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EXPLORING COUNTRY CHARACTERISTICS THAT ENCOURAGE EMISSIONS REDUCTION

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Abstract

We explore the relation between sound institutions favouring innovation and technology investment and firms' emissions reduction. Even though emission abatement is achieved at the firm or plant level, we postulate that structural and institutional fac- tors underpinning green innovation, skills and technology adoption at the country level are of material importance. Advances in technology and infrastructure are the main drivers for the reduction of emissions and are, in turn, intrinsically linked to overall country characteristics. Sound institutions can act as enablers and accelerators for firms and industries in the green transition process, hence we find an attenuating effect on emissions conditional on firm attributes.

Keywords: Emissions; Institutions; Technological infrastructure; Skills; Innovation; EU ETS

JEL-Classification: E02; G32; Q55; Q56; Q58

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1 Introduction

Climate change mitigation and adaptation are pivotal topics in the policy dialogues of the European Union (EU). The EU has set ambitious climate goals, encapsulated in the EU Climate Law and delineated in initiatives like the EU Green Deal and the "Fit for 55" package, demanding substantial efforts from all stakeholders involved. To enhance Europe's green transition, it is necessary to recognize the existing disparities across the EU Member States in terms of technological readiness, availability of skilled labour and innovation capacity. While environmental policies hold the potential for positive outcomes, the presence of robust institutions at the national level becomes imperative as facilitators and catalysts for businesses engaged in the transition towards a sustainable, green economy.

In this study, we take a novel approach and delve into the interplay between specific national structural characteristics and the effectiveness of EU environmental policies, while controlling for firm and industry characteristics. Our main hypothesis is that countries' sound institutions that promote innovation and technology investment, have a positive effect on firms' ability to reduce emissions. These institutions play a critical role in driving the transformational change needed to address climate change effectively and unlock the economic potential of the green economy. They provide the necessary support to enable businesses to adopt sustainable practices, innovate, and invest in clean technologies.

We relate and contribute to the literature that argues that as most environmental problems represent negative external effects, institutional factors that enhance technology and innovation play an important role together with environmental policy measures (see Section 2.3 for related literature).[1] Insofar as innovation is considered the most important driver of emission abatement, national policies at the country level can act as enablers, both directly through government investment in R&D and incentives for firm innovation and indirectly through the fostering of technology infrastructure, skills and stakeholders'

[1] Many studies have examined whether more stringent environmental regulation promotes environmental innovation (for a review of the empirical literature on this issue see Jaffe, Newell, and Stavins 2003; Popp 2006; Johnstone and Labonne 2009; Popp, Newell, and Jaffe 2010; Costantini and Mazzanti 2012).

cooperation. Green innovation is underpinned by environmental externalities in addition to the appropriation externalities related to knowledge creation and innovation (Jaffe, Newell, and Stavins, 2005), thus warranting the supporting role of the state and well-functioning institutions. Appropriating the gains from environmental innovation is even more uncertain than standard innovation activity. Anderson, Convery, and Di Maria (2010) underscore that switching to green technologies depends on infrastructural barriers directly addressed by the state. Rogge, Schneider, and Hoffmann (2011) note that informal institutions, or "context factors"also affect investment decisions and the shift towards environmental innovation.

To analyze the channels that connect national attributes and environmental degradation as measured by firms' emissions, we exploit the European Union's Emissions Trading System (EU ETS) Company Database that consolidates information as reported by the European Union Transaction Log, which is a source of verified greenhouse gas (GHG) emissions information, set up by the European Commission. The dataset includes companies from 31 European countries (*i.e.*, the EU-28 zone, Norway, Iceland and Liechtenstein) and spans the period 2005-2018 (see, Section 2.1 for an overview of the system). We merge these data with a novel database of indicators that measure structural traits at the country level from the competitiveness publications of IMD World Competiteveness Center (IMD) (see, Section 2.2 for an overview of the indicators). We generate a panel dataset of 540 firms, featuring 6,459 firm-years observations, and succeed on employing a rich novel sample with respect to levels of infrastructure and institutional characteristics.

Our main dependent variable is the logarithm of a firm's "verified emissions" operating in a given country divided by the number of the firm's installations. We use seven indicators from the IMD capturing structural characteristics which are detrimental for technological advancement and innovation, *i.e.*, the availability of skilled labour, the availability of competent senior managers, the number of computers per capita, the availability of digital/technological skills, the existence of public-private partnerships that are supportive to technological development, the existence of legal environment that is supportive for the development and application of technology, and the existence of laws relating to scientific research that encourage innovation. All in all, these indicators are related to the efficiency of the labour market which in turn is a crucial factor for business efficiency, as well as to the technological infrastructure of the country. For completeness, we also use three similar indicators from the World Economic Forum (WEF), *i.e.*, technological readiness, business sophistication, and innovation capacity (see, Section 2.2 for an overview of these indicators).

