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Climate change policies and technologies: diffusion and interaction with institutions and governance

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Abstract

Climate change is a global-scale structural change, affecting economies across the world, alongside global fragmentation, digitalisation and demographics. This paper analyses the diffusion of climate policies and technologies and the role of institutions and governance in that process. It discusses theory, models and data available to date, and the empirical evidence for the 20 European Union and all 40 countries covered by the OECD's Environmental Policy Stringency index. The results indicate that institutions and governance have significant effects towards a greater speed and spread of diffusion of climate policies and technologies, and that separating the speed and spread effects is essential for assessing the green transition.

Keywords: adaptation, mitigation, renewability, sustainability, transition
JEL codes: E02, O11, Q20, Q55, Q58

Non-Technical Summary

While changes in local climate have been observed since ancient times, the study of climate change as a global phenomenon is relatively recent, with its roots in the 19th century. Since then, however, helped by the development of models and methods to solve them since the 1970s, research into climate change, its causes and consequences as well as how to combat and slow it down, has intensified. Nowadays, climate change is widely acknowledged to be a key challenge for humanity that may require action at all levels - individual, local, regional, national and global with participation of both private and public sectors, as well as academia.

The challenges from climate change are becoming progressively more acute. The data show that the change in trends of temperatures and atmospheric conditions are materialising with increasing clarity. At the same time, extreme weather events and episodes are snowballing in intensity, frequency and duration, and are affecting greater and greater areas of the planet. Critically, the speed and spread of climate change increasingly appears to be such that it is now experienced and observable within a human lifetime and all around the world.

The key concern in relation to climate change is, of course, how soon (and with what speed) the challenge may be tackled. The logic behind this concern is very simple - the faster and more comprehensive the response, the sooner the challenge can be addressed, and the greater the chances of the consequences being contained and subdued before becoming cataclysmic and causing fundamental changes to the planet's capacity of sustaining life as we know it.

Two aspects relevant for possible action against climate change are being considered in this paper - climate change policies and technologies. Climate change technologies can be related to renewable energy, more efficient use of energy, to the reduction of energy requirements or greener methods for achieving goals. Climate change policies include taxes and subsidies on certain types of energy or emissions, as well as rules and regulations relating to the environmental impact of human activities.

The paper follows a distinction usually being made between policies and technologies that are about mitigation and those that are about adaptation. Mitigation is about limiting climate change, or at least controlling it, while adaptation is about coping and dealing with the fallout from climate change. The reason for the distinction is that speed and spread of diffusion may differ between mitigation and adaptation efforts, and so may the respective role of institutions and governance.

The paper tries to assess how fast and how far those policies and technologies are diffusing, and to what extent this depends on institutions and governance. This is because efficient and high quality institutions and governance have been found to be beneficial in a number of ways, and so might be expected to be beneficial also in the struggle for a stable climate. A better understanding of the role that institutions and governance play may help to step up the efforts against climate change and increase the chances of succeeding in slowing or even reversing the process.

The paper finds - for the 20 European Union and all 40 countries covered by the OECD's Environmental Policy Stringency (EPS) index - that higher quality of institutions and governance tend to be associated with a greater speed of diffusion as well as greater spread of climate policies and technologies, and that distinguishing the speed and spread effects is important in estimating the green transition. Institutions and governance may help to preserve the climate but it is worth noting that even in advanced countries they are often developing slowly and, in many cases, massively curtailed.

1 Introduction

Climate change is a global-scale structural change, affecting advanced and developing economies worldwide, alongside global fractionalisation, digitalisation and population demographics. While changes in local climate have been observed since ancient times, the study of climate change as a global phenomenon is relatively recent, with its roots in the 19th century. Since then, however, and helped especially by the development of models and methods to solve them since the 1970s, research into climate change, its causes and consequences as well as how to combat it and slow it down, has intensified.

Climate change is now widely acknowledged as a key challenge for humanity, requiring action at individual, local, regional, national, and global levels. Although climate change is affecting the entire planet, its economic effects are very different across the globe, as noted for example by Krusell and Smith Jr (2022), thus giving rise to inequalities that contribute to the intricate political economy of climate change.

The global reference point for the corresponding efforts is the United Nations Framework Convention on Climate Change (UNFCCC), established in 1992, and parent treaty for the 1997 Kyoto protocol (setting emission targets for the period 2008-2012 relative to 1990), the 2012 Doha amendment (setting emission targets for 2013-2020), and the 2015 Paris agreement (establishing targets to limit maximum global warming) adopted at the corresponding meetings of its top decision-making body, the Conference of Parties (or COP).

The key concern in relation to climate change is, of course, the speed at which this challenge is being addressed. This paper focuses on that concern, by modelling and estimating the diffusion of both climate change policies and technologies[1], for both adaptation and mitigation[2]. The paper employs the term 'policies' to denote what in the texts on climate change is often referred to as 'policies and measures' (or PaMs). Adaptation includes the analysis and monitoring of climate change, and the building of defences and resilience against climate change. Mitigation is about making human activity climate-neutral, or at least reducing the climate imprint of humanity[3].

The working hypothesis of this paper is that there are cross-country differences in the diffusion of climate change policies and technologies (CCPs and CCTs, respectively, or CCPTs), and their adaptation and mitigation facets (CCAPs/CCATs and CCMPs/CCMTs, respectively) and that those differences may be traced to structural features in general, and institutions and governance in particular. In order to test this hypothesis, the paper uses a standard model of diffusion, applies it to indicators of climate change policies and technologies, and obtains results

[1]The domains of the UNFCCC's adaptation committee and technology mechanism, the Climate Technology Centre and Network, CTCN.

[2]Covered, respectively, in work streams 2 and 3 of the Intergovernmental Panel on Climate Change (IFCC), the key body for climate change analytics in the international institutional architecture.

[3]A further distinction could be made between ex-ante mitigation (such as preserving nature/natural habitats) and ex-post mitigation (such as carbon storage) but this is outside the scope of this paper.

for the 20 European Union and all 40 countries covered by the OECD's Environmental Policy Stringency (EPS) index, given the relevance of that index in policy discussions..

One of the advantages of the paper is that it considers both CCPs and CCTs, both mitigation and adaptation, both specific and a composite indicator, and how institutions and governance affect their development. Another advantage is that it uses a data set with a wide distribution of countries, thus enabling a cross-country or at least cross-grouping comparisons.

The paper also offers a larger set of results than prepared for and reported in the report of the 2022-2023 ESCB Expert Group on Productivity (see ESCB Expert Group on productivity, innovation and technological change (2024b), specifically box 2), for the climate workstream of which this paper was initiated.[4] The set of further results reported here are notably for the EPS as an additional measure of CCPTs and alternative variables for institutions and governance, in order to identify their most important aspects.

The paper is structured as follows. Theory and models of diffusion when applied to climate change policies and the interplay with institutions and governance are reviewed in Section 2. The data and data sources for climate change policies and technologies, and the corresponding caveats are presented in Section 3. The methodology and estimated equations are detailed in Section 4 and the results reviewed in Section 5. The conclusions follow in Section 6.

2 Theory and Models

This section is devoted to the theory and models of diffusion that may be applied to CCPTs (Section 2.1), including the specificities of that application (Section 2.2), the connection to the green transition (Section 2.3), as well as the role that may be played in the diffusion of CCPTs by institutions and governance (Section 2.4).

2.1 The Diffusion of Climate Policies and Technologies

As far as technologies and innovation in general are concerned, models of diffusion have been explored for some time, with the seminal work including Bass (1969) and Rogers (1962). They suggest that the diffusion curve of a technology follows an S-shape, owing to mechanisms that entail a gradual pick-up over time, the speed of which initially picks up, then reaches a turning point, before converging to a specific level before potentially turning downwards.[5] As pointed out in Baccianti et al. (2022), the heterogeneity of agents is a key factor driving the S-shape of diffusion curves - see Young (2010) and references therein to the early models of contagion[6] and

[4]The results in the report are based on a different sample of countries. In this paper, the sample consists of the 20 European and all 40 countries covered by the EPS.

[5]For a study of different diffusion models applied to technology see also Comin and Hobijn (2010), Geroski (2000) or Jaakkola (1996). The papers of Baccianti et al. (2022), Labhard and Lehtimäki (2022) and Hoffreumon and Labhard (2022) apply the model presented in the seminal papers to digital technologies.

[6]For example Bass (1969) and Mahajan and Peterson (1985).

social influence and social learning[7] as the source of the heterogeneity and the resulting diffusion patterns.

While the simple diffusion model has been developed in a specific context, the application to such a wide variety of diffusion processes shows that the model and its underpinnings are quite general. The model is also parsimonious and, therefore, practical in situations where data availability remains limited. The generality, parsimony and practicality of the model are also advantages over the alternatives, including the other relative common approach of Comin and Hobijn (2004) and Comin and Hobijn (2010).

The Bass (1969) diffusion model has also been previously applied to study CCTs. A number of applications are listed for example in Kulmer et al. (2022), such as electricity (Lee and Huh, 2017) and electric vehicles (van der Kam et al., 2018), solar energy (Dong et al., 2017; Kurdgelashvioli et al., 2019; Guidolin and Mortarino, 2010), wind energy (Xu et al., 2016) or renewable energy more broadly (Devezas et al., 2008).[8] As noted by Kulmer et al. (2022), the typical S-shape does not always show in the data. This does not necessarily imply that the diffusion process is fundamentally different; it may simply indicate that the sample period is too short, or the policy or technology too short-lived, for the entire S-curve to be observed or having unfolded.

As for the diffusion of CCPs, there is an extensive literature in political science, as reviewed for example recently by Blatter et al. (2022) who stress learning, competition, emulation and coercion as the key mechanisms identified in that literature, as discussed and researched inter alia in Braun and Gilardi (2006), Gilardi and Wasserfallen (2019), Graham et al. (2013), Margetti and Gilardi (2016), Shipan and Volden (2008), Simmons et al. (2006), Volden et al. (2008) and Walker (1969). They propose a set of four types of diffusion paths as a coherent conceptual framework, interest-driven ones (based on exchange of information or externalities), rights-driven ones (hierarchy-based or conditionality-based), ideology-driven (by principled or policy beliefs) and recognition-driven (policy expertise or expert attention).

2.2 The Appropriate Diffusion Model

As noted in Section 2.1, there are a number of existing applications of the S-curve diffusion model to climate policies and technologies. Still, it might be argued that the diffusion of CCTs and CCPs may be rather specific. In this section, we review a few points that may be raised in connection to this issue, taking in turn the frequently-cited financing aspect - the importance of financial resources and firms' challenges in financing green investment - and the often-noted obsolescence brought about by green investment.

[7] See for example Schelling (1971, 1978), Granovetter (1978) and Granovetter and Soong (1988).

[8] There is a large literature on how to promote the diffusion of climate change technologies, for example Hall and Helmers (2011) for CCTs in general, and Dechezleprêtre et al. (2011) and Dechezleprêtre et al. (2008) for CCMTs. Another interesting angle is whether technologies may be a substitute for policies, as suggested by Barrett (2021), which will be discussed in Section 2.4.

The financing aspect is frequently noted as a key element holding back green investment and the adoption of CCTs. The financing and insurance gaps are well-known and considerable, and arguably much greater than in the case of other technologies or policies. The elements that would contribute to the closing of those gaps are numerous and equally well-known - including the re-targeting of taxes and subsidies, the enhancements to capital market access and functioning, especially venture capital, as well as the strenghening of strutural charcteristics. They are in fact a salient feature of innovation in general and of technological revolutions, such as the introduction of digital and climate technologies, in particular.

Another often noted aspect is the obsolescence brought about by green innovation. As the adoption of climate technologies proceeds, other technologies may become obsolete. The extent to which this happens is going to depend on the extent to which the CCTs and other technologies act as substitutes or complements. In this respect, CCTs could be considered similar to the digital technologies that are discussed in Anderton and Cette (2021), Anderton et al. (2020) and ESCB Expert Group on productivity, innovation and technological change (2024a). In both cases, certain types of capital and labour are going to be replaced, and the installation of new capital and the creation of new jobs can potentially take more time than the scrapping of old capital and obsolete jobs.

