Policy sequencing refers to the idea that the adoption of some policies enables or supports the subsequent adoption of other policies. In the field of climate policy, it has been proposed that certain policies can be used to remove barriers to later, more stringent policies. Possible barriers include high abatement costs, their distribution in society, insufficient institutions and concerns about free-riding. Policy sequencing is one theory that can explain the observed diversity of policy instruments and their combinations in climate policy, in addition to the simultaneous presence of several market failures and theories of second-best substitutes of first-best policies.

Evidence on the sequencing of climate policies can provide important orientation for policymakers and inform expectations about future policy adoption. This is especially relevant for countries without stringent climate policies. However, not much is known about the extent to which policy sequencing actually describes the adoption of climate policies in different socio-economic contexts, possibly because data have been sparse. The richest evidence on climate policy sequencing has been reported for Germany and California and for two climate policies in the European Union, suggesting that sequencing successfully reduced barriers to higher stringency. In addition, evidence for the energy and transport sectors shows that countries tend to adopt regulatory instruments and subsidies before pricing policies.

The concept of climate policy sequencing is generally applicable to a variety of instrument types and not restricted to a specific emission sector. For example, positive externalities of green technological innovation can be addressed with public funding for research and development, eventually lowering abatement costs. Lower abatement costs, in turn, can make more stringent policies more politically acceptable. Public goods properties of infrastructure can be addressed with public investments facilitating private low-carbon choices, which can similarly lower the costs of abatement and political resistance.

Political opposition to stringent climate policies can generally also be addressed through grants and subsidies that support the growth of a green sector, broadening the support base for climate policy. Furthermore, standards on environmental performance can provide long-term orientation and help coordinate private investments in the development of green technologies.

In this study, we examined sequences of climate policies covering all emission sectors and all climate policies for 37 countries, including all G20 economies. Furthermore, we studied the relationship between policy sequences and subsequent carbon pricing policies. We focused on countries that adopted either a national carbon tax or a country-wide emission trading system (ETS) between 2000 and 2020, and we combined an international dataset of climate policies with a comprehensive dataset on carbon pricing policies (World Bank Carbon Pricing Dashboard). We aggregated the 72 instrument categories of the original dataset to eight different instrument types, and we distinguished between five sectors. We used a variety of statistical methods, including matching and linear regression.

We first provide descriptive evidence on policy sequences in terms of instrument types based on pairwise conditional empirical frequencies. We found relatively similar sequences across sectors and countries. This is especially true for the relative position of carbon pricing, which tends to be the last instrument type in most sectors and in most countries.

We next examined the statistical associations between countries’ climate policy sequences and their adoption of carbon pricing policies. To do so, we quantified the length of policy sequences using the number of instrument types of policies adopted by a country prior to carbon pricing. For every country, we focused on those sectors that were eventually targeted with a carbon price. We found that in all sectors more than half of all countries used the majority of the other seven instrument types prior to carbon pricing.
Early adopters of carbon pricing.

Excluding this group of relatively highly developed countries and

Fig. 3. We found similar results with a regression analysis in which

Tends to have longer policy sequences than those that do not. We

Control for different sets of country characteristics previ-

We found large variations across counties, in the year in which they adopted carbon pricing with the year of

Hypothesis (Fig. 2b). Specifically, we found that countries that adopted carbon pricing had already implemented on average 1.49 instrument types more than countries that did not adopt carbon pricing in the same year. The difference is the largest for transport (3.09), followed by especially long sequences in energy and transport (Extended Data Fig. 2).

Economists have promoted carbon pricing for many decades, but

If policy sequences matter for the adoption of carbon pricing, we expect that countries that adopt carbon pricing in a given year will tend to have longer policy sequences than those that do not. We used a matching algorithm and found evidence consistent with this hypothesis (Fig. 2b). Specifically, we found that countries that adopted carbon pricing had already implemented on average 1.49 instrument types more than countries that did not adopt carbon pricing in the same year. The difference is the largest for transport (3.09), followed by especially long sequences in energy and transport (Extended Data Fig. 2).