Controlling for firm characteristics, macroeconomic variables, industry and phase effects we find a negative and significant relation between these variables and firm's verified emissions per number of installations. For example, increasing by one standard deviation the country indicator for skilled labour decreases firms' emission per installation by 21.4%. A similar result holds for the competent managers variable indicating the importance of labour market for business efficiency. Moreover, technological infrastructure appears to play a significant role while the importance of a supportive legal environment for technology development and research innovation is highlighted. Accordingly, results show that public and private ventures promoting technological development may play a significant role in the emisssions abatement process.

Using firm-level data for emissions is a major step toward limiting omitted-variable bias while we also include industry and phase fixed effects as well as several firm and macroeconomic variables. Nonetheless, we also present estimations using GMM to tackle any potential endogeneity concerns. Overall, the results underscore the mitigating effect that specific national attributes (efficient labour market and technological infrastructure, and supportive legal environment), can exert on firms' emissions, controlling for firm and industry characteristics.

Finally, as a robustness on the choice of the structural characteristics variables and in order to highlight the factors that are similarly important in all EU countries for emission reduction as well as to point out those aspects that could be strengthened at the country level, we conduct a factor analysis of a vast number of variables of the IMD world competitiveness indicator (and WEF). In particular, we augment the seven IMD variables used in baseline regression analysis with (a) another four variables for labor markets, *i.e.*, finance skills, attracting and retaining talent, brain drain, and foreign highly skilled personnel; (b) one variable for management practices, *i.e.*, entrepreneurship; (c) three variables for institutional framework, *i.e.*, legal and regulatory framework, adaptability of government policy, and transparency; (d) three extra variables for technological infrastructure, *i.e.*, funding of technological development, computers in use, communications technology; (e) two extra variables for scientific infrastructure, *i.e.*, intellectual property rights, and knowledge transfer; and (f) three variables for finance, *i.e.*, stock markets, stock market capitalization, and venture capital. We similarly and use all twelve pillars of the Global Competitiveness Index of the WEF and the index itself.

We conduct factor analysis of the above indicators and we term the respective three factor scores as (i) institutional framework, (ii) national competitiveness and (iii) skills. In a regression analysis using each of these factors as the main independent variable it turns out that national competitiveness and skills are negative and significant. These corroborate previous findings on the importance of these factors in the emissions abatement process for the EU ETS participating firms.

Our results are significant for several reasons. First, we inform the debate on the design of policy regimes intended to mitigate environmental damage. However, we are the first to link national structural characteristics with the firm's emissions reduction process. Instead of looking at a single macroeconomic variable or channel, we consider a large number of variables taken from IMD competitiveness indicators while using factor analysis we demonstrate which country characteristics encourage emissions reduction at the firm level.

Second, we show that skills and technological infrastructure play an important role for the success of environmental policies. In fact, the empirical finding that technological infrastructure in a country matters in controlling firms' emissions is a novelty. The scope of environmental policies is to align firm incentives with emission abatement. A longer-term objective of the cap-and-trade policy is to stimulate innovation that will help with the transition to a low-carbon economy. Institutional environments that foster knowledge accumulation as well as assimilation are pivotal since green innovation exhibits significant path-dependence and is characterized by spatially bound spillovers (Aghion, Dechezleprêtre, Hemous, Martin, and Van Reenen, 2016).

Third, our preliminary analysis that results are mainly driven by Phase III are related to the debate that the efficiency of any environmental policy depends primarily on its stringency, its implementation and monitoring in conjunction with external factors (Anderson et al., 2010; Rogge et al., 2011; Abid, 2017). In the case of the ETS, the lack of stringency during Phases I and II and the increased degree of uncertainty has resulted in poor innovation incentives according to the empirical studies. Given the short time span available for empirical research and the fact that tangible innovative results require time to realize, the view among scholars is that EU firms have adopted a "wait-and-see"approach vis-a-vis the ETS and innovation (Rogge et al., 2011; Borghesi, Cainelli, and Mazzanti, 2015; Löfgren, Wråke, Hagberg, and Roth, 2014; Calel and Dechezleprêtre, 2016)

Our findings also inform the strand of studies that endeavor to assess the effectiveness of the EU emissions trading system and inform any policy debate around the design of the mechanism itself for enhancing environmental innovation. For instance, Andreou and Kellard (2021) report that for the period 2005-2016 while ETS contributed in reducing emissions for participating installations, it failed to adequately compensate environmentally proactive firms or penalise polluters. A better understanding of the link between national strengths and weaknesses, and pollution is important because the global transition to a low-carbon economy will need to be underpinned by regulation and incentives to many economies with quite different characteristics. Addressing environmental degradation and promoting actions towards climate change mitigation and climate change adaptation requires a joint effort from multiple stakeholders in industry, research and academia, public authorities, and civil society. Identifying the features that affect the response from the private sector will allow to complement a more effective choice of incentives to reach the low-carbon goal.

Finally, we aim to shed light on the specific structural characteristics of distinct countries that facilitate more effective emission reduction strategies. This analysis will help identify the institutional and policy factors that act as enablers for businesses in their pursuit of sustainable practices. Ultimately, the findings of this study can inform policymakers, businesses, and researchers about the importance of fostering a supportive institutional environment and adopting policies that promote innovation and technology investment. By understanding the interplay between national competitiveness variables and emissions reduction, we can advance our understanding of the pathways to a sustainable, low-carbon economy and pave the way for effective climate action within the EU and beyond.