This suggests that the basic diffusion model may also be expected to provide a useful characterisation of the diffusion of climate technologies and policies, although parameters, notably those relating to the curvature of the S-curve, may be different. If climate-related technology and policy constitutes a revolution, and if in the context of such revolutions the initial delay is substantial and the subsequent pick-up fast, this would translate into a more pronounced curvature of the diffusion curve, with a more delayed but then swifter acceleration in adoption.

2.3 The Connection to the Green Transition

To some extent, recent developments in CCTs and CCPs can also be attributed to the concept of the green transition, which refers to the transformation of economies, industries, and societies towards environmentally sustainable practices. It broadly refers to a shift from fossil fuel based systems to sustainable, low-carbon technologies and has become a major global trend during this decade and implies a fundamental reconfiguration of production systems, energy infrastructures and economic value creation, with major implications for global economic relations.

Many of these developments can be attributed to demographic and political economy aspects, as governments and researchers have observed the increasing effects of climate change and have attempted to create policy mechanisms that can accelerate technological innovation through economic incentives while managing disruptions to existing industrial structures.

When it comes to the literature, political economy aspects of the associated technological innovation, economic restructuring and global governance often concentrate on the political economy of green energy, but Besley and Persson (2023) study it from the viewpoint of consumption patterns, market failures and government failures and Söderholm (2020) from the policy challenges encountered when pursuing sustainable technological change.

2.4 The Interplay with Institutions and Governance

The contributions noted in Section 2.1 tend to stress the context in which policy diffuses, notably the international context or 'other polities', in the terminology of political science. Specifically on CCPs, some of those mechanisms are explored by Schoenefeld et al. (2022) for CCAPs and Linsenmeier et al. (2022) or Dolphin and Pollitt (2021) for CCMPs. In essence, the mechanisms are similar to those identified in the literature on technology diffusion, and equally founded in heterogeneity, i.e. all actors not all actors acting alike. Both technology and policy adopters are learning from one another, influencing another, or being influenced by one another. In fact, the influential political science contribution by Kingdon (1984) has highlighted the fact that several forces may interact and superimpose in the policy diffusion process.

One of the forces determining how technologies and policies diffuse is the framework or setting within which policies and technologies diffuse, and a key element of that, or so the hypothesis is in this paper, are institutions and governance. Indeed, that element may play a role in particular in the transition risks (see ESCB Expert Group on productivity, innovation and technological change (2024b)).

3 Data

This section describes the data used in this paper, including general aspects in Section 3.1, the data on CCPTs in Section 3.2, the data on institutions and governance in Section 3.3 and control variables in Section 3.4. Except for the data on CCPTs, the data correspond to those also used in Baccianti et al. (2022) and Labhard and Lehtimäki (2022), for the reasons outlined there, including notably the availability of long time and cross-section dimensions. A listing of all the countries and country groupings in the sample can be found in Appendix A and all series codes and transformations for all the data used in Appendix B.

3.1 Sources, Sample and Countries

The data used in this paper are compiled mainly from the databases of the World Bank and OECD. The sample extends from 1996 to 2020, providing $T = 25$ points of annual data. The panels are constructed based on the country coverage of the EPS, with the EU countries panel consisting of $N = 20$ countries and the full panel of $N = 40$ countries.

3.2 Climate Change Policies and Technologies

In contrast to climate change itself, large-scale data on climate-related policies and technologies are still relatively rare, and can potentially be difficult to interpret. This is not to say that initiatives to bring together and classify relevant data do not exist, as for example the mitigation/adaptation-related measures among the set of climate-change-related indicators and statistics put together for example by the Conference on European Statistics (CES).[9]

While data availability has slowly been improving, there is no shortage of remaining challenges. There may be a limited challenge of mislabelling (if confined to CCPTs), which can also become serious if it reflects greenwashing. Another general challenge may be the tendency, if not fallacy, to work on data that are available, thus putting the spotlight on (proxies for) CCPTs that are not the most approriate for the assessment of the question at hand.

Moreover, specific data are subject to specific challenges. Data on expenditures, taxes and subsidies, for example, tend to be measured as per cent of GDP, and a given percentage could be owed to the tax rate (i.e. policy), but also the tax base.[10] Further, data on expenditures, taxes and subsidies also say little about their impact.[11] Finally, expenditures, taxes and subsidies may be calibrated on concerns that are unrelated to climate change, such as the need for and/or ease of spending/collection.

The data used in this paper for CCPTs are compiled from the databases of the World Bank and OECD, in both cases ensuring cross-country comparability. The OECD is the source of the series for specific technologies and policies as well as the EPS index, which has the advantage of complementing the specific series for CCPs with a more encompassing measure of CCPs, and of being a measure that is commonly used in policy discussions and evaluations. It is a country-specific and internationally comparable measure of the stringency of environmental policy. Stringency refers to the extent to which environmental policies impose an explicit or implicit price on polluting or environmentally harmful behaviour. The World Bank is the source of the data on CO2 emissions.

The four series for specific technologies and policies are the following: Environmental technology patents and climate-related technology patents are used as indicators for CCATs and CCMTs. The use of patents data as a measure for technological innovations is standard. Patents data have the advantage of being leading indicators, thus enhancing predictive (and possibly explanatory) power. The de jure diffusion signalled by patents though does not necessarily translate into de facto diffusion, or does so with a substantial delay, which may be a drawback

[9] The CES indicators and statistics include 3 for CCAPs ('expenditure', 'land under productive vs sustainable use', 'green spaces urban'), 4 for CCMPs ('expenditures', 'energy and transport-related taxes', 'climate adaptation/mitigation-related subsidies', 'carbon trading price'), 1 for CCATs ('water use efficiency'), and 1 for CCMTs ('renewable energy share in energy use and consumption').

[10] There is a similar issue in relation to carbon prices which could be high because of low supply of certificates owing to CCPs or high demand for certificates for continued emissions.

[11] There is a similar issue regarding patents which are counted but may have a wide variety of impacts depending on the specific technology and how it is used.

of these series.

These series are complemented by CO2 emissions and environmentally-related taxes as series for CCAPs and CCMPs. The emissions series has been chosen because of its direct link to trading schemes and emission limits. Lower emissions, all else being equal, suggest a greater diffusion of climate change policies. It should be noted that this variable is measuring the supposed realised effects of policies rather than the policies themselves. The tax series, by contrast, reflects policies directly, with higher taxes tantamount to a greater diffusion.

The EPS, compiled and published by the OECD, is a composite index made up of in total 14 series.[12] The purpose of the EPS is to provide a measure of the restrictiveness of policy-induced opportunity cost of environmentally-relevant behaviours. It covers market-based policies (predominantly taxes), non market-based policies (essentially limits on emissions), technology support and adoption support policies. It is calibrated to be between 1 and 6, with the value of 1 indicating the lowest and the value of 6 the highest possible policy stringency. Full details on the EPS may be found in Dechezleprêtre et al. (2022) for the current version in use since 2022, and for the former version in Botta and Kozluk (2014). The descriptive statistics of all the series are listed in Table 1.

Table 1: Descriptive statistics of variables capturing CCPTs

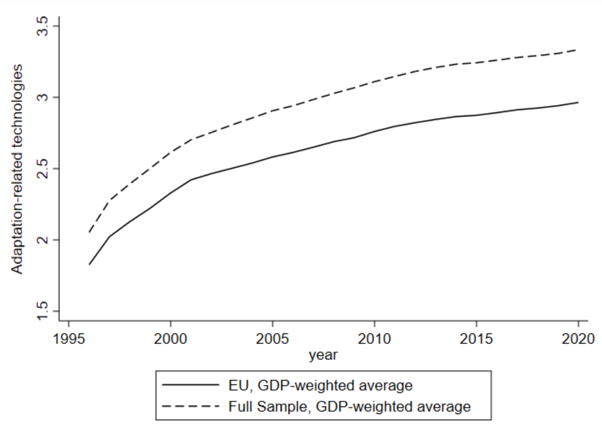
Variable	Mean	SDev	Min	10th	90th	Max
EU countries						
CCAT (patents, log)	6.30	1.52	0.00	4.43	8.15	9.63
CCMT (patents, log)	8.07	1.61	3.43	5.98	10.20	12.34
CCAPs (emissions, log)	2.09	0.36	1.11	1.15	2.49	3.25
CCMPs (taxes, pct)	2.74	0.70	1.20	2.04	3.66	5.36
EPS (composite indicator)	2.51	0.95	0.06	1.28	3.71	4.89
All countries						
CCAT (patents, log)	6.96	1.96	0.00	4.79	9.53	11.97
CCMT (patents, log)	8.62	2.90	0.00	6.08	11.38	14.11
CCAPs (emissions, log)	1.95	0.60	-0.23	1.23	2.70	3.25
CCMPs (taxes, pct)	2.41	0.88	-1.53	1.32	3.46	5.36
EPS (composite indicator)	2.04	1.15	0.06	0.50	3.61	4.89

Notes: 'Mean' is the arithmetic mean, 'SDev' the standard deviation, 'Min' the minimum, '10th' the 10th, '90th' the 90th percentile, 'Max' the maximum. The sample is 1996 to 2020. The country groupings are detailed in Table A.1 in Appendix A, the variables in Table B.1 in Appendix B.
Sources: OECD, World Bank, authors' calculations.

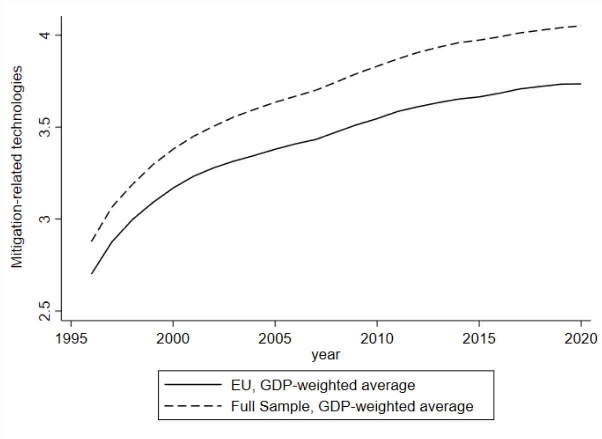
[12] The 14 series in the EPS are 'CO2 Trading Scheme', 'Renewable energy Trading Scheme', 'Carbon Dioxides (CO2) Tax', 'Nitrogen Oxides (NOx) Tax', 'Sulphur Oxides (SOx) Tax', 'Diesel Tax', 'Emission limit value NOx', 'Emission limit value SOx', 'Emission limit value PM', 'Emission limit value sulphur', 'Technology Support Policies', 'Low-carbon R expenditures', 'Wind Energy support (Auctions and FITs)' and 'Solar Energy support (Auctions and FITs)'.

