of observations is small relatively to the number of explanatory variables, we also estimate a more parsimonious model with only selected explanatory variables. For this model we choose GDP per capita and the reserves of fossil fuels. Because reserves of oil and gas are higly correlated, we include only reserves of coal and reserves of oil in this model. Furthermore, we use Lasso model selection to identify the most important explanatory variables. Lasso estimation optimises a model that strikes a balance between the explained variation and model complexity as measured by the number of explanatory variables. As a popular method for model shrinkage, it is particularly suitable for the detection of influential variables among several correlated variables. In addition, we also examine the association between the size of policy portfolios at the time of implementation of a pricing policy and the economy-wide average carbon price. To this aim, we estimate a similar linear regression model with the average carbon price as dependent variable.

3 Results

3.1 The temporal sequence of climate policies

We focus on policy sequences of countries that eventually adopted a carbon pricing policy. Overall we find similar sequences of policy instruments across sectors and countries (Figure 4). This is especially true for the relative position of carbon pricing. Pooling policy adoption in all countries and sectors, carbon pricing tends to be the last instrument type. If we pool policies only across countries but keep sectors separate, we find that carbon pricing is the last instrument type in every sector. Furthermore, in 12 out of the 15 countries, carbon pricing tended to be used for the first time in a specific sector after the use of any of the other instrument types. Overall, we hence find that carbon pricing tends to be implemented last, after the adoption of all or almost all the other seven instrument types.

The results also reveal some recurrent patterns of sequencing for the other seven instrument types. Focusing on the results by sector, we find two groups of instrument types. The first group consists of four early instrument types: Regulatory instruments, Grants, subsidies, and other financial incentives, Information and education, and Policy support. The second group of four late instrument types includes Research, development, and deployment, Voluntary agreements, Procurement and investment, and Carbon pricing. With the exception of voluntary agreements and financial incentives in Agriculture, policies of the first group tend to be implemented before policies of the second group in all sectors (Figure 4).

We find more variation of sequencing at the level of individual countries (Figure 4). The most frequent patterns are a relatively early adoption of Regulatory instruments and Policy support instruments and a relatively late adoption of Procurement and investment and Carbon pricing. The relative positions of the remaining four instrument types (Grants, subsidies, and other financial incentives; Research, development, and deployment; Voluntary agreements; Information and education) show greater variation across countries.

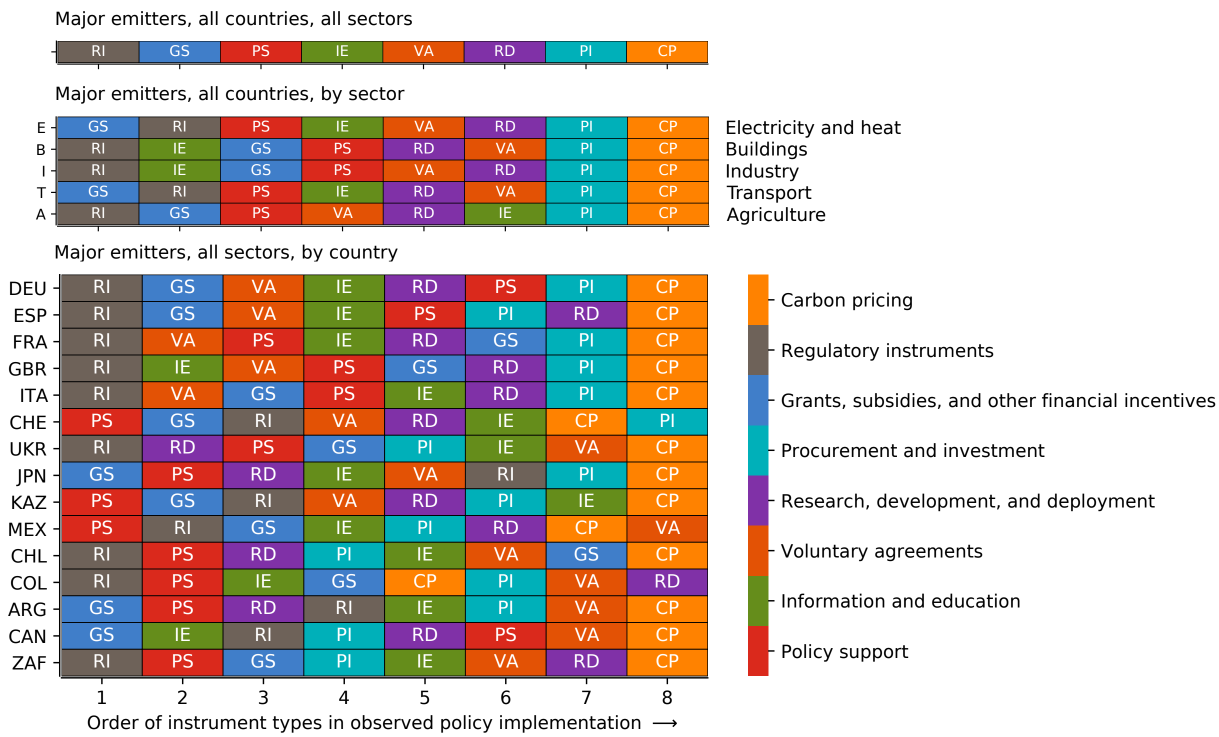

Figure 4. **Policy sequences of countries with a carbon price**. Sampling criteria is adoption of carbon price by the end of 2020 and availability of comprehensive data on climate policy adoption. See Figure 2 and Tables A4 and A5 in the Appendix for further information on sampling.