Section 2 describes the EU ETS mechanism and the national indicators from IMD and WEF employed. It also presents some related literature and the main hypothesis. Section 3 gives an overview of the data and methodology employed. Section 4 provides the empirical results and section 5 concludes.

2 Firms' emissions and national structural indicators

2.1 EU ETS

The EU ETS is the first and largest market for GHG emissions worldwide covering more than 11,000 manufacturing and power plants and about 45% of the EU's GHG emissions. The EU ETS operates in all EU-28 countries plus Norway, Switzerland and Liechtenstein. The EU ETS works on the 'cap and trade' principle. Firms receive (at the installation level) emission allowances, which in total do not exceed a predetermined annual cap set by the scheme. A cap is also set on the total amount of certain GHG that can be emitted by all installations covered by the system. The cap is reduced over time so that total emissions fall. Within the cap, firms can trade extra allowances with one another as needed. The limit on the total number of allowances available ensures that they have a value.

Set up in 2005, the EU ETS is presently in its fourth phase of operation. In Phase I (2005-2007) and II (2008-2012) allowances were given free of charge, whereby in Phase III (2013-2020) some allowances were purchased through auctions. Phase IV (2021-2030) aims to reduce the emissions of participating installations by 43 percent of 2005 values. Studies suggest that some abatement in GHG emissions has occurred and that the phased design has led to improvements (e.g., dealing with the initial over-allocation of allowances) in the mechanism (Laing, Sato, Grubb, Comberti, et al., 2013; Martin, Muûls, and Wagner, 2016).

Figure 1 shows "allocated" and "verified" GHG emissions for the total of all installations operating in the EU ETS for the period 2005-2018. Certainly, the system, based on the latest data, has coincided with reduced emissions overall within participating installations. Between 2005 and 2018, verified GHG emissions of ETS participants have fallen by approximately 23%.

[Insert Figure 1, here]

Turning now to the three phases of the system we make some interesting observations. First, arguably Phase I has been a period of adjustment both for the firms and for the regulators and Phase II was characterized by a slow pace of adjustment following the 2008 financial crisis. Allocated emissions stood at 2.3 billion tons of CO2 equivalent (2336 MtCO2e) in 2005, rose to 2.4 billion during Phase I and dropped to 2.2 billion at the end of Phase II in 2012. Second, allocated and verified emissions were drastically reduced after 2012. Allocated emissions provided for free to installations across the EU more than halved in 2013, dropping at 1 billion tons in 2013 followed by a gradual reduction of approximately 6% year-on-year during Phase III[2]. However, excess emissions (verified exceeding allocated) surged as firms found it challenging to keep up with the pace of emissions abatement. On average, firms under the EU ETS responded to the 57% curtailment of free permits from Phase II to Phase III with a mere 8.2% reduction in verified emissions as shown in Figure 1. The median firm emitted less than its allocated quota during the first two phases while exceeding the allocated

[2] Phase III ended in 2020, however our data cover up to 2018.

level by around 19 thousand tons in the 2013-2018 period and total excess emissions for ETS installations skyrocketed from 44 million tons throughout Phase II (2009-2012) to 5.7 billion tons in the period from 2013 to 2018.

On average, for the 2005-2018 period firms emit 2.31 million tons showing however a notable dispersion since the median firm records emissions of 259 thousand tons. Apart from some firm characteristics such as the size and the number of installations a considerable amount of variation stems also from industry and time characteristics. The Power and Heat sector dominates the emissions under the ETS aegis with more than a cumulative 18 billion tons over the whole 2005-2018 period.[3] This sector showed the sharpest reduction in allocated emissions by 88% generating sizable excess emissions despite the almost 400 million tons curtailment from 2012 to 2018.[4] Finally, it is noteworthy that the only sectors that enjoyed an increase in free permits for emissions after 2012 were Aluminum and Mining, mostly reflecting EU considerations over carbon leakage. The threefold increase of free permits to firms in the Aluminum sector was accompanied by a surge in verified emissions from almost 3 million tons in Phases I and II to 13.5 million tons after 2012 leading to the persistence of excess emissions of around 2 million tons per year.

Overall, Phase III induces a yearly decrease in allocated emissions by 1.5%. But although the vast majority of countries have reduced their emissions, this reduction is not linear in all countries as shown in Figure 2.

[Insert Figure 2, here]

[3] Although it is the most highly represented sector with 290 firms, emissions per installation surpass 2 billion tons whereas the Oil and Gas industry comes second with a cumulative 1/2 billion tons of emissions per installation. In terms of median industry firm, the highest level of emissions per installation is recorded for the Cement and Lime sector with 345 million tons for the 2005-2018 period, with the Iron and Steel, Oil and Gas and Power and Heat industries following with levels within 100 and 150 million tons.