Figure 1: The diffusion of Climate Change Technologies and Policies

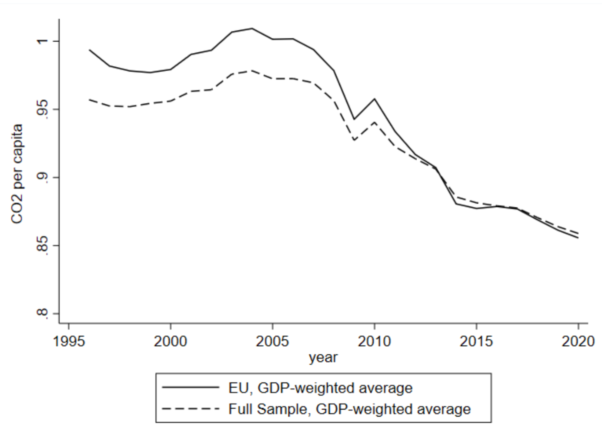
(a) CCAT



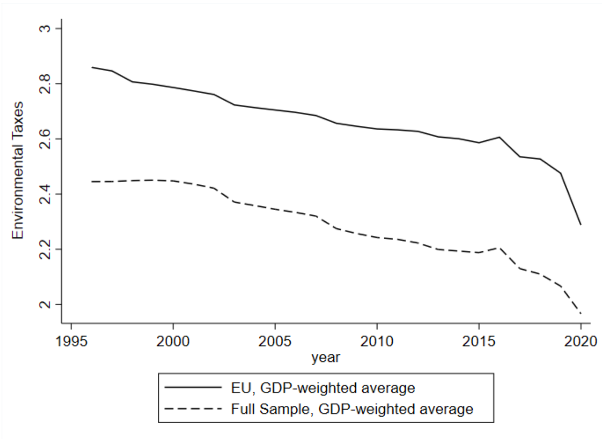
(b) CCMT



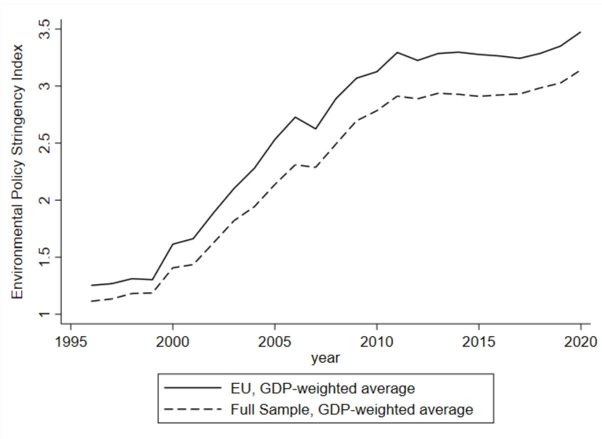
(c) CCAP



(d) CCMP



(e) EPS



As documented in Table 1, the EU countries tend to have fewer CCATs/CCMTs than other countries in the sample if measured by patents, and also more stringent policies according to the EPS as well as higher CCAPS and CCMPs on the basis of CO2 emissions and environmentally-related taxes, respectively. For all CCPTs though the dispersion tends to be smaller in the EU countries which could be an indication of more heterogeneity in the process or more generally among the EU countries relative to the other countries. The diffusion patterns are illustrated for both country groupings in Figure 1 and, for each of the two country groupings along with the respective country grouping's maximum and minimum, in Figure B.1 in Appendix B.

3.3 Institutions and Governance

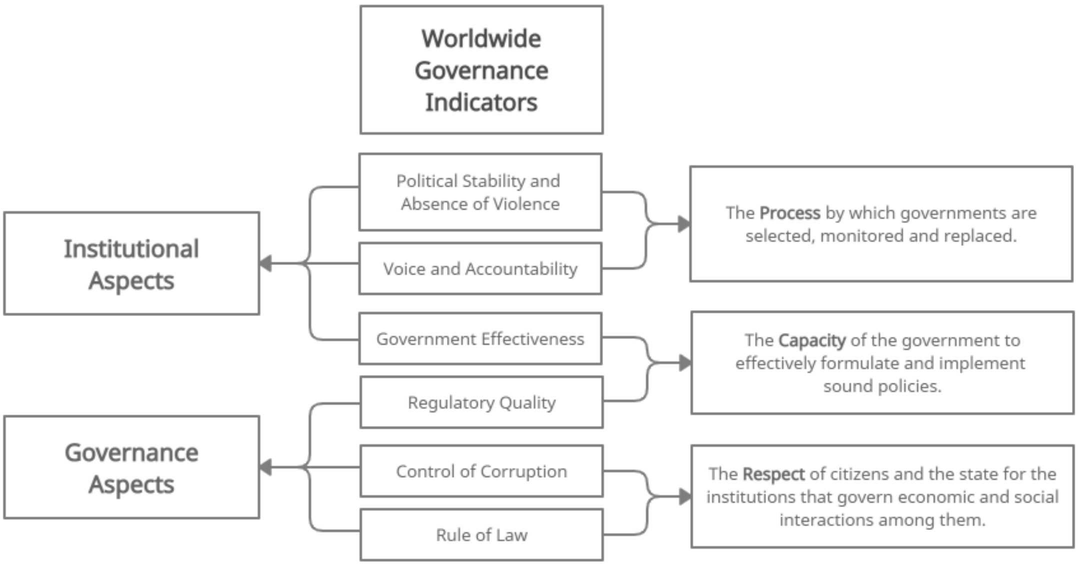
The data for institutions and governance are from the same sources as those in Baccianti et al. (2022) and Labhard and Lehtimäki (2022). They are based on data from the Worldwide Governance Indicators (WGI) described in Kaufmann et al. (2010), and published by the World Bank beginning in 1996.

The WGI consists of six distinct indicators. The 'control of corruption' indicator measures the abuse of public power for private gain and the influence and interference of elites and private interests. The 'government effectiveness' indicator captures the quality of public services, civil service, its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. The 'political stability and absence of violence' indicator measures the likelihood of violence, including terrorism. The 'regulatory quality' indicator measures the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development. The 'rule of law' indicator refers to the rules of a society, including contract enforcement, property rights, police and courts as well as the likelihood of crime and violence. Finally, the 'voice and accountability' indicator relates to the perceived participation in the selection of government, as well as freedom of expression, association and media.

As in Baccianti et al. (2022), the indicators 'government effectiveness', 'political stability and absence of violence' and 'voice and accountability' were averaged for 'Institutions' (the framework or structure) and the indicators 'regulatory quality', 'rule of law' and 'control of corruption' averaged for 'Governance' (how things are run given the framework or structure).[13] The relationships between the indicators available from the World Bank, those constructed by the authors and the three categories suggested by Kaufmann et al. (2010) are illustrated in Figure 2.

[13] In the absence of strong priors about the relative importance of the different aspects, averages were based on equal weights for all the indicators. As noted in Baccianti et al. (2022), this approach (and the WGI on which it is based) aims at aspects of institutions and says little if anything on the type of institution that may be most beneficial, a challenge inter alia for work aiming to identify which types of institutions are most conducive to enhancing growth, as noted e.g. in Dellepiane-Avellaneda (2010).

Figure 2: Worldwide Governance Indicators and the summary measures



Source: Baccianti et al. (2022, p.12), based on World Bank data and Kaufmann et al. (2010).

The descriptive statistics for different aspects of institutions and governance are provided in Table 2. The table shows that the EU countries score better than other countries for any aspect covered in the table, and also display greater homogeneity than the full sample. In fact, for every indicator, whether institutions and governance, or WGI Total, Process, Capacity or Respect, the maximum score is attributed to one of the EU countries while the minimum scores can be found for other countries in the sample.

Table 2: Descriptive statistics of institutional variables

Variable	Mean	SDev	Min	10th	90th	Max
EU countries						
Institutional aspects	1.15	0.36	0.23	0.66	1.62	1.86
Governance aspects	1.27	0.54	0.05	0.57	1.96	2.13
WGI total	1.21	0.44	0.16	0.64	1.77	1.97
Process (K1)	1.27	0.62	-0.03	0.41	2.07	2.23
Capacity (K2)	1.29	0.45	0.19	0.69	1.88	2.14
Respect (K3)	1.07	0.30	0.21	0.68	1.47	1.70
All countries						
Institutional aspects	0.88	0.69	-1.12	-0.26	1.60	1.86
Governance aspects	1.06	0.80	-0.90	-0.22	1.94	2.13
WGI total	0.97	0.74	-0.94	-0.22	1.76	1.97
Process (K1)	1.05	0.88	-1.05	-0.29	2.04	2.23
Capacity (K2)	1.10	0.68	-0.65	-0.01	1.83	2.14
Respect (K3)	0.75	0.71	-1.38	-0.40	1.46	1.70

Notes: ‘Mean’ is the arithmetic mean, ‘SDev’ the standard deviation, ‘Min’ the minimum, ‘10th’ the 10th, ‘90th’ the 90th percentile, ‘Max’ the maximum. The sample is 1996 to 2020. The country groupings are detailed in Table A.1 in Appendix A, the variables in Table B.1 in Appendix B.
Sources: World Bank, authors’ calculations.

3.4 Control Variables

This section is about the control variables included to account for factors other than institutions and governance that could play a role in the diffusion of CCPTs. The variables considered here follow Baccianti et al. (2022) and are real GDP (per capita), as an indicator of the broader state of development, and human capital. The descriptive statistics for the control variables are provided in Table 3. As the table shows, the differences between EU countries and other countries are relatively minor. The most notable differences relate to real GDP per capita, which is slightly higher in the EU and human capital, which varies somewhat more in non-EU countries.

Table 3: Descriptive statistics of control variables

Variable	Mean	SDev	Min	10th	90th	Max
EU countries						
Real GDP per capita	10.56	0.40	9.49	10.09	10.89	11.70
Human Capital, Education Index	0.81	0.07	0.63	0.68	0.89	0.95
All countries						
Real GDP per capita	10.33	0.67	7.71	9.51	10.92	11.70
Human Capital, Education Index	0.78	0.12	0.35	0.72	0.90	0.95

Notes: 'Mean' is the arithmetic mean, 'SDev' the standard deviation, 'Min' the minimum, '10th' the 10th, '90th' the 90th percentile, 'Max' the maximum. The sample is 1996-2020. The country groupings are detailed in Table A.1 in Appendix A, the variables in Table B.1 in Appendix B.
Sources: OECD, World Bank, UNDP, authors' calculations.

4 Methodology

In order to study the process of diffusion, this paper uses the contagion model, in other contexts sometimes called the 'epidemic' model of diffusion. As the name suggests, the origins of the model are in medical sciences, specifically epidemiology where it is used to predict contagion, endemics and pandemics given certain parameters (such as infection and recovery rates). It is commonly applied to the analysis of technology diffusion in economics (see for example Geroski (2000)).[14] The model is based on the logic that exposure or contact to technology is going to entail adoption of technology, with the speed of the process and its final point depending on past exposure and a number of other factors.

The model has the form:

$$\Delta s_{c,t} = \beta(\tilde{X}_{c,t})[\bar{s}_{c,t}(\bar{X}_{c,t}) - s_{c,t}], \tag{1}$$

which defines a law of motion in which $\Delta s_{c,t}$ is the change in the adoption rate in country c at time t, $\beta\tilde{X}_{c,t}$ is the speed of diffusion, $s_{c,t}$ is the saturation rate and $\bar{s}_{c,t}(\bar{X}_{c,t})$ is the long-run (saturation level of the) adoption rate, and the actual and the long-run saturation rate depend on country characteristics $\tilde{X}_{c,t}$ and $\bar{X}'_{c,t}$ respectively. Those sets of country characteristics can be different, as different sets of variables could drive the speed of convergence and the long-run saturation level.

The model in equation (1) generates an S-shape of (non-linear) adoption process over time that is reflected in the data (see Figure 3).[15] The rate of adoption picks up in the early stages

[14] The model has also been applied to other fields in economics, such as economic convergence (alpha convergence, in terms of levels). An alternative approach, incorporating technology diffusion into a neoclassical growth model, is taken by Comin and Hobijn (2010).

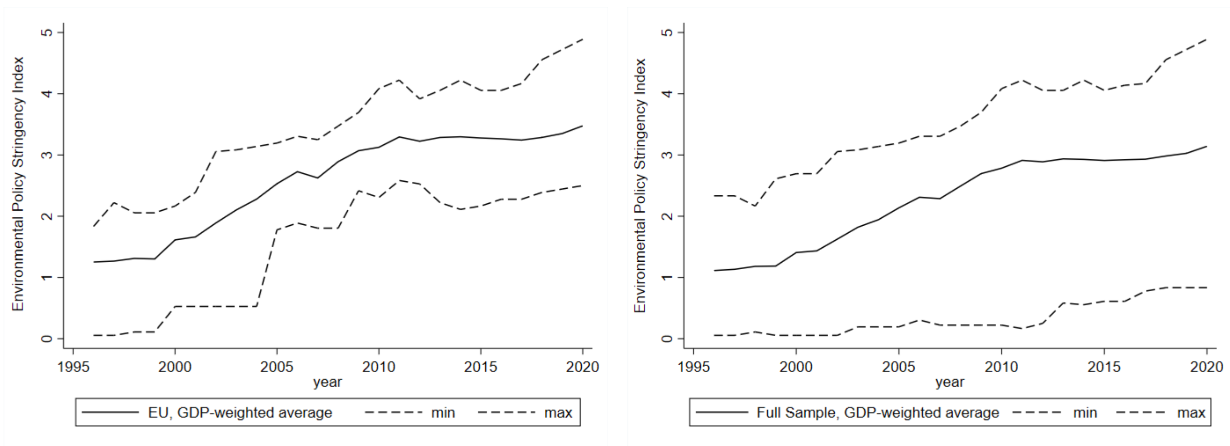
[15] A technical comparison and analysis of diffusion models and the shapes they generate in the context of technology diffusion can be found in Jaakkola (1996).

of adoption and slows down in the later stages as the adoption rate approaches a long-term saturation level. In the model the key role in the diffusion process is the exposure to the technology, which is initially limited, and then increases, up to the point where exposure has no further effects as the technology has already been adopted by most of the agents who are not 'immune' to it.