3.2 The build-up of climate policy portfolios over time

The results presented in the previous Section suggest that carbon pricing tends to be adopted after the adoption of climate policies with all or almost all other instrument types. We use this insight as motivation to examine whether the climate policy portfolios of countries that adopted carbon pricing in a specific year systematically differ from the portfolios of countries that did not adopt it.

To do so, we quantify the size of countries' policy portfolios as the number of instrument type - sector combinations that a country has already used prior to a given year. The temporal evolution of the portfolios of countries that eventually adopted carbon pricing is shown in Figure 5a. The visualisation reveals some interesting patterns. There appear to be at least three different kinds of trajectories of how countries built up their policy portfolios over time. Countries of the first group, including Canada, Japan, and South Africa, exhibit a relatively rapid expansion of their portfolio followed by a slow further expansion over several years that eventually includes the adoption of carbon pricing. Countries of the second group, including Argentina and Switzerland, show a steady gradual expansion of their portfolios up until the introduction of carbon pricing. Countries of the third group, including the current EU members in the sample, show a rapid expansion of policies almost immediately followed by the introduction of carbon pricing.

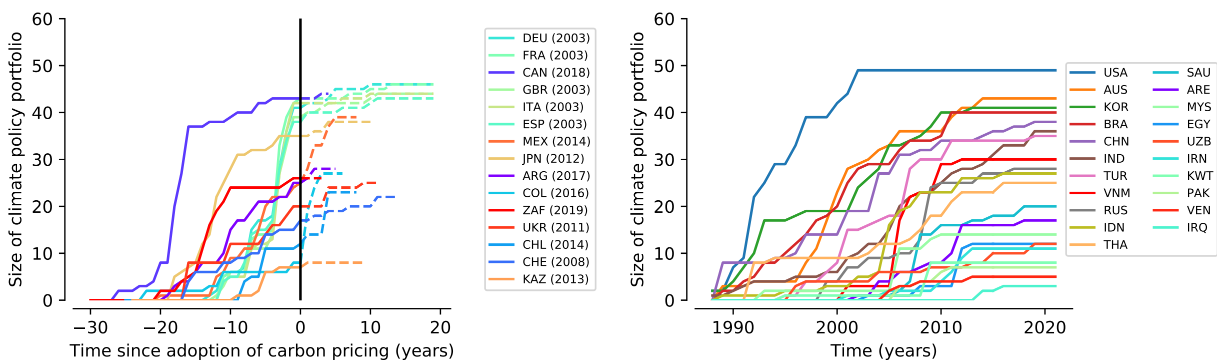

Figure 5. **Development of countries' climate policy portfolios over time**. Shown is the number of instrument type - sector combinations used in countries' policy portfolios.

This diversity of trajectories also means that the average time between the adoption of new instrument type - sector combinations and the adoption of carbon pricing systematically differs in the sample. For Canada, Japan, and South Africa, this average time is about 18, 13, and 14 years respectively. For Argentina and Switzerland, the corresponding values are 11 and 10 years respectively. For the current EU countries, the average time is about 5 years.

3.3 Policy portfolios of adopters versus non-adopters of carbon pricing

We next examine to what extent the size of countries policy portfolios can be considered a good predictor of the adoption of carbon pricing. To do so, we first compare the policy portfolios of countries that had adoped a carbon price by then end of 2020 with those that had not. At the time countries of the first group adopted carbon pricing, they had used on average 29.5 instrument type - sector combinations (Figure 5a). We then contrast this number with the size of portfolios of countries without a national carbon price. By the end of 2020 those countries had used policies with on average about 23.9 instrument type - sector combinations (Figure 5b). In 2015, which is the average year of adoption of carbon pricing, they had used on average about 19.7 combinations.

To compare countries that adopted carbon pricing in a given year with those that did not more systematically, we match countries based on a random assignment. This has the advantage that we also consider countries as possible control countries that had not adopted carbon pricing in year t but adopted it in year t' with $t < t' < 2020$. For inference, we calculate bootstrapped confidence intervals (Section 2). We find that countries that adopted a carbon price in a given year had policy portfolios that were on average about 11.12 instrument type-sector combinations larger than the portfolios of those that did not. This difference is significant at a confidence level of $\alpha = 0.05$. Overall, countries that adopted carbon pricing in a given year hence tended to have significantly larger climate policy portfolios than those that did not.