[4] Emission abatement was modest in the Iron and Steel sector where total emissions hovered around 200 million tons around 2012 after a significant reduction compared to Phase I. The 27% drop in allocated permits after 2012 balanced verified and allocated emissions thereafter wiping out surplus allocations accumulated by the firms in the sector prior to Phase III.

2.2 National indicators

Competitiveness at the national level and country competitiveness rankings have gained importance and various studies are carried out on the subject. There is no generally accepted definition for the concept of national competitiveness, as it has a number of definitions and measuring methods. The two most popular institutions publishing national competitiveness reports are the International Institute for Management Development (IMD) and the World Economic Forum (WEF).

The IMD World Competitiveness Center, defines competitiveness as *the capacity of a government to foster prosperity*. An economy's competitiveness cannot be related only to GDP and productivity because firms also have to cope with political, social and cultural dimensions. Governments therefore need to provide an environment characterized by efficient infrastructures, institutions and policies that encourage sustainable value creation by the firms.

The IMD World Competitiveness Yearbook (WCY), first published in 1989, assesses the performance of 64 economies. It utilizes data over 335 variables, including a combination of hard and survey data, to measure various aspects of competitiveness. The ranking methodology focuses on four key dimensions: (a)*economic performance*; this dimension evaluates domestic economy; (b)*government efficiency*; this dimension measures the extent to which government policies encourage competitiveness within the country; (c)*business efficiency*; this dimension assesses how effectively firms realize their performance in a profitable and responsible manner; and (d)*infrastructure*; this dimension examines the adequacy of basic, technological, scientific and human resources in meeting the requirements of businesses.

Each broad category contains five sub-categories divided by focal point. Economic performance is divided into *domestic economy*, *international trade*, *international investment*, *employment*, and *prices*. Government efficiency is divided into *public finance*, *tax policy*, *institutional framework*, *business legislation*, and *societal framework*. Business efficiency is divided into *productivity and efficiency*, *labor market*, *finance*, *management practices*, and *attitudes and values*. Infrastructure is divided into *basic infrastructure*, *technological infrastructure*, *scientific infrastructure*, *health and environment*, and *education*. For each of these sub-categories a vast number of indicators is used combining both hard and survey data.

Our focus is on *business efficiency* and *infrastructure* and, more specifically, on (a) *labor market* as measured by the availability of skilled labour (*Skilled labour*), and the availability of competent senior managers (*Competent*); (b) *technological infrastructure* as measured by the number of computers per capita (*Computers*), the availability of digital/technological skills (*Digital skills*), the existence of public-private partnerships that support technological development (*PPP*), and the existence of a legal environment that supports the development and application of technology (*Tech development*); and (c) *scientific infrastructure* as measured by the existence of laws relating to scientific research that encourage legislation (*Research legislation*).

Figure 3 shows the average ranking of the countries participating in the EU ETS scheme during the Phase III period for these seven IMD indicators used in subsequent empirical analysis in Section 4.

[Insert Figure 3, here]

The World Economic Forum (WEF) defines national competitiveness as *the set of institutions, policies and factors that determine the level of productivity of an economy*. The Global Competitiveness Index (GCI) tracks since 2005 the performance of around 140 countries with respect to the factors and institutions identified by empirical and theoretical research as determining improvements in productivity, which in turn is the main determinant of long-term growth and an essential factor in economic growth and prosperity. The GCI combines 114 indicators grouped into 12 pillars: *institutions*, *infrastructure*, *macroeconomic environment*, *health and primary education*, *higher education and training*, *goods market efficiency*, *labor market efficiency*, *financial market development*, *technological readiness*, *market size*, *business sophistication*, and *innovation*. For completeness we focus again on *Technological readiness*, *Business sophistication*, and *Innovation capacity*.

Figure 4 shows the average ranking of the countries participating in the EU ETS scheme during the Phase III period for these three WEF indicators used in subsequent empirical analysis in Section 4.

[Insert Figure 4, here]

2.3 Related literature

The cap-and-trade ETS was expected, inter alia, to induce firm level innovation away from brown technologies (European Commission, 2005). The studies performed so far about the effects of the EU ETS on innovation provide mixed evidence (Hoffmann, 2007; Anderson et al., 2010; Schmidt, Schneider, Rogge, Schuetz, and Hoffmann, 2012; Borghesi et al., 2015). A cap-and-trade system imposes extra costs on firms (e.g., Deschenes 2014). Andreou and Kellard (2021) find poorer firm performance for environmentally proactive firms, suggesting that there is an economic cost to good environmental behaviour.

At the same time, previous empirical evidence suggests that firm performance outcomes are primarily determined by the development of institutions – defined as regulative, normative, and cognitive structures and processes – in the country (North, 1992; Scott, 1995). Both formal and informal constraints and the development of institutional frameworks can have a profound effect on a firm's behavior (Henisz and Swaminathan 2008; Meyer and Peng 2005, p. 613; North 1992; Peng 2004; Peng, Wang, and Jiang 2008, p. 923; Williamson 2000) given that institutional settings create incentive-constraint structures within which firms operate.