Figure 3: Diffusion of CCPs

(a) EPS, EU countries

(b) EPS, all countries



Source: World Bank, authors' calculations.

This pattern of the adoption rate is also consistent with network effects - the fact that the benefits of a technology are higher with a greater spread of that technology. These network effects do not have any obvious analogy in the other contexts in which the model is being used. However, they are important in the context of technology diffusion and support the logic of an S-shaped (non-linear) adoption process over time, and are another reason for the choice of this particular model for the empirical analysis in this paper. As with most technologies, the speed of adoption picks up in the early stages and in the later stages slows down as the adoption rate approaches the long-term saturation level.

In the empirical implementation, both the speed of technology and policy diffusion and the steady-state adoption rate are allowed to depend on institutions and governance. Results are shown both for a specification in which institutions and governance affect only the steady-state adoption rate, i.e. $\tilde{X}_{c,t} = f(X_{c,t}^{INST})$ and $\bar{X}_{c,t} = f(X_{c,t}^{INST}, X_{c,t}^{CCVAR})$, and for a specification in which they affect both the steady-state adoption rate and the speed of diffusion, i.e. $\tilde{X}_{c,t} = f(X_{c,t}^{INST}, X_{c,t}^{CCVAR})$ and $\bar{X}_{c,t} = f(X_{c,t}^{INST}, X_{c,t}^{CCVAR})$. The econometric approach is chosen to study the initial fast increase of climate change technologies and policies, which slows down as the more efficient ones are further developed, the discovery of completely novel ones becomes less frequent and the levels converge towards a long-term saturation level, which can be observed in Figure 1.

In the first case, the estimated equation is:

$$\Delta X_{c,t}^{CCVAR} = \beta_1 X_{c,t-1}^{CCVAR} + \beta_2 X_{c,t-1}^{INST} + \beta_3 X_{c,t-1}^{C}, \tag{2}$$

where $\Delta X_{c,t}^{CCVAR}$ is the change in the adoption rate in country c at time t, $X_{c,t-1}^{CCVAR}$ is the adoption rate at time $t-1$, $X_{c,t-1}^{INST}$ is the term capturing institutions and governance at time $t-1$ and $X_{c,t-1}^{C}$ is the set of control variables, also at time $t-1$. In the other case, the estimated equation is:

$$\Delta X_{c,t}^{CCVAR} = \beta_1 X_{c,t-1}^{CCVAR} + \beta_2 X_{c,t-1}^{INST} + \beta_3 X_{c,t-1}^{C} + \beta_4 (X_{c,t-1}^{CCVAR} * X_{c,t-1}^{INST}) \tag{3}$$

where the terms with coefficients β_1, β_2 and β_3 are the same as in equation (2), and the added term with coefficient β_4 captures the effect of the interaction of the climate change variable with institutions and governance on the speed of diffusion.

The control variables in $X_{c,t-1}^{C}$ in equations (2) and (3) are the same. Real GDP per capita is used to control potential income and economic development effects in the diffusion process, and human capital to capture the capability of the population for adopting new technology or policies. The two variables intend to control for economic key factors in the process of technological change outside the aspects under focus in this study.

Turning to the expected signs, the two control variables are likely to have positive signs, suggesting a positive effect on the steady-state diffusion rate in the medium and longer term. Real GDP per capita captures the fact the better-off countries may find it easier to fund investment into digital technologies and/or to facilitate its installation as well as improved opportunities for dedicating resources to advancing green transition technologies and policies. This should, ultimately, support their spread. Human capital is complementary to new technologies and policies (including climate change aspects), and so should also show a positive coefficient. The more humna capital is available, the more likely it is that new technologies are explored, evaluated and eventually adopted.

As for the signs on institutions and governance, the expectation is for a positive effect on the steady-state adoption rate in the medium to long run, i.e. a positive coefficient on the corresponding lagged terms $X_{c,t-1}^{INST}$, and a positive effect on the speed of adoption, i.e. a negative coefficient on the interaction term $(X_{c,t-1}^{INST} * X_{c,t-1}^{CCVAR})$.[16] This is because, as noted in section 2.4, institutions and governance are considered key elements of the economic framework conditions that support technological advancement and innovation more generally.

[16]For equations (2) and (3), in the case of the lagged and interaction terms, a negative sign means a positive effect on the rate of technology or policy adoption; in the case of the other terms, a positive coefficient means a positive effect on the long-term level of adoption.

5 Results

This section turns to the results obtained when applying the methodology outlined in Section 4 to data for the countries covered by the EPS. Results are presented both for the entire cross-section of the EPS of 40 countries labelled 'All countries' as well as the subset of 20 'EU countries' for which data is available and covered by the index as detailed in Section 3.1. The results therefore are comparable across the different CCTs/CCPs and the different measures of CCTs and CCPs.

The results for specific CCPTs are analysed in Section 5.1, those for CCPs as captured by the EPS in Section 5.2, the relationship of CCTPs to the EPS is studied in more detail in Section 5.3. In Sections 5.1 to 5.3 the focus is on 'Institutions' and 'Governance' as discussed in Section 3.3. As it is also important to take proper account of the different facets of institutions and governance and, therefore, the results for the overall indicator 'WGI Total', as well as the 'Process', 'Capacity' and 'Respect' aspects described in Kaufmann et al. (2010) are discussed in Section 5.4 and are included in Appendix C, Tables C.1 to C.5.

Throughout Section 5, results are reported for the specification with one lag. The specifications with further lags - given the delays that might be expected in the diffusion process, as noted for example by Young (2010) - were checked and the results found to be qualitatively unchanged.

5.1 Specific Climate Change Policies and Technologies (CCPTs)

Focussing first on the results for CCTs (Tables 4 and 5, respectively), the results suggest that the diffusion process is indeed driven to some extent by institutions and governance, in relation to the speed and the spread. The equations show a very good fit overall, according to adjusted R^2 and F statistics. Institutions and governance are significant for the spread in 7 out of 8 cases for the EU countries, at least at a 10% significance level and 5 of 8 cases for the entirety of EPS countries. For the speed of diffusion, institutions and governance are statistically significant for 3 out of 4 cases for both studied samples. Among the control variables, real GDP enters significantly in all cases, and human capital in the case of the EU countries but not the entirety of EPS countries.

Table 4: CCATs (patents, environmentally-related technologies)

	EU countries				All countries			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Climate(-1)	-0.134***	-0.123***	-0.155***	-0.156***	-0.129***	-0.129***	-0.109***	-0.108***
	(0.017)	(0.016)	(0.020)	(0.024)	(0.017)	(0.017)	(0.017)	(0.021)
Institutions (-1)								
Institutions	-0.105***		-0.200**		-0.061**		0.066**	
	(0.030)		(0.074)		(0.026)		(0.030)	
Governance		-0.039*		-0.216***		-0.052**		0.061
		(0.019)		(0.070)		(0.021)		(0.047)
Interactions(-1)								
Climate			0.013				-0.018***	
x Institutions			(0.008)				(0.002)	
Climate				0.021***				-0.011***
x Governance				(0.006)				(0.004)
Controls (-1)								
Real GDP	-0.089***	-0.092***	-0.085***	-0.052*	0.152***	0.150***	0.090**	0.081*
	(0.025)	(0.025)	(0.026)	(0.029)	(0.034)	(0.036)	(0.034)	(0.044)
Human Capital	-0.112	-0.104	-0.066	-0.156	-0.375***	-0.330***	-0.302***	-0.274***
	(0.097)	(0.098)	(0.096)	(0.094)	(0.074)	(0.074)	(0.069)	(0.070)
Constant								
Constant	2.094***	1.984***	2.173***	1.864***	-0.193	-0.217	0.233	0.268
	(0.276)	(0.284)	(0.265)	(0.250)	(0.231)	(0.247)	(0.244)	(0.308)
Sample start	1996	1996	1996	1996	1996	1996	1996	1996
Sample end	2020	2020	2020	2020	2020	2020	2020	2020
Countries	20	20	20	20	40	40	40	40
N	480	480	480	480	960	960	960	960
F-stat	148.3***	135.9***	137.7***	121.8***	114.2***	111.8***	116.8***	104.7***
Adjusted R^2	0.88	0.87	0.87	0.86	0.84	0.83	0.84	0.83

Notes: Fixed Effect (cross-section weights) of the change in climate variable (dependent) on lagged climate variable, institutions and controls. White cross-section standard errors and covariance (d.f. corrected) in parentheses. *** significant at 1% level, ** significant at 5%, * significant at 10%. The country groupings are detailed in Table A.1 in Appendix A, the variables in Table B.1 in Appendix B.

Table 5: CCMTs (patents, climate-change technologies)

	EU countries				All countries			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Climate(-1)	-0.127***	-0.112***	-0.152***	-0.158***	-0.120***	-0.116***	-0.106***	-0.107***
	(0.020)	(0.020)	(0.026)	(0.032)	(0.020)	(0.020)	(0.020)	(0.023)
Institutions (-1)								
Institutions	-0.128***		-0.288***		-0.075***		0.023	
	(0.034)		(0.078)		(0.025)		(0.037)	
Governance		-0.025		-0.328***		-0.045**		0.009
		(0.022)		(0.109)		(0.018)		(0.049)
Interactions(-1)								
Climate			0.018***				-0.011***	
x Institutions			(0.005)				(0.002)	
Climate				0.030***				-0.004
x Governance				(0.009)				(0.003)
Controls (-1)								
Real GDP	-0.098***	-0.107***	-0.101***	-0.067**	0.140***	0.134***	0.094**	0.091**
	(0.030)	(0.025)	(0.030)	(0.023)	(0.035)	(0.039)	(0.035)	(0.042)
Human Capital	0.026	0.045	0.078	0.018	-0.265***	-0.251***	-0.202***	-0.174**
	(0.124)	(0.115)	(0.125)	(0.083)	(0.072)	(0.078)	(0.065)	(0.068)
Constant								
Constant	2.284***	2.135***	2.502***	2.181***	-0.018	-0.023	0.276	0.270
	(0.361)	(0.322)	(0.381)	(0.301)	(0.208)	(0.244)	(0.216)	(0.248)
Sample start	1996	1996	1996	1996	1996	1996	1996	1996
Sample end	2020	2020	2020	2020	2020	2020	2020	2020
Countries	20	20	20	20	40	40	40	40
N	480	480	480	480	960	960	960	960
F-stat	112.0***	97.4***	107.3***	92.8***	95.9***	97.9***	94.7***	85.0***
Adjusted R^2	0.84	0.82	0.84	0.82	0.81	0.81	0.81	0.79

Notes: Fixed Effect (country) estimates (cross-section weights) of the change in climate variable (dependent) on lagged climate variable, institutions and controls. White cross-section standard errors and covariance (d.f. corrected) in parentheses. *** significant at 1% level, ** significant at 5%, * significant at 10%. The country groupings are detailed in Table A.1 in Appendix A, the variables in Table B.1 in Appendix B.