Carbon pricing (CP)

Regulatory instruments (RI)

Grants, subsidies and other financial incentives (GS)

Procurement and investment (PI)

Research, development and deployment (RD)

Voluntary agreements (VA)

Information and education (IE)

Policy support (PS)

Fig. 1 | Climate policy sequences of countries with a carbon price. Policy sequences derived from pairwise conditional frequencies: earlier instrument types were adopted earlier more often than later instrument types in all sectors and countries in the sample (Methods). The sampling criteria are the adoption of carbon pricing between 2000 and 2020 and the availability of data on climate policies. For a visualization of the sample of countries, see Extended Data Fig. 1. Countries are indicated by ISO three-letter country codes.

Bars to the adoption of carbon pricing, such as relatively high abatement costs, might eventually also affect the stringency of those pricing policies. To test this hypothesis, we examined the statistical association between the length of policy sequences in the year of the first adoption of a national carbon pricing policy and the stringency of that policy. We measured the stringency with the emission-weighted economy-wide average carbon price in the first year of implementation. We found that countries with longer policy sequences tended to implement carbon pricing policies with higher average carbon prices (Fig. 2d). Again, we found that the result is robust to alternative model specifications (Supplementary Table 6). We found the same pattern if we focused on specific sectors for energy and industry (Supplementary Tables 7 and 8).

Even though the relatively small number of countries with carbon pricing policies prevents us from identifying unequivocally causal relationships, our results provide suggestive evidence that policy sequences have played an important role in the adoption of carbon pricing policies and their initial stringency. These policy sequences prior to carbon pricing extended over long periods, on average 20 years in our sample—time horizons over which a gradual removal of barriers appears plausible. We suspect that the decline of the length of these sequences between 2000 and 2020 can be at least partially explained by an international diffusion of technologies and demonstration effects.

Regarding our result that countries with longer policy sequences tended to adopt pricing policies with higher average carbon prices, a possible explanation is that earlier policies might have allowed for emission reductions at relatively low costs, reflected in a higher carbon price for a similar effectiveness. An alternative explanation is that countries have used carbon pricing policies in a sense as substitutes for longer policy sequences. This is reflected, for example, in terms of the number of permits or in replacing free permits with auctioned permits over time.

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Online content

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Methods

Data
We used data on climate policies from the Climate Policy Database (https://climatepolicydatabase.org), which provides to our knowledge the most comprehensive international dataset on climate policies. The dataset is based on other international datasets, reports and country-specific documents, and it 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 and the Organisation for Economic Co-operation and Development policy instruments database. The dataset can generally be considered complete for G20 economies (including EU member countries that are individual members of the G20, but not other EU members) and 18 other countries. For these countries, climate policies have been systematically collected, and the dataset has gone through a validation with national stakeholders and experts. The non-G20 counties are mostly advanced and emerging economies in Europe, Asia and Latin America but also encompass some less-developed countries and two countries in Africa (Extended Data Fig. 1).

Every policy in the dataset carries information on policy objectives, administrative level, instrument types, targeted sectors and more. We dropped all policies that do not have climate change mitigation as one of their objectives. This applied to around 7% of the policies in the sample. We examined these policies in more detail and found that around 65% of these policies can be expected to have substantial co-benefits for climate change mitigation. In a robustness test, we therefore kept this subset of policies. The results are qualitatively and quantitatively almost identical (Supplementary Fig. 2; other figures are available upon request). Furthermore, we neglected any policies at the subnational level and applied all EU policies to the member countries’ policy portfolio. If a country became a member after the policy was decided in the EU, we used the year of joining the EU as the date of policy adoption.

We aggregated the 72 instrument categories into seven instrument types based on the instrument typology of the International Energy Agency (Supplementary Table 3). We distinguished among the five sectors of the IPCC AR5 WGIII (electricity and heat production; transport; buildings; industry; and agriculture, forestry and other land use) and one additional sector, general, for policies that do not target specific sectors. We used the Carbon Pricing Dashboard of the World Bank to define carbon pricing policies in the climate policy data and for information on their coverage in terms of GHG emissions and price levels.

We obtained country characteristics 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 can be found in Supplementary Table 1.

Policy sequences
The eight instrument types resulted in 40,320 possible sequences. To identify policy sequences, we first considered all possible pairs of instrument types. For each of these 28 pairs, we examined which of the two instrument types tends to be adopted first across sectors and countries. We then used the relative timing of these pairs to construct the overall sequence.