Finally, developing and fostering sound institutions affects public choice and matters for the enforcement and effectiveness of environmental policies (Halkos and Tzeremes, 2013). Empirical studies have documented the adverse environmental effect of corruption in developing and transition economies (Damania, Fredriksson, and List, 2003; Pellegrini and Gerlagh, 2006; Abid, 2017) as it deteriorates environmental quality, directly through politics and then by its indirect effect of diminishing real income. Abid (2017) uses data from the World Bank Worldwide Governance Indicators (WGI) and finds that institutional development is associated with lower emissions. In addition, for EU countries, institutions appear to have an indirect effect on emission abatement by bolstering the efficiency of public expenditure. Gani (2012) finds that rule of law, political stability and control of corruption can help developing economies reduce emissions per capita, a result corroborated by the findings of Bhattacharya, Churchill, and Paramati (2017) and Sekrafi and Sghaier (2018). Bae, Li, and Rishi (2017) argue that democracy and economic freedom increase emissions' reduction while Lau, Choong, and Eng (2014) find that there is a significant positive relationship between institutional quality and reduced emissions. Similarly, Ibrahim and Law (2016) demonstrate that clear institutional reforms improve environmental quality and that the impact of trade on the environment tends to depend on a country's institutional context.

2.4 Main Hypothesis

Our primary research question investigates the influence of a country's sound institutions on the environmental performance of firms operating in the country, as measured by their emissions. Specifically, we propose that firms operating in supportive environments characterized by business efficiency and favorable policies experience lower fixed and transaction costs. As a result, they are more likely to adopt green technologies and engage in green innovations.

Therefore, our main hypothesis is as follows:

Main Hypothesis: *National structural indicators, which encompass a sound institutional framework and policies promoting innovation and technology investment, have a positive impact on firms' ability to reduce emissions.*

The central question in the relationship is which criteria among the many variables that measure different facets of national competitiveness are the most significant and to what extent they determine firms emissions abatement.

As a first motivation, Figure 5 shows that there is a negative relationship between each of the seven IMD variables and firms' emissions at the country level, measured as the logarithmic of verified emissions scaled by the number of installations of the firm. A similar picture is drawn when using the three WEF indicators in Figure 6.

[Insert Figure 5, here]

[Insert Figure 6, here]

3 Empirical analysis

3.1 Data and variables

The raw dataset EU ETS Company Database includes 1,018 publicly listed and private companies from 31 European countries (*i.e.*, EU-28, Norway, Iceland, and Liechtenstein), accounting for more than 90% of GHG emissions from EU ETS companies and featuring 14,196 firm-year observations.[5] The sample spans the period 2005-2018 and covers all three different EU ETS phases. The database includes information about the per firm number of facilities/installations, as well as the per firm allocated and verified emissions, covering different industries such as Oil and Gas, Power and Heat, Motor, Chemicals, Metals, et cetera. After eliminating observations with missing information about the sector that firms operate in, the full sample includes 925 firms featuring 11,578 firm-year observations.

Table 1 presents some basic summary statistics for the EU ETS sample.

[Insert Table 1, here]

For conducting the analysis, two filtering criteria have been applied:

i. industries with less than 1% representation in the sample are eliminated; we impose this filter to minimize the impact of sectors that are underrepresented in the sample (however, this exclusion is based on the number of observations not the volume of emissions relating to these observations).

[5] The ETS database reports data on the country of the firms' headquarters representing 46 countries both inside and outside the EU.

ii. observations at the top and bottom 1% of the distribution in terms of excess emissions as a share of allocated emissions are also eliminated; we have imposed this filter to minimize the impact of outliers evidenced by the large difference between the "mean" and "median" values of this variable before the imposition of filtering.[6]

We end up with 893 firms featuring 11,004 firm-year observations for the period 2005-2018 (23.1% from Phase I, 38.6% from Phase II and 38.3% from Phase III) from 11 industries. We merge these data with financial data from the ORBIS database (BvD) using the bigram string matching method based on the international company name. Our final sample comprises of 540 firms, featuring 6,459 firm-years observations. All continuous variables are winsorized at 1% from the top and bottom of their distribution.

Table A1 in the Appendix defines the variables employed in the empirical analysis and provides their sources. Table A2 in the Appendix shows correlation coefficients among the basic variables. Table 2 reports basic summary statistics for the variables used to test the main hypothesis.[7]

[Insert Table 2, here]

Our main dependent variable is the firm's log of verified emissions normalized by the number of installations reported for each firm (*Verified Installation*). The mean value of *Verified Installation* is 319 thousand tons for the whole period under consideration, however,

[6] This filtering automatically removes outliers of the same fashion in terms of excess emissions as a share of verified emissions.