Turning to the results for CCPs (Tables 6 and 7), the evidence for the role of institutions and governance is somewhat less strong. The specification remains significant, even though the fit is notably worse in terms of the adjusted R^2. This is mirrored in the significance of institutions and governance, 1 out of 8 for the EU and 5 out of 8 for the full sample of countries when looking at the spread and only significant for 2 cases for the speed when looking at the full sample and insignificant otherwise. Among the control variables GDP per capita remains significant for CCMPs but not always for CCAPs, for which instead human capital becomes significant. It should be noted that the country-level data used for the diffusion of environmentally-related taxation does not include the effect of novel approaches such as carbon pricing, emissions trading systems and green investment frameworks. While the use of these mechanisms is not strictly taxation, they have been observed to provide tangible and effective recalibration of economic incentives towards decarbonisation.

Table 6: CCAPs (CO2 emissions)

	EU countries				All countries			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Climate(-1)	-0.124***	-0.105***	-0.158**	-0.144**	-0.051***	-0.037**	-0.037**	-0.014
	(0.034)	(0.033)	(0.056)	(0.053)	(0.018)	(0.017)	(0.018)	(0.018)
Institutions (-1)								
Institutions	-0.066***		-0.003		-0.045***		-0.080***	
	(0.020)		(0.073)		(0.012)		(0.025)	
Governance		-0.005		0.048		-0.006		-0.052**
		(0.016)		(0.051)		(0.007)		(0.023)
Interactions(-1)								
Climate			0.031				-0.020*	
x Institutions			(0.033)				(0.010)	
Climate				0.031				-0.025**
x Governance				(0.025)				(0.011)
Controls (-1)								
Real GDP	-0.019	-0.039**	-0.025	-0.036*	-0.019	-0.023*	-0.010	-0.012
	(0.019)	(0.019)	(0.019)	(0.018)	(0.014)	(0.013)	(0.015)	(0.013)
Human Capital	0.279**	0.379***	0.296**	0.377***	0.163***	0.200***	0.169***	0.198***
	(0.104)	(0.105)	(0.110)	(0.106)	(0.056)	(0.057)	(0.056)	(0.056)
Constant								
Constant	-0.192	-0.098	-0.218	-0.192	0.015	0.021	-0.071	-0.062
	(0.216)	(0.204)	(0.225)	(0.232)	(0.111)	(0.107)	(0.128)	(0.111)
Sample start	1996	1996	1996	1996	1996	1996	1996	1996
Sample end	2020	2020	2020	2020	2020	2020	2020	2020
Countries	20	20	20	20	40	40	40	40
N	480	480	480	480	960	960	960	960
F-stat	3.3***	2.3***	3.2***	2.3***	4.5***	4.1***	4.5***	4.2***
Adjusted R^2	0.10	0.06	0.10	0.06	0.14	0.12	0.14	0.13

Notes: Fixed Effect (country) estimates (cross-section weights) of the change in climate variable (dependent) on lagged climate variable, institutions and controls. White cross-section standard errors and covariance (d.f. corrected) in parentheses. *** significant at 1% level, ** significant at 5%, * significant at 10%. The country groupings are detailed in Table A.1 in Appendix A, the variables in Table B.1 in Appendix B.

Table 7: CCMPs (environmentally-related taxes)

	EU countries				All countries			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Climate(-1)	-0.084***	-0.083***	-0.046	-0.093**	-0.091***	-0.089***	-0.082***	-0.094***
	(0.013)	(0.014)	(0.053)	(0.041)	(0.013)	(0.016)	(0.027)	(0.029)
Institutions (-1)								
Institutions	0.033		0.141		0.022		0.017	
	(0.027)		(0.140)		(0.025)		(0.056)	
Governance		-0.003		-0.023		-0.059***		-0.086**
		(0.035)		(0.083)		(0.014)		(0.035)
Interactions(-1)								
Climate			-0.039				-0.004	
x Institutions			(0.050)				(0.023)	
Climate				0.008				0.009
x Governance				(0.030)				(0.019)
Controls (-1)								
Real GDP	-0.108**	-0.110*	-0.118**	-0.110*	-0.105**	-0.092*	-0.096**	-0.089*
	(0.051)	(0.058)	(0.051)	(0.058)	(0.044)	(0.048)	(0.043)	(0.045)
Human Capital	-0.029	-0.062	-0.020	-0.052	-0.143	-0.181	-0.177	-0.138
	(0.139)	(0.164)	(0.143)	(0.157)	(0.158)	(0.152)	(0.152)	(0.148)
Constant								
Constant	1.331**	1.424**	1.329**	1.441**	1.401***	1.375***	1.329***	1.326***
	(0.526)	(0.572)	(0.538)	(0.589)	(0.383)	(0.419)	(0.374)	(0.397)
Sample start	1996	1996	1996	1996	1996	1996	1996	1996
Sample end	2020	2020	2020	2020	2020	2020	2020	2020
Countries	20	20	20	20	37	37	37	37
N	480	480	480	480	774	774	774	774
F-stat	5.5***	4.5***	5.0***	4.2***	4.4***	3.9***	4.6***	4.3***
Adjusted R^2	0.18	0.14	0.17	0.14	0.15	0.13	0.16	0.15

Notes: Fixed Effect (country) estimates (cross-section weights) of the change in climate variable (dependent) on lagged climate variable, institutions and controls. White cross-section standard errors and covariance (d.f. corrected) in parentheses. *** significant at 1% level, ** significant at 5%, * significant at 10%. The country groupings are detailed in Table A.1 in Appendix A, the variables in Table B.1 in Appendix B.

Overall, the results for specific CCTs suggest a significant role for institutions and governance in the diffusion of specific CCTs, both the speed and the spread, with state of development and human capital as alternative explanatory factors controlled for. This suggests that the findings of Baccianti et al. (2022) for the diffusion of digital technology are mirrored for climate-change technology (and policies), and provide a strong message to those standing in the way of enhancements in this respect in the relevant jurisdictions. The results for CCPs suggest that the drivers may be different from those for CCTs. In order to shed further light on this, Section 5.2 considers the evidence from the EPS.

In terms of caveats, it should be noted above all that the results are obtained for specific technologies, and the results therefore may not necessarily be representative of other technologies or policies. This caveat is addressed to some extent for the case of policies in the next section which is based on the EPS, an index of a number of CCPs.

5.2 CCPs as captured by the EPS

In this section, results are presented for the EPS, as further evidence regarding CCPs and a complement to the corresponding results in Section 5.1 which takes better into account the multitude of policies that are at disposal may be used to combat climate change, such as emission trading systems. It should be noted that even the EPS is not an all-encompassing measure of all CCPs and so, in this respect, is not perfect. However, it is a benchmark in many policy discussions, and so the results obtained for it are very relevant. They support the view that institutions and governance are important drivers of the diffusion process of CCPs.

As shown in Table 8, all specifications are significant. The fit is noticeably better when the interaction and the spread effect are included in the specification, which is a notable difference from the results on the specific series as presented in Tables 6 to 7 for policies (and Tables 4 and 5 for technologies), for which this was of less relevance. Institutions and governance are significant in 3 out of 4 cases for the EU and 2 out of 4 for the full sample of countries. This could be taken as an indication that institutions and governance are more relevant to the diffusion of climate-related policies than would be assumed on the basis of the results in Section 5.1. When it comes to the control variables both GDP per capita and human capital are significant.

The results from the EPS imply that the significance of institutions and governance is generally similar for technologies and policies. The effects might not show for the specific policies in Section 5.1 because the EPS is a better general proxy of environmental policies and technologies. One reason for why this is convincing is that data for specific policies might be contaminated by series-specific factors, even if they seem very relevant series to explore at face value. More generally, the results in this section suggest that the seminal diffusion model seems to apply to CCTPs in a manner similar to digital technologies, and the S-shaped pattern predicted in the seminal diffusion model to be a valid characterisation of different diffusion processes.

Table 8: CCPs (EPS)

	EU countries				All countries			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Climate(-1)	-0.188***	-0.172***	-0.654***	-0.513***	-0.131***	-0.127***	-0.461***	-0.472***
	(0.037)	(0.034)	(0.057)	(0.058)	(0.031)	(0.031)	(0.046)	(0.048)
Institutions (-1)								
Institutions	-0.185**		-1.244***		-0.045		-0.464***	
	(0.085)		(0.141)		(0.043)		(0.062)	
Governance		0.071		-1.037***		-0.000		-0.588***
		(0.062)		(0.138)		(0.039)		(0.057)
Interactions(-1)								
Climate			0.464***				0.265***	
x Institutions			(0.046)				(0.028)	
Climate				0.300***				0.229***
x Governance				(0.037)				(0.024)
Controls (-1)								
Real GDP	0.386***	0.241**	0.476***	0.608***	0.207***	0.181***	0.596***	0.676***
	(0.107)	(0.108)	(0.075)	(0.100)	(0.052)	(0.047)	(0.054)	(0.056)
Human Capital	1.054***	1.501***	-0.207	-0.416	0.668***	0.714***	0.856***	0.416**
	(0.303)	(0.355)	(0.231)	(0.326)	(0.180)	(0.223)	(0.181)	(0.182)
Constant								
Constant	-4.160***	-3.331***	-3.090***	-4.418***	-2.277***	-2.090***	-5.984***	-6.241***
	(1.063)	(1.053)	(0.778)	(0.909)	(0.501)	(0.453)	(0.541)	(0.538)
Sample start	1996	1996	1996	1996	1996	1996	1996	1996
Sample end	2020	2020	2020	2020	2020	2020	2020	2020
Countries	20	20	20	20	40	40	40	40
N	480	480	480	480	960	960	960	960
F-stat	3.2***	3.0***	34.7***	18.3***	3.0***	3.0***	14.8***	15.2***
Adjusted R^2	0.09	0.09	0.63	0.46	0.09	0.08	0.39	0.39

Notes: Fixed Effect (country) estimates (cross-section weights) of the change in climate variable (dependent) on lagged climate variable, institutions and controls. White cross-section standard errors and covariance (d.f. corrected) in parentheses. *** significant at 1% level, ** significant at 5%, * significant at 10%. The country groupings are detailed in Table A.1 in Appendix A, the variables in Table B.1 in Appendix B.

5.3 The relationships of CCTPs to the EPS

The conjecture in Section 5.2 that the EPS may be a better proxy for CCTPs than the specific series considered above, seems to be corroborated by the pairwise correlations, shown in Table 9. Irrespective of the type of correlation, those numbers in fact suggest a higher relation of the EPS with the series for technologies than those for policies.

Table 9: Correlations of CCTPs with EPS

	EU countries		All countries	
	Ordinary	**Spearman**	**Ordinary**	**Spearman**
CCATs	0.254	0.362	0.156	0.199
CCMTs	0.208	0.412	0.190	0.269
CCAPs	0.083	0.148	-0.060	-0.060
CCMPs	-0.027	-0.014	0.104	0.067

Notes: The table entries show the correlation coefficient of the series used as proxies for CCATs, CCMTs, CCAPs and CCMPs with the EPS. The sample start is 1996, the sample end is 2020. The country groupings are detailed in Table A.1 in Appendix A, the variables in Table B.1 in Appendix B.

Consistent with this, regressions on the EPS of the specific series considered potentially imply that the series for technologies are to some extent explained by the EPS, whereas no significant link can be found for the series for policies, as documented by the results in Table 10.

While the stringency of environmental policy has increased substantially over the sample for almost all the countries, it seems that environmentally-related taxation is almost unaffected. While policymakers often suggest designing tax policies, which would move agents (by design) towards non-harmful practices, the level of environmentally-related taxation seems to have been almost stationary for the past 25 years. This could be due to policymakers not matching their words with actions or potentially due to the difficult nature of implementing tax reforms. However, novel approaches such as carbon pricing, emissions trading systems and green investment frameworks have been established to implement a cost for carbon emission-based production.