As a robustness test, we also estimate a logit model with the adoption of carbon pricing as binary dependent variable and different sets of explanatory variables. As for the matching, we find a statistically significant positive association between the size of the policy portfolio and the adoption of carbon pricing (Table A2 in the Appendix). Results of a Lasso estimation suggest that the size of portfolio and the prevalence of gas reserves are the strongest determinants of the adoption of carbon pricing. As we include additional control variables, the estimated coefficient of the size of the portfolio becomes smaller and less significant. This suggests that at least part of the positive association is due to country characteristics that influence both the size of the policy portfolio and the adoption of carbon pricing.

3.4 Heterogeneity among adopters of carbon pricing

The results above suggest that the size of climate policy portfolios is positively associated with the probability of adopting carbon pricing in a given country in a given year. One possible explanation is that policies other than carbon pricing allow countries to remove barriers to a subsequent adoption of carbon pricing. To further illuminate this explanation we attempt to explain differences in the size of policy portfolios at the time of adoption of carbon pricing with a linear regression model with variables possibly influencing some of these barriers or acting as confounders in the analysis. That is, we estimate a model with the size of policy portfolio at the time of adoption as dependent variable and GDP per capita, education, control of corruption, and the prevalence of fossil fuels in a country as explanatory variables. To examine trends over time, we also include the year of adoption in the model. Because or the high number of variables relative to the number of observations, we also estimate a reduced model and use a Lasso model for variable selection.

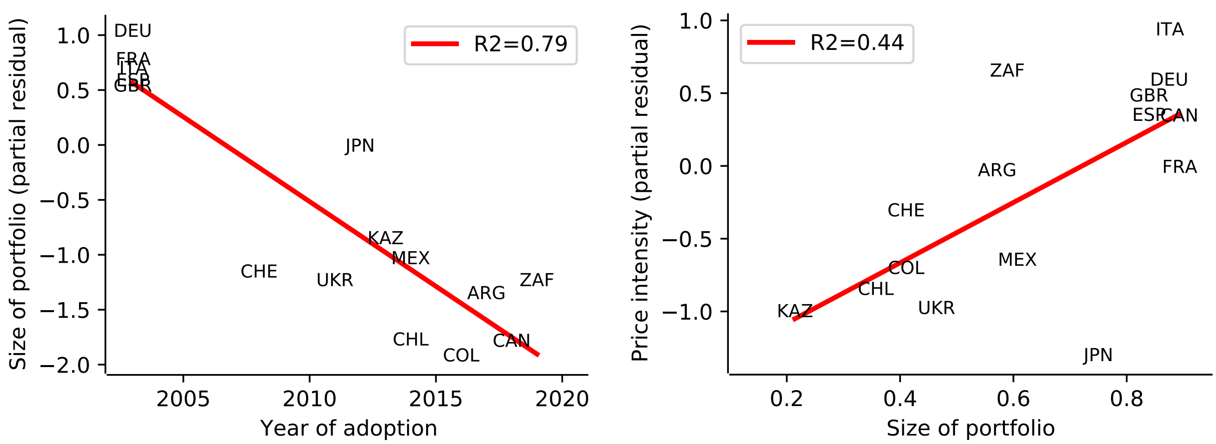

Figure 6. **Scatterplots of statistical associations between the year of the adoption of carbon pricing, the size of climate policy portfolios in that year, and the average carbon price in the first year of implementation**; to control for several variables including GDP per capita and reserves of fossil fuels, the figure shows partial residuals of the model in Column 2 (left) and Column 6 (right) in Table A3 in the Appendix.

We use this model to examine certain patterns in the data. Specifically, we find that after controlling for country characteristics the size of policy portfolios at the time of adopting a carbon price has decreased over the last 20 years (Figure 6 left). For example, when Canada adopted a national carbon price in 2019, its policy portfolio was substantially smaller than France's portfolio in 2003, after controlling for several country characteristics. This pattern is robust to different model specifications (Table A3 in the Appendix). Visual inspection also suggests that this pattern is relatively robust to dropping possible outliers. For example, it can also be identified if the group of EU ETS countries is considered as one observation or dropped from the sample (Figure 6 left).

We next regress the average carbon price of the first year of implementation on the size of countries' policy portfolios, controlling for the same country characteristics as in the previous regression. The carbon price is calculated as an economy-wide average price using information on the price level and the coverage from the World Bank. We find a positive association, meaning that countries with a larger policy portfolio at the time of adoption tended to implement carbon prices with higher price levels (Figure 6 right). A notable outlier is Japan which implemented a relative low price given its relatively large policy portfolio. The pattern is again robust to the different model specifications (Table A3 in the Appendix) but appears overall less significant and less robust to dropping individual countries from the sample (Figure 6 right).