[7] A careful look at Table 2 reveals some extreme values for the share of excess emissions as a share of allocated and verified emissions. Although the very high rate for the maximum value of excess emissions can raise doubt on the validity of the data and, hence, our estimates, a nuanced examination assures otherwise. More specifically, there are 30 firm-year observations with a percentage of more than 1000% of excess over allocated emissions in the final sample used in the empirical estimations. All of them are recorded during Phase III, whereby a sharp decline in allocated emissions was enforced. A small number of enterprises participating in the ETS did not abet their emissions resulting in the substantially elevated share of excess emissions recorded in Table 2. In the same vein, large negative values (less than -100%) of excess emissions compared to verified emissions are plausible when scrutinized. Almost half of the 97 firm-year observations in this category are recorded in 2011 and 2012, which could be interpreted as a preparation for Phase III even before the steep decline in allocated emissions. Moreover, chemical and mining industries actually witnessed an increase in allocated emissions from the scheme in Phase III, while some entities maintained a decreasing trend in their emissions. Nonetheless, removing observations does not alter the results reported in Section 4.These results are not shown in the paper and are available upon request.

declines significantly from 786.6 thousand tons for Phase I to 397.4 thousand tons for Phase II and finally to 282 thousand tons after 2012.

We include the following seven IMD indicators: skilled labour (*Skilled labour*), competent senior managers (*Competent*), computers per capita (*Computers*), digital/technological skills (*Digital skills*), public-private partnerships (*PPP*), development and application of technology (*Tech development*), and scientific research legislation (*Research legislation*). Similarly, we test three of the main WEF pillars, namely: technological readiness (*Technological readiness*), business sophistication (*Business sophistication*) and innovation capacity (*Innovation capacity*).

We control for several macroeconomic variables. Transforming production and reducing emission warrants capital investment so we include the share of gross fixed capital formation over GDP (*GFCF*) as well as the intensity of R&D investment (measured as a share of GDP) undertaken by the business sector (*Business R&D*). In addition, we control for GDP growth (*GDP growth*), the real interest rate (*Rate*) as an indicator of monetary stance and include a measure of financial development (*Financial development*), primarily through the stock market index from IMD. As a robustness check we also use liquid liabilities (*Liquid liabilities*) as a share of GDP (World Bank) or the financial development metric based on World Bank data introduced by De Haas and Popov (2018) (*Stock markets*).[8]

We use a parsimonious set of firm-level variables to capture size (the natural logarithm of total assets) (*Size*), total assets growth (*Total assets change*), return on equity (*ROE*), cash flow (*Cash flow*) as well as the logarithm of intangible assets (*Intangible*) since emission abatement is associated with innovative practices at the firm level.

[8] Data for GDP growth, GDP per capita and gross fixed capital formation are from Eurostat, business R&D intensity and real interest rate are from the OECD database and financial variables are from the World Bank database. An alternative indicator for financial development indicator is calculated from World Bank data following De Haas and Popov (2018) as the share of total credit plus stock market value over GDP.

3.2 Methodology

Our benchmark empirical model takes the form:

$$\textit{Verified Installation}_{ijt} = a + a_1 \textit{Institution}_{jt-1} + a_2 F_{ijt} + a_3 B_{jt} + a_5 T_{ft} + u_{ijt} \qquad (1)$$

In equation (1), *Verified Installation* is the logarithm of verified emissions of a firm i operating in country j in year t normalized by the number of installations of the firm i. *Institution* quantifies each variable of the IMD World Competitiveness (WEF) indicator used of country j in year *t-1* to address endogeneity issues from potential omitted variable bias. Equation (1) also includes vectors of firm (F) and macroeconomic (B) control variables. In addition, we include industry fixed effects to control for time-invariant industry characteristics that shape innovation as well as emissions given the architecture and implementation of the ETS. We also control for the three different phases of the scheme. We avert from using country fixed effects since our variables of interest are the institutional indicators which do not record considerable variation over the time sample. Finally, u is the stochastic disturbance.

The empirical analysis focuses on testing our main hypothesis, *i.e.*, which structural characteristics of the country as measured by the national competitiveness indicators are associated with firms' emissions controlling for various firm and macroeconomic variables. Hence, the parameter of interest is α_1, where a negative and statistically significant estimated coefficient implies a moderating effect of the country's indicator on verified emissions per installation controlling for firm and industry characteristics. We use a balanced panel dataset of 540 firms for the period covering 2005 to 2018.

Identifying a causal relationship is challenging due to possible omitted-variable bias. Using firm-level data emissions is a major step toward limiting omitted-variable bias. We also include industry fixed effects to account for the inherent characteristics of specific industries, for example the very high emissions intensity of the Power & Heat sector in our sample, when it comes to GHG emissions. Any remainder source of omitted-variable bias must be related with time-varying firm characteristics that correlate with national competitiveness and affect firms' emissions. Using several firm-year controls as well as macroeconomic variables further safeguards our analysis from such bias.

Nonetheless, apart from our baseline OLS results, we present estimations using a GMM approach to tackle potential endogeneity. Given the panel structure, we use lagged values of the institutional variables up to two periods as instruments and apply the two-step GMM estimator which utilizes a heteroskedasticity-robust weighting matrix. Having said that, the empirical results presented in the following section are not to be interpreted as direct indicators of a causal relationship from institutional variables to firm-level emissions.