Table 10: Effect of EPS on other variables

	EU countries				All countries			
	(1) CCATs	**(2) CCMTs**	**(3) CCAPs**	**(4) CCMPs**	**(5) CCATs**	**(6) CCMTs**	**(7) CCAPs**	**(8) CCMPs**
EPS(-1)	-0.095***	-0.082***	0.011**	-0.002	-0.095***	-0.082***	0.011***	-0.009
	(0.018)	(0.018)	(0.005)	(0.009)	(0.018)	(0.017)	(0.003)	(0.006)
Constant	0.339***	0.305***	0.015	-0.011	0.320***	0.288***	-0.019***	0.008
	(0.054)	(0.054)	(0.010)	(0.024)	(0.047)	(0.045)	(0.005)	(0.015)
Countries	20	20	20	20	40	40	40	40
N	500	500	500	500	1000	1000	1000	1000
F-stat	37.0***	31.8***	1.7**	3.5***	29.8***	27.9***	5.5***	3.6***
Adjusted R^2	0.60	0.56	0.03	0.10	0.55	0.53	0.15	0.11

Notes: Fixed Effect (country) estimates (cross-section weights) of the change in climate variable (dependent) on the lagged EPS. White cross-section standard errors and covariance (d.f. corrected) in parentheses. *** significant at 1% level, ** significant at 5%, * significant at 10%. The sample start is 1996, the sample end is 2020. The country groupings are detailed in Table A.1 in Appendix A, the variables in Table B.1 in Appendix B.

Environmental policy stringency also seems to have a negative effect on the amount of patented climate change technologies. A more stringent policy environment often sets more barriers to introducing new technologies for common use, so this result also has implications for policymakers on whether some limits could be relaxed to enhance innovation as well as introducing new technologies to actual use. As climate change is constantly advancing, reducing bureaucratic barriers to the diffusion of new technologies could accelerate their adoption and help mitigate damage to the living conditions of the planet.

5.4 The role of different aspects of institutions and governance

So far this paper has focused on the role of institutions and governance, both of which are encompassing a number of aspects. This begs the question what role is played by specific aspects of institutions and governance. In this section, we look at the evidence, distinguishing between the three categories suggested in Kaufmann et al. (2010) and shown in Figure 2 - Process (by which governments are selected, monitored and replaced), Capacity (of the government to effectively formulate and implement sound policies) and Respect (of citizens for the institutions that govern economic and social interactions among them).[17] The results suggest that it depends on whether it is technologies (CCTs) or policies (CCPs), adaptation or mitigation, as well as the country grouping, as summarised in Table 11.

For the EU countries and technologies CCTs, both Process (K1) and Capacity (K2) tend to be significant at 1% or 5% levels, Respect (K3) to a lesser extent, especially when the interaction is considered in the estimated equation. For policies (CCPs), in contrast, significance is much less overall, with Capacity (K2) signifcant in couple of cases, and Respect (K3) only in one case and Process (K1) in none of the cases studied. This sugests that Capacity (K2), relating to the effectiveness of government, may be the most important institutional and governance feature for the EU countries overall. For the EPS, all three aspects are highly significant in the specification including the interaction term, without it only Respect (K3) appears as significant (at 5%) once.

For the broader set of countries, Respect (K3) seems more important overall, at least in relation to technologies (CCTs) and adaptation policies (CCAPs). All three features matter consistently only for adaptation policies (CCAPs), and not across technologies (CCTs), a marked contrast to the results for the EU countries, which may be explained by the progress that has already been made in relation to institutions and governance in the EU countries. For the EPS, all features are highly significant in the specification including the interaction term, the same finding as for the EU countries.

[17] The descriptive statistics for Process, Capacity and Respect are provided in Table 2 alongside those for Institutions, Governance, and the WGI Total.

Table 11: Aspects of institutions and governance

		EU countries			All countries		
		(1)/(3)	(2)/(4)	(2')/(4')	(5)/(7)	(6)/(8)	(6')/(8')
CCATs							
	WGI Total	***	***	***	**		***
	Institutions	***	**		**	**	***
	Governance	*	***	***	**		***
	Process (K1)	**	***	***	**		***
	Capacity (K2)	***	***	***	**		
	Respect (K3)	***		*	*	***	***
CCMTs							
	WGI Total	***	***	***	***		**
	Institutions	***	***	***	***		***
	Governance		***	***	**		
	Process (K1)		**	**	*		
	Capacity (K2)	**	***	***	***		
	Respect (K3)	***	**		***	*	***
CCAPs							
	WGI Total	**			***	***	**
	Institutions	***			***	***	*
	Governance					**	**
	Process (K1)				***	**	*
	Capacity (K2)	**		**	**	***	**
	Respect (K3)	**			**	**	*
CCMPs							
	WGI Total				*		
	Institutions						
	Governance				***	**	
	Process (K1)				***	**	
	Capacity (K2)	**				**	**
	Respect (K3)						
EPS							
	WGI Total		***	***		***	***
	Institutions	**	***	***		***	***
	Governance		***	***		***	***
	Process (K1)		***	***		***	***
	Capacity (K2)		***	***		***	***
	Respect (K3)	**	***	***		***	***
	Sample start	1996	1996	1996	1996	1996	1996
	Sample end	2020	2020	2020	2020	2020	2020
	Countries	20	20	20	40	40	40
	N	480	480	480	960	960	960

Notes: Significance level of Fixed Effect (country) estimates (cross-section weights) of the change in climate variable (dependent) on institutions and the corresponding interaction term, in Tables 5 to 8. The numbers in parentheses refer to the corresponding specification(s). A prime indicates the result for the interaction term, no prime the result for the coefficient on institutions. F*** significant at 1% level, ** significant at 5%, * significant at 10%. or CCMPs the full sample consists of 37 countries and 774 observations. The country groupings are detailed in Table A.1 in Appendix A, the variables in Table B.1 in Appendix B.

6 Conclusions

Bringing together economics, environmental sciences and instiutional analysis, this paper has considered evidence for the role of institutions and governance in the diffusion of climate-related technologies and policies across the EU and a broader set of countries. It has been using series for specific climate-related adaptation and mitigation technologies and policies, CCTPs, as well as a summary measure of climate-related policies as provided by the Environmental Policy Stringency (EPS) index. The findings suggests that institutions and governance matter for speed and spread of diffusion of climate-related technologies and policies, with factors such as the level of economic advancement of countries, measured by real GDP per capita, and human capital controlled for.

The results point towards a very broad and strong effect on technologies and a less profound one on policies, especially when it comes to CCMPs as proxied by environmentally-related taxation, which have been essentially stationary during the past 25 years. However, the results for the EPS imply a fundamental relationship between policies and institutions, especially when the interaction is controlled for.

Potentially interesting and policy-relevant results also arise from the relationship of the EPS against other variables. Countries with a higher level of environmental policy stringency tend to have less innovation (technology) but also have reached a lower level of carbon dioxide emissions per capita which is taken as indicative of greater diffusion of CCAPs. CCMPs, as proxied by environmentally-related taxes, are almost unaffected by the EPS.

These results point towards a need to lower the barriers to innovation and amount of bureaucracy needed to establish new technologies to combat the advancement of climate change as well as a potential disconnect between the communication and action of policymakers when it comes to introducing climate-friendly taxation, which can also be mitigated to some extent by using novel approaches such as carbon pricing, emissions trading systems and green investment frameworks.

This paper is by no means the first to add to the case for better institutions and governance, but it highlights that they may carry substantial and wide-ranging benefits and may also assist in the struggle for a stable climate. Institutions and governance structures in fact may be essential in developing comprehensive, strategic and effective responses to the complex challenges arising from climate change, which require coordinated, long-term approaches from policymakers. Strenghening institutions and governance structures therefore, alongside cross-national learning, international cooperation and knowledge transfer can contribute to acccelerating climate change mitigation and adaptation efforts.

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Appendix

A Countries and Country Groupings

Table A.1: Countries and Country Groupings

EU countries (20)
Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden
All countries (40)
Australia, Austria, Belgium, Brazil, Canada, Chile, China, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, India, Indonesia, Ireland, Israel, Italy, Japan, Korea (Rep. of), Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Russia, Slovak Republic, Slovenia, South Africa, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States

Notes: The country groupings are based on the countries covered by the OECD's EPS index.

B Data Description and Sources

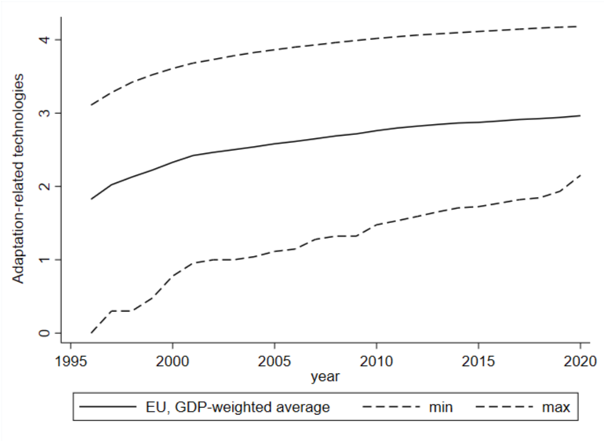
Table B.1: Variables

Variable/Description (and transformation)	Code	Source
Control of Corruption	CC.EST	World Bank
Government Effectiveness	GE.EST	World Bank
Political Stability	PS.EST	World Bank
Regulatory Quality	RQ.EST	World Bank
Rule of Law	RL.EST	World Bank
Voice and Accountability	VA.EST	World Bank
Respect (average of CC.EST, RL.EST)	-	Kaufmann et al. (2010)
Capacity (average of GE.EST, RQ.EST)	-	Kaufmann et al. (2010)
Process (average of PS.EST, VA.EST)	-	Kaufmann et al. (2010)
Institutions (average of GE.EST, PS.EST, VA.EST)	-	Authors
Governance (average of CC.EST, RQ.EST, RL.EST)	-	Authors
Total (average of all six indicators)	-	Authors
Climate change technology patents (number, integer)	..	OECD
Environmental technology patents (number, integer)	..	OECD
Environmental taxes (revenue, % of GDP)	..	OECD
CO2 emissions (metric tons per capita)	..	World Bank
Environmental Policy Stringency ($0 \leq \text{EPS} \leq 6$)	..	OECD
Real GDP per capita (log)	NY.GDP.PCAP.KD	World Bank
Human Capital, Education Index	-	UNDP

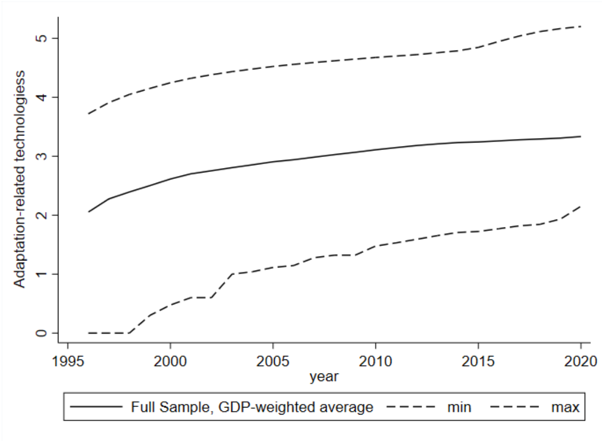
Notes: 'Political Stability' is short for 'Political Stability and Absence of Violence'. 'Respect' is short for 'the respect of citizens and the state for the institutions that govern economic and social interactions among them'. 'Capacity is short for 'the capacity of the government to effectively formulate and implement sound policies'. 'Process' is short for 'the process by which governments are selected, monitored and replaced'. 'OECD' is the Organisation of Economic Cooperation and Development. 'UNDP' is the United Nations Development Programme.