4 Discussion and Conclusions

While carbon pricing is only one of many policy instruments to achieve internationally agreed climate targets, economic theory and empirical evidence on its effectiveness (Andersson, 2019; Mideksa, 2021; Green, 2021) suggest an important role for it in future national climate policy portfolios. The relationship between carbon pricing and other climate policies is generally multifaceted. Specifically, alternative instrument types can be considered as second-best substitutes of first-best policies (Bennear and Stavins, 2007; Fischer et al., 2021), complementary instruments that target different market failures (Bertram et al., 2015; Bataille et al., 2018; Stiglitz, 2019), and as instruments that remove barriers to a first-best policy (Meckling et al., 2017; Pahle et al., 2018).

Here we contribute empirical evidence on this latter idea of climate policy sequences preceding carbon pricing by examining policy adoption of G20 economies and other large emitters focusing on countries that eventually adopted a carbon price. Our analysis also builds on previous more normative work on the benefits of alternative instrument types (Peñasco et al., 2021) and policy mixes (van den Bergh et al., 2021) including complementarities between carbon pricing and other instruments (Bertram et al., 2015), and more generally improves our understanding of climate policy adoption by examining its temporal dimension. Furthermore, we contribute to debates around the political economy of carbon pricing, and the feasibility of climate policy more broadly (for example, Klenert et al. (2018); Dolphin et al. (2019); Levi et al. (2020); Ostry et al. (2021)).

Our results for the first time provide quantitative and international empirical evidence on how countries have built up their portfolios over time before eventually adopting a national carbon tax or permit system. The results suggest that carbon pricing was indeed adopted relatively late in countries individual policy sequence. Furthermore, we find qualitatively different trajectories of how countries built up their climate policy portfolios over time. While some countries did so gradually, other countries implemented national carbon pricing at the end of a quick expansion of their portfolios. A third group of countries expanded their portfolios quickly but then waited several years before eventually adopting a national price on carbon. We suspect that these more gradual or sudden expansions of portfolios reflect a country's exposure to and relative timing of domestic and international events, domestic barriers to a a carbon price, and whether carbon pricing was part of a long-term climate strategy before its adoption.

Furthermore, we find that countries that adopted a carbon price in a specific year tended to have significantly larger climate policy portfolios than those that did not adopt carbon pricing. Because this methodology is not able to control for all possible confounders, we do not consider the relationship between policy portfolios and the adoption of carbon pricing as necessarily causal. Nevertheless, we illustrate in Figure 1 how the results are generally consistent with the idea that certain barriers to carbon pricing can be removed with other climate policies.

Examining heterogeneity among adopters of carbon pricing, we find large variation in the size of countries' policy portfolios at the time of adoption. Furthermore, over the last 20 years the size of these portfolios appears to have declined. We note that this pattern is consistent with generally declining abatement costs and international influences including the international diffusion of technological innovation (Dechezleprêtre et al., 2011; Barrett, 2021) and growing economic opportunities for green technologies (Yamazaki, 2017). Furthermore, previous research suggests that policies themselves diffuse internationally as countries learn and mirror each other (Fankhauser et al., 2016; Thisted and Thisted, 2020).

Furthermore, we find that countries that had larger climate policy portfolios at the time they adopted a carbon pricing policy tended to implement an overall higher initial economy-wide average carbon price. Our results are therefore also consistent with the idea that climate policies prior to the adoption of a pricing policy can pave the way for higher stringency. This is especially important because prior evidence suggests that carbon prices tend to be relatively sticky (Dolphin et al., 2019).

Motivated by these insights, we find that several countries including some of the worlds' largest emitters of GHG have reached the stage at which other countries went on to adopt a price on carbon, in terms of the instrument types of implemented policies (Figure A2 in the Appendix). This could mean that those countries have exhausted the extensive margin of their climate policy portfolios in terms of sectors and instrument types other than carbon pricing, leaving essentially three avenues for future climate policy: higher stringency of existing policies, additional policies of existing sector and instrument type combinations, and carbon pricing as the last step in the sequence.

Our results suggest important avenues for future empirical research. Because of data limitations, we are not able to examine the experience of some of the earliest adopters of carbon pricing. As data collection efforts are ongoing, future research might focus on these countries. Furthermore, we expect that early climate policies not only lower barriers for the adoption of a pricing policy but also likely influence its effectiveness (Kriegler et al., 2018; Roelfsema et al., 2018). This influence on effectiveness might be in addition to the effect of prior policies on the initial price level that we report here. For example, broad sectoral coverage of mitigation policies can address emission leakage of pricing policies (Rajagopal, 2017). Future research might explore how the size of climate policy portfolios influences the reductions in GHG emissions obtained with a certain carbon price.