As a further robustness and for considering the vast number of variables used in the IMD global competitiveness indicator, we also conduct a factor analysis to explore the determinants of competitiveness that are significant for European economies. From a set of p variables, factor analysis extracts a reduced set of m components or factors that accounts for most of the variance in the$p$ variables. In other words, a set of p variables is reduced to a set of m underlying superordinate dimensions. These underlying factors are inferred from the correlations among the p variables.

For the factor analysis we consider an augmented set of 38 indicators from IMD and WEF. In particular, from IMD we take the following indicators:(a) another four variables for labor markets, *i.e.*, finance skills, attracting and retaining talent, brain drain, and foreign highly skilled personnel; (b) one variable for management practices, *i.e.*, entrepreneurship; (c) three variables for institutional framework, *i.e.*, legal and regulatory framework, adaptability of government policy, and transparency; (d) three extra variables for technological infrastructure, *i.e.*, funding of technological development, computers in use, communications technology; (e) two extra variables for scientific infrastructure, *i.e.*, intellectual property rights, and knowledge transfer; and (f) three variables for finance, *i.e.*, stock markets, stock market capitalization, and venture capital. Similarly we use all twelve pillars of the Global Competitiveness Index (GCI) of the WEF and the index itself.

We perform a principal component factor analysis using the augmented set of indicators. We use oblique (as opposed to varimax) rotation to allow for potential correlation among the three distinguished factors. This option is also preferable when there is an unobserved common factor underlying almost all the observed variables, as it can be postulated for the IMD and WEF indicators. We then compute the factor score for each observation using regression scoring and substitute it for *Institution* in equation (1).

4 Empirical Results

Table 3 shows the results from OLS estimations.[9] All estimations include industry and phase fixed effects and heteroskedasticity-robust standard errors.[10] After controlling for firm characteristics, macroeconomic variables and industry effects we find a negative and significant relationship.

The last row in Table 3 shows the decrease in firms' emissions per installation associated with a ceteris paribus improvement in the respective indicator by one standard deviation. For example, increasing the indicator of skilled labour (*Skilled labour*) by one standard deviation decreases firms' emission per installation by 21.4%. A similar result holds for the competent managers variable (*Competent*) indicating the importance of labour market efficiency. Moreover, technology infrastructure appears to play a significant role since increasing by one standard deviation the computers per capita variable (*Computers*) decreases firms' emissions per installation by 37.9%. A similar increase in the indicator that assesses whether digital/technological skills (*Digital skills*) in a country are readily available leads to a reduction in firms' emissions per installation by 14.9%. The importance of a supportive environment for technology development and research innovation is highlighted. A one standard deviation in the indicator measuring the existence of supportive towards techno-

[9] Note that all regressions using the WEF indicators exclude 2018 due to the change in the way GCI and its sub-indicators are calculated in that year.

[10] As a proxy for financial development we use the stock market index of IMD; however, they do not alter if we include liquid liabilities or an indicator variable for above average financial development based on the De Haas and Popov (2018) metric.

logical development ventures between the public and private sector (*PPP*) decreases firm's emissions by 14.1%. Accordingly, a one standard deviation increase in the indicator for the existence of a legal environment which is supportive for the development and application of technology (*Tech development*) is associated with a 11.2% reduction in verified emissions per installation. Finally, an one standard deviation increase in the indicator for laws relating to scientific research that do encourage innovation (*Research legislation*) reduces firms' emissions per installation by 13.9%.

As for the WEF indicators the regression results corroborate our previous findings about the importance of business efficiency, technological infrastructure and supportive innovation systems. In particular, a one standard deviation increase in the *Business sophistication* pillar yields a 33.2% abatement in emissions per installation; a one standard deviation increase in the *Technological readiness* pillar yields a 19.3% reduction and a one standard deviation increase in the *Innovation capacity* pillar yields a 27.8% decrease. Thus, the results underline a sizeable effect of the included structural country attributes in the emission reduction process at the firm level.

Regarding the rest of the controls, in general, as expected larger firms appear to emit more indicated by the positive and significant coefficient of total assets, whereas firms with more intangible assets are associated with less emission intensity. The latter can be interpreted as a proxy for the effect of firm-level innovation (partially captured in intangible investment) on the decline in emission intensity. Taking this into consideration our results indicate that the country's structural characteristics matters for emission abatement controlling for firm-level efforts on the innovation front. Economic growth results in firms' emitting more emissions significantly in six out of ten specifications whereas there is robust evidence of the emission reducing role of capital investment.