Figure B.1: Diffusion of CCTPs

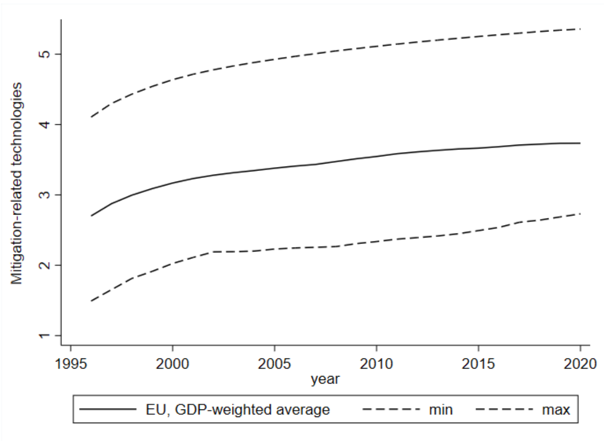
(a) CCATs, EU countries



(b) CCATs, all countries



(c) CCMTs, EU counties



(d) CCMTs, all countries

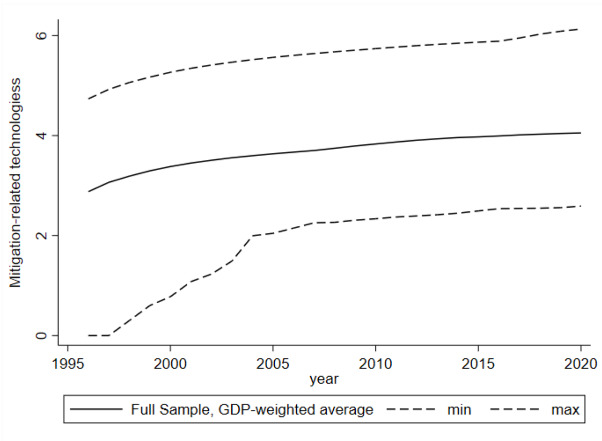
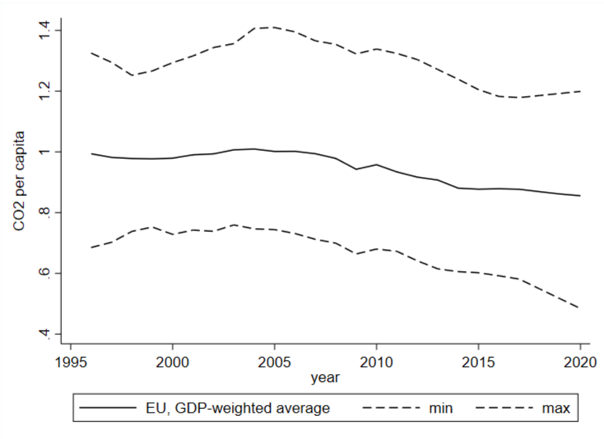
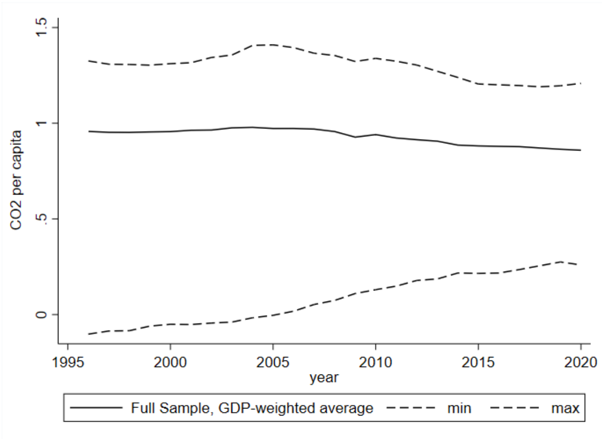


Figure B.1: Diffusion of CCTPs (continued)

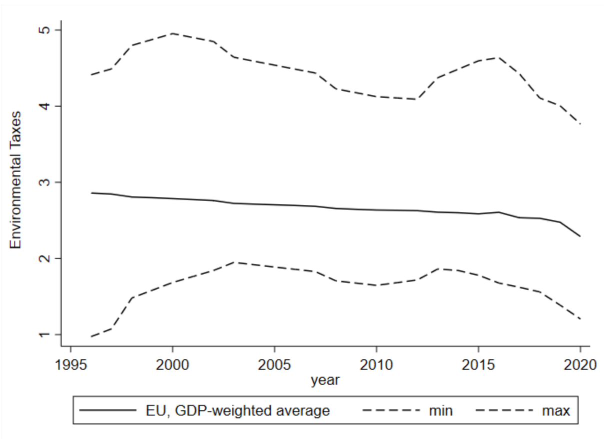
(e) CCAPs, EU countries



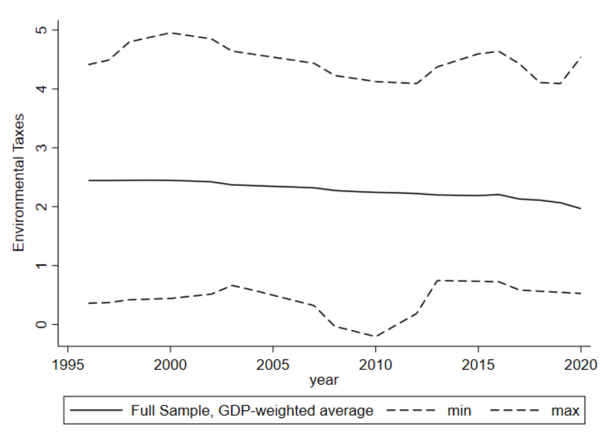
(f) CCAPs, all countries



(g) CCMPs, EU countries



(h) CCMPs, all countries



Source: OECD, World Bank, authors' calculations.

C Results for other institutions and governance variables

Table C.1: CCATs (patents, environmentally-related technologies)

	EU countries								All countries							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Climate(-1)	-0.130***	-0.170***	-0.123***	-0.153***	-0.124***	-0.174***	-0.133***	-0.119***	-0.130***	-0.109***	-0.129***	-0.109***	-0.126***	-0.117***	-0.131***	-0.111***
	(0.016)	(0.024)	(0.016)	(0.021)	(0.016)	(0.025)	(0.017)	(0.016)	(0.017)	(0.019)	(0.017)	(0.021)	(0.016)	(0.022)	(0.018)	(0.017)
Institutions(-1)																
WGI Total	-0.096***	-0.301***							-0.080**	0.044						
	(0.031)	(0.086)							(0.031)	(0.045)						
K1			-0.039**	-0.195***							-0.055**	0.036				
			(0.018)	(0.056)							(0.0233)	(0.042)				
K2					-0.065***	-0.297***							-0.048**	0.001		
					(0.023)	(0.081)							(0.019)	(0.052)		
K3							-0.078***	0.018							-0.042*	0.105***
							(0.026)	(0.056)							(0.021)	(0.023)
Interactions(-1)																
Climate x WGI Total		0.025***								-0.014***						
		(0.008)								(0.003)						
Climate x K1				0.019***								-0.010***				
				(0.005)								(0.003)				
Climate x K2						0.030***									-0.004	
						(0.008)									(0.005)	
Climate x K3								-0.014*								-0.020***
								(0.008)								(0.002)
Controls(-1)																
Real GDP	-0.079***	-0.044	-0.094***	-0.055**	-0.083***	-0.041	-0.100***	-0.106***	0.161***	0.096**	0.149***	0.083*	0.145***	0.112**	0.148***	0.066**
	(0.026)	(0.029)	(0.025)	(0.024)	(0.027)	(0.031)	(0.023)	(0.025)	(0.037)	(0.042)	(0.035)	(0.042)	(0.036)	(0.045)	(0.032)	(0.029)
Human Capital	-0.132	-0.138	-0.109	-0.154	-0.136	-0.132	-0.056	-0.041	-0.385***	-0.314***	-0.343***	-0.290***	-0.344***	-0.332***	-0.320***	-0.221***
	(0.091)	(0.087)	(0.103)	(0.107)	(0.097)	(0.093)	(0.106)	(0.105)	(0.071)	(0.066)	(0.077)	(0.076)	(0.070)	(0.068)	(0.081)	(0.073)
Constant																
Constant	1.974***	1.932***	2.005***	1.875***	1.951***	1.879***	2.121***	2.071***	-0.254	0.188	-0.195	0.288	-0.169	0.074	-0.207	0.411*
	(0.276)	(0.241)	(0.286)	(0.239)	(0.290)	(0.245)	(0.266)	(0.278)	(0.248)	(0.290)	(0.243)	(0.292)	(0.256)	(0.319)	(0.224)	(0.212)
Sample start	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996
Sample end	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020
Countries	20	20	20	20	20	20	20	20	40	40	40	40	40	40	40	40
N	480	480	480	480	480	480	480	480	960	960	960	960	960	960	960	960
F-stat	144.5***	132.9***	136.2***	122.3***	132.9***	131.1***	143.9***	135.8***	111.4***	109.3***	111.2***	105.7***	111.1***	105.6***	117.1***	123.9***
Adjusted R^2	0.87	0.87	0.87	0.86	0.86	0.87	0.87	0.87	0.83	0.83	0.83	0.83	0.83	0.83	0.84	0.85

Notes: Fixed Effect (country) estimates (cross-section weights) of the change in climate variable (dependent) on lagged climate variable, institutions and controls. White cross-section standard errors and covariance (d.f. corrected) in parentheses. *** significant at 1% level, ** significant at 5%, * significant at 10%. The country groupings are detailed in Table A.1 in Appendix A, the variables in Table B.1 in Appendix B.

Table C.2: CCMTs (patents, climate change technologies)

	EU countries								All countries							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Climate(-1)	-0.122***	-0.173***	-0.112***	-0.147***	-0.115***	-0.172***	-0.128***	-0.124***	-0.119***	-0.107***	-0.116***	-0.106***	-0.115***	-0.117***	-0.121***	-0.108***
	(0.021)	(0.032)	(0.020)	(0.032)	(0.020)	(0.031)	(0.020)	(0.020)	(0.021)	(0.022)	(0.020)	(0.023)	(0.020)	(0.025)	(0.021)	(0.019)
Institutions(-1)																
WGI Total	-0.107***	-0.448***							-0.082***	-0.008						
	(0.037)	(0.120)							(0.029)	(0.051)						
K1			-0.015	-0.238**							-0.036*	0.014				
			(0.021)	(0.105)							(0.020)	(0.047)				
K2					-0.070**	-0.416***							-0.051***	-0.071		
					(0.026)	(0.105)							(0.018)	(0.003)		
K3							-0.123***	-0.091**							-0.062***	0.056*
							(0.028)	(0.041)							(0.021)	(0.031)
Interactions(-1)																
Climate		0.035***								-0.007**						
x WGI Total		(0.008)								(0.003)						
Climate				0.022**								-0.005				
x K1				(0.008)								(0.003)				
Climate						0.037***								0.003		
x K2						(0.009)								(0.005)		
Climate								-0.004								-0.013***
x K3								(0.003)								(0.003
Controls(-1)																
Real GDP	-0.083***	-0.061**	-0.113***	-0.084***	-0.090***	-0.067**	-0.107***	-0.105***	0.148***	0.102**	0.130***	0.086**	0.133***	0.120**	0.134***	0.074**
	(0.027)	(0.025)	(0.024)	(0.022)	(0.028)	(0.026)	(0.028)	(0.028)	(0.039)	(0.042)	(0.038)	(0.041)	(0.038)	(0.045)	(0.034)	(0.028)
Human Capital	-0.008	0.029	0.057	0.049	0.001	0.046	0.068	0.073	-0.290***	-0.215***	-0.243***	-0.165**	-0.252***	-0.215***	-0.233***	-0.162*
	(0.114)	(0.097)	(0.116)	(0.090)	(0.112)	(0.103)	(0.136)	(0.135)	(0.071)	(0.060)	(0.080)	(0.072)	(0.071)	(0.061)	(0.080)	(0.079)
Constant																
Constant	2.093***	2.327**	2.169***	2.209***	2.069***	2.311***	2.339***	2.289***	-0.082	0.215	0.002	0.306	-0.011	0.104	0.014	0.452**
	(0.327)	(0.327)	(0.325)	(0.316)	(0.338)	(0.316)	(0.345)	(0.333)	(0.235)	(0.250)	(0.233)	(0.236)	(0.247)	(0.270)	(0.209)	(0.184)
Sample start	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996
Sample end	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020
Countries	20	20	20	20	20	20	20	20	40	40	40	40	40	40	40	40
N	480	480	480	480	480	480	480	480	960	960	960	960	960	960	960	960
F-stat	106.3***	102.6***	97.6***	91.7***	98.8***	102.2***	115.8***	109.2***	95.5***	87.6***	95.0***	84.8***	95.8***	87.6***	100.9***	103.1***
Adjusted R^2	0.83	0.84	0.82	0.82	0.82	0.84	0.85	0.84	0.81	0.80	0.81	0.79	0.81	0.80	0.82	0.82

Notes: Fixed Effect (country) estimates (cross-section weights) of the change in climate variable (dependent) on lagged climate variable, institutions and controls. White cross-section standard errors and covariance (d.f. corrected) in parentheses. *** significant at 1% level, ** significant at 5%, * significant at 10%. The country groupings are detailed in Table A.1 in Appendix A, the variables in Table B.1 in Appendix B.