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A Supplementary Information

Causality and the empirical framework

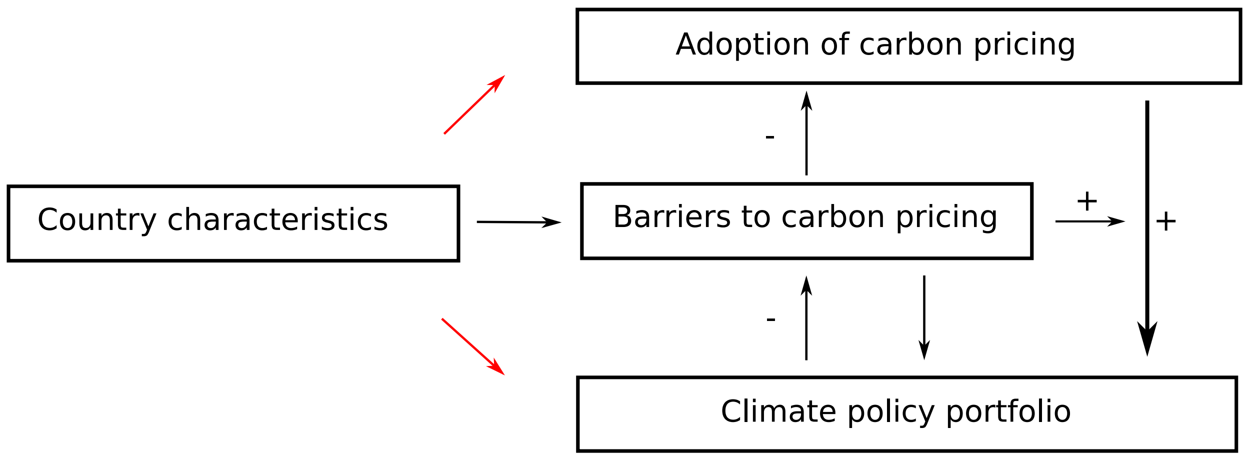

Figure A1. **Causal diagram with possibly confounding country characteristics**. The red arrows indicate how country characteristics can confound the statistical association between the climate policy portfolio and the adoption of a carbon pricing policy due to an influential variable that is omitted in a linear regression.

Descriptive statistics

Table A1. Descriptive statistics of country characteristics included in the regression analyses for all countries in the sample of G20 economies and other major emitters (see Table A4) covering the years 1988-2020. Sources are listed in Section 2.

Variable	Unit	Mean	Std.	Min.	Max.	No. obs.
log GDP per capita PPP	2010 USD	9.19	1.29	5.99	11.28	1188
Control of corruption	index	0.17	1.05	-1.60	2.15	1188
Education	index	0.65	0.16	0.20	0.94	1188
Reserves of coal	tons per capita	307.01	822.58	0.00	6702.82	1188
Reserves of gas	thousand cubic metres per capita	112.65	323.93	0.00	3541.63	1188
Reserves of oil	cubic metres per capita	419.63	1371.79	0.00	9586.25	1188

Results from regression analysis

Table A2. Results of a logistic regression on the adoption of carbon pricing (binary variable). Standard errors in parentheses (clustered at country level). All models are estimated with Maximum Likelihood. The variable selection of the reduced models in Column 4 is obtained with a Lasso model with shrinkage parameter $\alpha = 0.1$. Size of portfolio is measured as described in Section 2. Significance as follows: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Dependent variable:	Adoption of carbon pricing			
Explanatory variables:	Treatment	All	Selected	Lasso
Column:	1	2	3	4
log GDP per capita PPP		0.4495	0.5640*	
		(0.8221)	(0.3402)	
Coal reserves		-1.2343	-0.5379	
		(1.4830)	(0.5035)	
Oil reserves		-1.5461		
		(1.1937)		
Gas reserves		-0.0085*	-0.0073	-0.0108
		(0.0044)	(0.0084)	(0.0157)
Control of corruption		-1.1384		
		(0.8139)		
Education		19.0651***		
		(6.0125)		
Policy portfolio	0.1072***	0.0485	0.0808***	0.0994***
	(0.0245)	(0.0338)	(0.0221)	(0.0242)
Intercept	-4.4354***	-20.3759**	-8.8369***	-3.9841***
	(0.7497)	(8.1861)	(3.3383)	(0.7238)
Ps. R2	0.33	0.51	0.39	0.35
AIC	641.66	479.73	595.02	625.47
No. countries	36	36	36	36
N	1188	1188	1188	1188