This can be expressed with conditional frequencies. We considered the adoption of policies with two different instrument types as events $X$ and $Y$. We examined the conditional frequency of event $Y$ preceding event $X$ across countries and sectors:

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

with the number of times an event is observed in the data denoted as $n(\cdot)$. We then derived the relative order of all possible pairs of instrument types by comparing $f(Y_{t-1}|X_t)$ and $f(Y_{t-1}|X_t')$. Because we were interested in existing policies at the time of decision of a new policy, we excluded all observations after an event is observed for the first time (that is, after the first time a specific instrument is adopted in a specific sector in a specific country).

Policy sequences at the time of adoption of carbon pricing
For the additional statistical analysis, we quantified the length of climate policy sequences for every country and for every year on the basis of that country’s climate policy portfolio, similar to prior work that has quantified, for example, the intensity of all climate policies implemented by a country. We measured the length of the climate policy sequence of a given country in a given year using the average number of the eight instrument types that a country has used prior to a given year in the different sectors. This yielded a number between 0 and 8 for every country and every year. We also calculated this number for individual sectors. We complemented this information with a range of control variables informed by prior work: GDP per capita, education, control of corruption and the fossil fuel reserves of a country.

We compared the length of climate policy sequences of countries that adopted a national carbon price in a given year with the length of sequences of countries that did not adopt a carbon price by the same year. We refer to the first group of countries as treated countries and to the second group as control countries. We matched every treated country with one control country. We assigned every treated country a randomly chosen control country and iterate this random assignment 1,000 times. We then compared the average length of the policy sequences of treated countries with the average length of policy sequences of the control countries. For inference, we calculated confidence intervals with Monte Carlo simulations in which we intentionally ignored the distinction between treated and control countries. For robustness, we also estimated a logit model with the adoption of carbon pricing as a binary dependent variable, which allowed us to include certain country characteristics as control variables. The results of the logit model are presented in Supplementary Table 5.

Heterogeneity among adopters of carbon pricing
We estimated a linear regression model with our measure of policy sequences at the time of adoption as the dependent variable, a set of control variables, and the year of adoption of carbon pricing as the explanatory variable. We also estimated a more parsimonious model with only selected explanatory variables, for which we chose GDP per capita and the reserves of fossil fuels. Because reserves of oil and gas are highly correlated, we included only reserves of coal and reserves of oil in this model. Furthermore, we used lasso model selection to identify the most important explanatory variables. Lasso estimation optimizes 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 examined the association between the policy sequence at the time of implementation of a pricing policy and the economy-wide average carbon price. To this end, we estimated a similar linear regression model with the average carbon price as the dependent variable. The results of these regressions are reported in Supplementary Table 6.

Data availability
All data are publicly available and were obtained from the following sources: climate policy data, https://climatepolicydatabase.org (CC-BY-NC 4.0); data on carbon pricing policies, https://carbonpricedashboard.worldbank.org/ (CC-BY 4.0: https://datacatalog.worldbank.org/public-licenses); data on education from the Human Development

Nature Climate Change
Indicators, https://hdr.undp.org/en/data (Creative Commons Attribution 3.0 IGO: https://hdr.undp.org/terms-use); data on GDP per capita and control of corruption, https://data.worldbank.org/ (CC-BY 4.0: https://datacatalog.worldbank.org/public-licenses); data on fossil fuel reserves, https://www.eia.gov/ (public domain: https://www.eia.gov/about/copyrightsReuse.php).

Code availability
A replication package is available at https://github.com/mlinzze/climate-policy-sequences.

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Author contributions
M.L., A.M. and G.S. designed the research. M.L. collected and analysed the data. M.L., A.M. and G.S. wrote the manuscript.

Competing interests
The authors declare no competing interests.

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Extended Data Fig. 1 | Sample of countries included in the analysis. Map shows whether the data on climate policies can be considered complete. See also Supplementary Table 2. Basemap adapted from World Bank Official Boundaries under a Creative Commons license CC BY 4.0.
Extended Data Fig. 2 | Length of climate policy sequences at the time of adoption of the first carbon pricing policy. The histograms show the cumulative percentages of countries that used the given number of instrument types in the corresponding sector before they adopted their first carbon pricing policy.