Table C.3: CCAPs (CO2 emissions per capita)

	EU countries								All countries							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Climate(-1)	-0.115***	-0.170***	-0.105***	-0.125**	-0.116***	-0.198***	-0.118***	-0.138**	0-043**	-0.023	-0.037**	-0.023	-0.041**	-0.013	-0.044**	-0.034*
	(0.034)	(0.057)	(0.034)	(0.051)	(0.034)	(0.057)	(0.035)	(0.056)	(0.017)	(0.018)	(0.017)	(0.018)	(0.017)	(0.016)	(0.018)	(0.018)
Institutions(-1)																
WGI Total	-0.051**	0.034							-0.034***	-0.078***						
	(0.021)	(0.063)							(0.010)	(0.025)						
K1			-0.013	0.016							-0.016***	-0.046**				
			(0.013)	(0.044)							(0.006)	(0.019)				
K2					-0.040**	0.084							-0.021**	-0.083***		
					(0.017)	(0.059)							(0.009)	(0.027)		
K3							-0.043**	-0.003							-0.026**	-0.057**
							(0.019)	(0.080)							(0.010)	(0.022)
Interactions(-1)																
Climate		0.045								-0.025**						
x WGI Total		(0.030)								(0.012)						
Climate				0.017								-0.017*				
x K1				(0.023)								(0.010)				
Climate						0.063**								-0.031**		
x K2						(0.028)								(0.011)		
Climate								0.020								-0.019*
x K3								(0.037)								(0.010)
Controls(-1)																
Real GDP	-0.017	-0.020	-0.034*	-0.033*	-0.022	-0.027	-0.031	-0.033*	-0.017	-0.005	-0.020	-0.012	-0.018	-0.004	-0.024*	-0.014
	(0.021)	(0.020)	(0.018)	(0.018)	(0.020)	(0.020)	(0.018)	(0.018)	(0.013)	(0.014)	(0.013)	(0.013)	(0.014)	(0.014)	(0.013)	(0.015)
Human Capital	0.298**	0.309**	0.359***	0.357***	0.340***	0.367***	0.320***	0.327***	0.167***	0.172***	0.183***	0.184***	0.184***	0.189***	0.182***	0.191***
	(0.108)	(0.112)	(0.107)	(0.108)	(0.098)	(0.105)	(0.102)	(0.106)	(0.056)	(0.056)	(0.057)	(0.056)	(0.057)	(0.058)	(0.055)	(0.056)
Constant																
Constant	-0.227	-0.306	-0.122	-0.168	-0.222	-0.352	-0.123	-0.141	-0.007	-0.099	0.006	-0.055	-0.010	-0.107	0.044	-0.057
	(0.223)	(0.242)	(0.210)	(0.234)	(226)	(0.244)	(0.212)	(0.223)	(0.112)	(0.122)	(0.109)	(0.114)	(0.113)	(0.116)	(0.112)	(0.132)
Sample start	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996
Sample end	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020
Countries	20	20	20	20	20	20	20	20	40	40	40	40	40	40	40	40
N	480	480	480	480	480	480	480	480	960	960	960	960	960	960	960	960
F-stat	2.8***	2.8***	2.4***	2.3***	2.6***	2.7***	2.9***	2.8***	4.2***	4.3***	4.1***	4.1***	4.1***	4.5***	4.3***	4.3***
Adjusted R^2	0.08	0.13	0.06	0.06	0.07	0.08	0.08	0.08	0.13	0.13	0.12	0.12	0.12	0.14	0.13	0.13

Notes: Fixed Effect (country) estimates (cross-section weights) of the change in climate variable (dependent) on lagged climate variable, institutions and controls. White cross-section standard errors and covariance (d.f. corrected) in parentheses. *** significant at 1% level, ** significant at 5%, * significant at 10%. The country groupings are detailed in Table A.1 in Appendix A, the variables in Table B.1 in Appendix B.

Table C.4: CCMPs (environmentally-related taxes)

	EU countries								All countries							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Climate(-1)	-0.085***	-0.077	-0.079***	-0.083**	-0.094***	-0.116**	-0.080***	-0.032	-0.088***	-0.090***	-0.089***	-0.088***	-0.088***	-0.120***	-0.089***	-0.075***
	(0.014)	(0.047)	(0.014)	(0.038)	(0.014)	(0.052)	(0.011)	(0.045)	(0.014)	(0.029)	(0.017)	(0.029)	(0.013)	(0.025)	(0.012)	(0.025)
Institutions(-1)																
WGI Total	0.030	0.051							-0.043*	-0.067						
	(0.039)	(0.118)							(0.022)	(0.046)						
K1			-0.040	-0.047							-0.071***	-0.085**				
			(0.038)	(0.082)							(0.017)	(0.037)				
K2					0.082**	0.032							0.007	-0.054**		
					(0.032)	(0.104)							(0.017)	(0.023)		
K3							-0.003	0.164							0.000	0.019
							(0.028)	(0.143)							(0.027)	(0.068)
Interactions(-1)																
Climate		-0.008								0.007						
x WGI Total		(0.040)								(0.021)						
Climate				0.003								0.004				
x K1				(0.028)								(0.018)				
Climate						0.018								0.027**		
x K2						(0.036)								(0.013)		
Climate								-0.062								-0.015
x K3								(0.055)								(0.028)
Controls(-1)																
Real GDP	-0.122**	-0.124**	-0.093	-0.093	-0.149***	-0.143**	-0.110**	-0.122**	-0.099**	-0.092*	-0.096*	-0.092*	-0.116**	-0.103**	-0.101**	-0.103**
	(0.057)	(0.057)	(0.057)	(0.057)	(0.053)	(0.054)	(0.050)	(0.050)	(0.047)	(0.046)	(0.047)	(0.045)	(0.046)	(0.044)	(0.043)	(0.042)
Human Capital	-0.011	-0.007	-0.123	-0.121	0.053	0.055	-0.053	-0.047	-0.197	-0.178	-0.190	-0.166	-0.096	-0.115	-0.182	-0.180
	(0.153)	(0.152)	(0.161)	(0.152)	(0.158)	(0.161)	(0.133)	(0.135)	(0.154)	(0.148)	(0.155)	(0.148)	(0.158)	(0.150)	(0.160)	(0.163)
Constant																
Constant	1.471**	1.475**	1.331**	1.335**	1.661***	1.656***	1.409**	1.405**	1.435***	1.367***	1.443***	1.387***	1.482***	1.426***	1.402***	1.402***
	(0.566)	(0.574)	(0.572)	(0.583)	(0.533)	(0.537)	(0.513)	(0.527)	(0.417)	(0.404)	(0.413)	(0.394)	(0.408)	(0.402)	(0.361)	(0.355)
Sample start	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996
Sample end	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020
Countries	20	20	20	20	20	20	20	20	37	37	37	37	37	37	37	37
N	480	480	480	480	480	480	480	480	774	774	774	774	774	774	774	774
F-stat	4.9***	4.5***	4.3***	4.1***	6.8***	6.4***	5.2***	4.8***	4.0***	4.3***	4.0***	4.1***	4.8***	5.3***	4.4***	4.3***
Adjusted R^2	0.16	0.15	0.14	0.14	0.22	0.21	0.17	0.16	0.13	0.15	0.13	0.14	0.16	0.18	0.15	0.15

Notes: Fixed Effect (country) estimates (cross-section weights) of the change in climate variable (dependent) on lagged climate variable, institutions and controls. White cross-section standard errors and covariance (d.f. corrected) in parentheses. *** significant at 1% level, ** significant at 5%, * significant at 10%. The country groupings are detailed in Table A.1 in Appendix A, the variables in Table B.1 in Appendix B.

Table C.5: EPS (Environmental Policy Stringency Index)

	EU countries								All countries							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Climate(-1)	-0.176***	-0.854***	-0.172***	-0.472***	-0.167***	-0.561***	-0.192***	-0.730***	-0.128***	-0.483***	-0.127***	-0.438***	-0.127***	-0.520***	-0.132***	-0.394***
	(0.036)	(0.060)	(0.035)	(0.054)	(0.035)	(0.061)	(0.037)	(0.051)	(0.031)	(0.047)	(0.031)	(0.046)	(0.031)	(0.049)	(0.032)	(0.043)
Institutions(-1)																
WGI Total	-0.081	-1.166***							-0.032	-0.554***						
	(0.083)	(0.144)							(0.043)	(0.060)						
K1			-0.030	-1.010***							-0.032	-0.525***				
			(0.058)	(0.117)							(0.039)	(0.060)				
K2					0.110	-0.777***							0.030	-0.470***		
					(0.067)	(0.129)							(0.037)	(0.057)		
K3							-0.215**	-1.528***							-0.052	-0.456***
							(0.081)	(0.155)							(0.037)	(0.061)
Interactions(-1)																
Climate		0.374***								0.255***						
x WGI Total		(0.043)								(0.027)						
Climate				0.260***								0.200***				
x K1				(0.032)								(0.022)				
Climate						0.345***								0.269***		
x K2						(0.040)								(0.027)		
Climate								0.562***								0.233***
x K3								(0.045)								(0.026)
Controls(-1)																
Real GDP	0.339***	0.565***	0.310**	0.658***	0.219*	0.385***	0.399***	0.362***	0.198***	0.665***	0.198***	0.634***	0.164***	0.639***	.0209***	0.517***
	(0.108)	(0.093)	(0.113)	(0.095)	(0.109)	(0.088)	(0.107)	(0.054)	(0.049)	(0.055)	(0.047)	(0.057)	(0.048)	(0.051)	(0.051)	(0.055)
Human Capital	1.183***	-0.395	1.256***	-0.529	1.507***	0.114	1.010***	0.025	0.662***	0.619***	0.646***	0.493**	0.765***	0.584***	0.669***	0.973***
	(0.321)	(0.290)	(0.368)	(0.314)	(0.315)	(0.264)	(0.300)	(0.213)	(0.196)	(0.177)	(0.217)	(0.197)	(0.219)	(0.169)	(0.174)	(0.187)
Constant																
Constant	-3.915***	-3.881***	-3.737***	-4.849***	-3.167***	-2.850***	-4.231***	-1.840***	-2.194***	-6.365***	-2.178***	-5.936***	-1.988***	-6.117***	-2.289***	-5.322***
	(1.051)	(0.881)	(1.075)	(0.868)	(1.067)	(0.880)	(1.076)	(0.639)	(0.473)	(0.539)	(0.456)	(0.545)	(0.458)	(0.497)	(0.499)	(0.557)
Sample start	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996	1996
Sample end	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020
Countries	20	20	20	20	20	20	20	20	40	40	40	40	40	40	40	40
N	480	480	480	480	480	480	480	480	960	960	960	960	960	960	960	960
F-stat	3.0***	24.6***	3.0***	16.0***	3.0***	23.7***	3.3***	49.1***	3.0***	15.7***	3.0***	13.4***	3.0***	18.5***	3.1***	11.3***
Adjusted R^2	0.09	0.54	0.09	0.43	0.09	0.53	0.10	0.71	0.08	0.40	0.08	0.36	0.08	0.45	0.08	0.32

Notes: Fixed Effect (country) estimates (cross-section weights) of the change in climate variable (dependent) on lagged climate variable, institutions and controls. White cross-section standard errors and covariance (d.f. corrected) in parentheses. *** significant at 1% level, ** significant at 5%, * significant at 10%. The country groupings are detailed in Table A.1 in Appendix A, the variables in Table B.1 in Appendix B.

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