Table A3. Results of linear regression on the size of climate policy portfolio at the time of adoption of a national carbon pricing policy. Robust standard errors in parentheses. All models are estimated with OLS. The variable selection of the reduced models in Columns 4 and 8 is obtained with a Lasso model with shrinkage parameter $\alpha = 0.1$. Size of portfolio is measured as described in Section 2. Carbon price at implementation is calculated as an economy-wide average price. The positive coefficient of oil reserves in Columns 2-4 becomes insignificant if Canada is dropped from the sample, consistent with the results by Best and Zhang (2020). Significance as follows: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Dependent variable:	Size of portfolio at time of adoption				Carbon price at implementation			
Explanatory variables:	Treatment	All	Selected	Lasso	Treatment	All	Selected	Lasso
Column:	1	2	3	4	5	6	7	8
log GDP per capita PPP		-0.3065	-0.3598			-0.0551	0.3032	
		(0.6389)	(0.3817)			(0.4820)	(0.2632)	
Coal reserves		-0.2631	-0.4717***	-0.3787***		0.1396	0.0563	
		(0.3648)	(0.1061)	(0.0904)		(0.2898)	(0.1056)	
Oil reserves		0.6041**	0.4866**	0.3336***		-0.1718	-0.1624**	-0.1193
		(0.2159)	(0.1808)	(0.0669)		(0.1832)	(0.0571)	(0.0722)
Gas reserves		-0.9966				0.3461		
		(1.0017)				(0.9932)		
Control of corruption		-0.1574				0.5966		0.3323**
		(0.3191)				(0.3191)		(0.1357)
Education		0.1547				-0.2415		
		(0.1926)				(0.1894)		
Policy portfolio					0.5960***	0.4805*	0.4957**	0.3960**
					(0.1507)	(0.2066)	(0.1577)	(0.1320)
Year of adoption	-0.5067**	-0.9301*	-0.9112**	-0.6283***				
	(0.2043)	(0.4650)	(0.3138)	(0.1679)				
Intercept	-0.0336	0.0176	0.1769	0.0722	-0.1687	-0.0713	-0.1265	-0.1332
	(0.1883)	(0.1798)	(0.1281)	(0.1873)	(0.1959)	(0.3606)	(0.2123)	(0.2012)
R2	0.27	0.76	0.71	0.66	0.42	0.66	0.53	0.58
N	15	15	15	15	15	15	15	15

Policy portfolios by the end of 2020

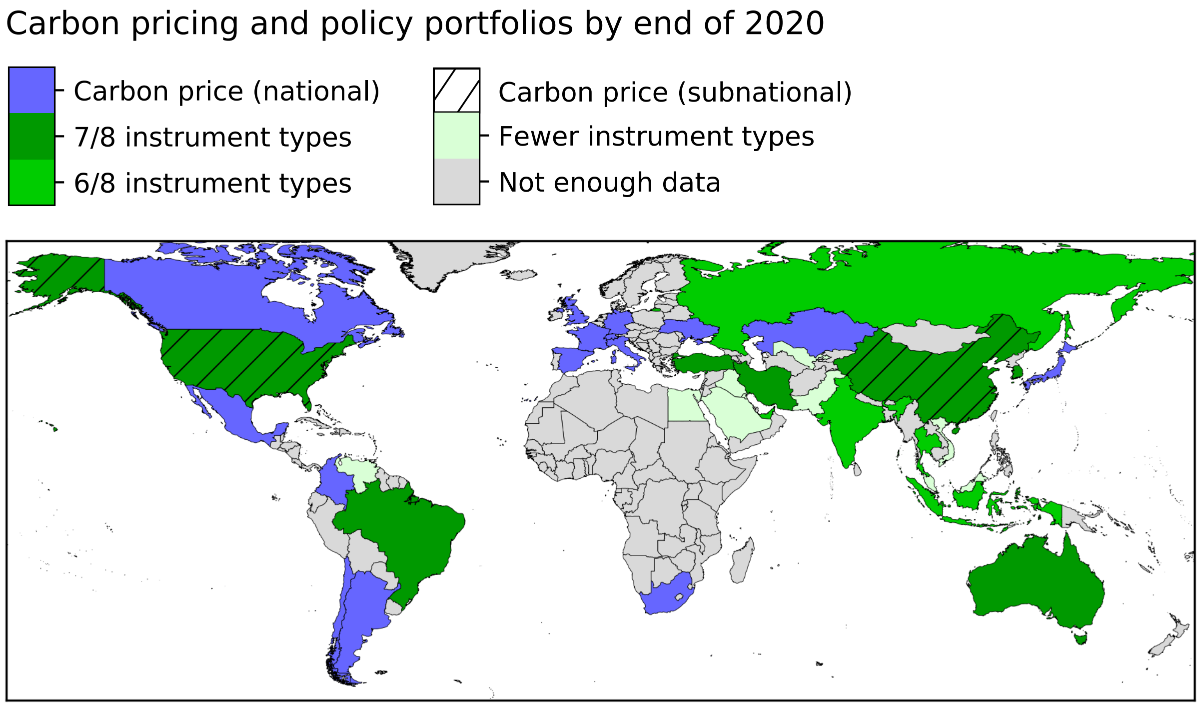

Figure A2. **Carbon pricing policies and the number of instrument types in countries' policy portfolios**. Map shows the policy portfolios as of end of 2020. Number of instrument types only shown for countries without a carbon price at the national level.

Sample of countries

Table A4. List of countries included in the main analysis and their carbon pricing policies by the end of 2020. Sectors: E = Electricity and Heat Production, I = Industry, B = Buildings, T = Transport, A = AFOLU.

			Carbon pricing, first adoption		Carbon pricing, sectors				
ISO code	G20	Other major emitter	National	Subnational	E	I	B	T	A
ARG	Yes		2018		X	X	X	X	X
AUS	Yes								
BRA	Yes								
CAN	Yes		2019	2007	X	X	X	X	X
CHN	Yes			2013					
DEU	Yes		2005		X	X		X	
FRA	Yes		2005		X	X		X	
GBR	Yes		2005		X	X		X	
IDN	Yes								
IND	Yes								
ITA	Yes		2005		X	X		X	
JPN	Yes		2012		X	X	X	X	X
KOR	Yes								
MEX	Yes		2014		X	X	X	X	X
RUS	Yes								
SAU	Yes								
TUR	Yes								
USA	Yes			2009					
ZAF	Yes		2019		X	X	X	X	
ARE		Yes							
CHE		Yes	2008		X	X	X	X	
CHL		Yes	2017		X	X			
COL		Yes	2017		X	X	X	X	X
EGY		Yes							
ESP		Yes	2005		X	X		X	
IRN		Yes							
IRQ		Yes							
KAZ		Yes	2013		X	X	X		
KWT		Yes							
MYS		Yes							
NIG		Yes							
PAK		Yes							
THA		Yes							
UKR		Yes	2011		X	X	X		
UZB		Yes							
VEN		Yes							
VNM		Yes							

Table A5. List of countries not included in the main analysis because of insufficient data on policy adoption, but which had a national carbon price implemented by the end of 2020.

				Carbon pricing, first adoption		Carbon pricing, sectors				
ISO code	G20	Other major emitter	EU ETS	National	Subnational	E	I	B	T	A
SGP				2019		X	X			
HRV			Yes	2013		X	X		X	
ISL			Yes	2013		X	X	X	X	X
LIE			Yes	2008		X	X	X	X	
NZL				2008		X	X		X	X
BGR			Yes	2007		X	X		X	
ROU			Yes	2007		X	X		X	
AUT			Yes	2005		X	X		X	
BEL			Yes	2005		X	X		X	
CYP			Yes	2005		X	X		X	
CZE			Yes	2005		X	X		X	
EST			Yes	2005		X	X		X	
GRC			Yes	2005		X	X		X	
HUN			Yes	2005		X	X		X	
IRL			Yes	2005		X	X		X	
LTU			Yes	2005		X	X		X	
LUX			Yes	2005		X	X		X	
MLT			Yes	2005		X	X		X	
NLD			Yes	2005		X	X		X	
PRT			Yes	2005		X	X		X	
SVK			Yes	2005		X	X		X	
LVA			Yes	2004		X	X			
SVN			Yes	1996				X	X	
DNK			Yes	1992				X	X	
NOR			Yes	1991		X	X	X	X	X
SWE			Yes	1991				X	X	
FIN			Yes	1990			X	X	X	
POL			Yes	1990		X	X	X	X	X

Instrument types and sectors

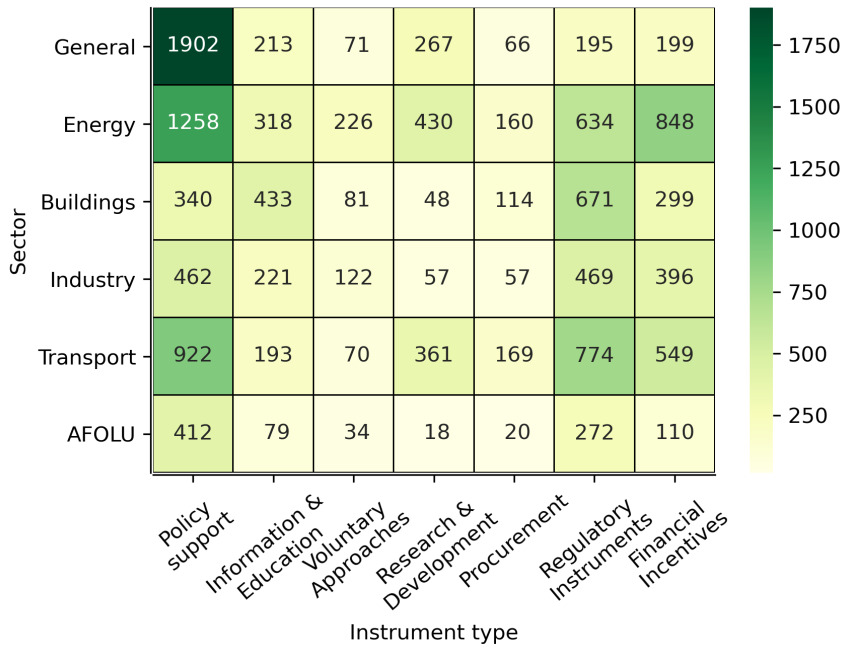

Figure A3. **Frequency of instrument types in different sectors.** Heatmap is based on all policies adopted by countries in the sample. Notes: AFOLU = Agriculture, Forestry, and other Land Use.

Instrument types and instrument categories

Table A6. List of instrument categories, their instrument type, and their frequency in the sample of 37 countries.

Instrument type	Instrument category	Number
Grants, subsidies, other fin. incentives	Grants and subsidies	342
Grants, subsidies, other fin. incentives	Tax relief	191
Grants, subsidies, other fin. incentives	Feed-in tariffs or premiums	128
Grants, subsidies, other fin. incentives	Loans	96
Grants, subsidies, other fin. incentives	Fiscal or financial incentives (other)	91
Grants, subsidies, other fin. incentives	Energy and other taxes	74
Grants, subsidies, other fin. incentives	GHG emission reduction crediting and offsetting mechanism	43
Grants, subsidies, other fin. incentives	GHG emissions allowances	42
Grants, subsidies, other fin. incentives	Market-based instruments (other)	34
Grants, subsidies, other fin. incentives	Tendering schemes	28
Grants, subsidies, other fin. incentives	Net metering	19
Grants, subsidies, other fin. incentives	other CO2 taxes	19
Grants, subsidies, other fin. incentives	Economic instruments (other)	16
Grants, subsidies, other fin. incentives	Retirement premium	11
Grants, subsidies, other fin. incentives	User charges	8
Grants, subsidies, other fin. incentives	Removal of fossil fuel subsidies	1
Information and Education	Information provision	315
Information and Education	Advice or aid in implementation	172
Information and Education	Endorsement label	78
Information and Education	Comparison label	69
Information and Education	Professional training and qualification	39
Information and Education	Information and education (other)	29
Information and Education	Green certificates	27
Information and Education	Performance label (other)	14
Information and Education	White certificates	13
Information and Education	Barrier removal (other)	1
Policy Support	Strategic planning	692
Policy Support	Institutional creation	177
Policy Support	Policy support (other)	153
Policy Support	Political & non-binding climate strategy	72
Policy Support	Political & non-binding GHG reduction target	67
Policy Support	Political & non-binding renewable energy target	62
Policy Support	Formal & legally binding renewable energy target	43
Policy Support	Formal & legally binding climate strategy	40
Policy Support	Formal & legally binding GHG reduction target	39
Policy Support	Political & non-binding energy efficiency target	29
Policy Support	GHG reduction target (other)	21
Policy Support	Formal & legally binding energy efficiency target	20
Policy Support	Renewable energy target (other)	20

Table A7. List of instrument categories, their instrument type, and their frequency in the sample of 37 countries (cont.).

Instrument type	Instrument category	Number
Policy Support	Coordinating body for climate strategy	18
Policy Support	Target (other)	12
Policy Support	Energy efficiency target (other)	7
Policy Support	Climate strategy (other)	3
Procurement and investment	Infrastructure investments	123
Procurement and investment	Procurement rules	62
Procurement and investment	Funds to sub-national governments	44
Procurement and investment	Direct investment (other)	18
Regulatory Instruments	Other mandatory requirements	192
Regulatory Instruments	Monitoring	178
Regulatory Instruments	Product standards	129
Regulatory Instruments	Sectoral standards	115
Regulatory Instruments	Regulatory Instruments (other)	100
Regulatory Instruments	Building codes and standards	99
Regulatory Instruments	Vehicle fuel-economy and emissions standards	93
Regulatory Instruments	Obligation schemes	88
Regulatory Instruments	Auditing	75
Regulatory Instruments	Codes and standards (other)	58
Regulatory Instruments	Grid access and priority for renewables	29
Regulatory Instruments	Industrial air pollution standards	3
Regulatory Instruments	Vehicle air pollution standards	2
Research, Development and Deployment	Technology deployment and diffusion	131
Research, Development and Deployment	Technology development	112
Research, Development and Deployment	Demonstration project	108
Research, Development and Deployment	RD&D funding	93
Research, Development and Deployment	Research & Development and Deployment (RD&D) (other)	72
Research, Development and Deployment	Research programme (other)	11
Voluntary Approaches	Negotiated agreements (public-private sector)	153
Voluntary Approaches	Public voluntary schemes	25
Voluntary Approaches	Voluntary approaches (other)	23
Voluntary Approaches	Unilateral commitments (private sector)	9

PUBLICATIONS

Policy Sequencing Towards Carbon Pricing
Working Paper No. **WP/2022/066**