[Insert Table 3, here]

Table 4 shows GMM estimations with two period lags as instruments for each of the indicators.[11] The potential omission of significant covariates in the emissions regression would create endogeneity and therefore bias the OLS results. The Anderson *CC* statistic confirms the relevance of the instruments whereas the Hansen J test confirms the validity of the chosen instruments except for the case of *Computers*. We test the endogeneity assumption using a difference-in-Sargan endogeneity statistic and conclude that in six out of ten specifications the indicators can be treated as exogenous. All variables remain negative and significant and the same holds for the rest of the control variables. Furthermore, we observe that the relevant semi-elasticities are greater in size implying a greater moderating effect of some country characteristics. Increasing computers per 1000 persons by one standard deviation (189 personal computers) is associated with a 37.9% drop in emissions per firm installation based on the results depicted in column (3). Improving the economy's innovation capacity as measured by the relevant WEF indicator reduces emissions per installation by 33.1% as shown in column (10).

Overall, the results from Tables 3 and 4 underscore the mitigating effect that technological infrastructure, labour markets and supportive institutions can exert on firm-level emissions, controlling for firm and industry characteristics.

[Insert Table 4, here]

Figure 7 shows coefficients for the ten institutional variables along with 95% confidence intervals for regressions as in Table 3 distinguishing between Phases I&II and Phase III. Phase I was a test phase for both firms and regulators and not conceived to result in major emission cuts. At the same time, Phase II was characterized by a slow pace of adjustment following the 2008 financial crisis with emission intensity affected by the seminal declined in economic activity in the EU. On the other hand, Phase III marked the implementation of the auctioning system and the introduction of the market stability reserve, both of which effectively tackled the problem of allowance oversupply. Moreover, as outlined in Section 3 the majority of the participating corporations faced a sharp decline in allocated permits,

[11] Results with three and four lagged values as instruments (not reported here) corroborate our findings.

thus gas to factor in the cost of auctioned emission allowances in their strategy. Against this background, we expect our results to be driven mainly by developments during Phase III. In fact, it is evident from Figure 7 that the majority of national indicators turn out negative and significant only for the period 2013-2018, *i.e.*, creating a more robust framework with an increased carbon price fostered stronger incentives for reducing emissions, which were further bolstered by a supportive institutional environment. Table 5 replicates the baseline regressions of Table 5 for Phase III.[12]

[Insert Figure 7, here]

[Insert Table 5, here]

Finally, in Table 6 we substitute for the factor scores to reduce the number of potential indicators that affect firm emissions. Using the principal factor method, we find three factors from the augmented sample of 38 indicators which capture 85% of the total variation as shown in Table A3 in the Appendix (the first two factors alone cover more than 80% of total sample variation). The shared background of the variables in the analysis is underscored by the low rate of uniqueness in the variables. No variable shows a ratio of above 50% and the highest degree of uniqueness is embodied in the *foreign personnel with high skills* (48.6%) and *computers per capita* (44.3 %) IMD indicators.

Table A4 in the Appendix shows the respective factor loadings after the oblique rotation.[13] Based on the estimated effect of the observed indicators on the unobserved factors we broadly define the three factors as: (i) institutional framework, since almost all IMD variables are positively associated with a higher factor score; (ii) national competitiveness, as all WEF indicator are positively associated with a higher factor score; and (iii) skills due to the positive effect of skilled and digital labor, financial skills and also competence of managers.

The results from Table 5 corroborate the findings of Tables 3 and 4 on the importance of technological infrastructure, innovation systems and skills in the emissions abatement

[12] Results for baseline regressions for the other two phase periods are available upon request.

[13] Only correlations greater than 0.4 are shown in the Table for clarity.

process for the firms participating in the ETS. Factors 2 and 3 prove to significantly tame emissions irrespective for the estimation method, whereas the first factor associated with overall institutional framework is not significant in the estimations. Achieving a one standard deviatoin score for factor 3 relating to skilled labor force is associated with a reduction of firms' emissions per installation by more than 20%.

[Insert Table 6, here]

5 Conclusions

The transformation towards a sustainable pathway is heavily dependent on the advancement and adoption of green technologies and, hence is inherently connected to green innovation and the innovation process in general. Firm transformation and technological upgrading at the micro level depend on the accumulated firm capabilities in terms of physical infrastructure, knowledge and human capital. Nonetheless, innovation is governed by substantial externalities and market imperfections, even more so in the case of green innovation. Hence, institutions, policies and synergies at the country level are of pivotal importance for the green transformation required to reach climate goals. The development and functioning of innovation systems relies on sound institutional performance underpinning the broad concept of national development. While many firms have taken steps to reduce their own impact on the environment, to achieve lasting and significant change, firms will have to team up with multiple stakeholders across the industry, the government, the research community and civil society.

The aim of this study is to reveal the structural and institutional factors that determine and contribute to the green transition of European economies. Towards this direction, we examine the relation between country-specific characteristics and emissions of firms participating in the EU ETS. We use data on verified emissions at the firm level coupled with a bevy of structural indicators from IMD and WEF. We draw upon a balanced panel data set of 540 firms spanning from 2005 to 2018 and estimate the effect of a parsimonious set of country-level structural variables on emissions per installation.

Despite the fact that emission abatement is achieved at the firm or plant level, we postulate that structural and institutional factors at the country level are of material importance. Advances in technology and infrastructure are the main drivers for the reduction of GHG emissions and are, in turn, intrinsically linked to overall country characteristics. More specifically, developing functional innovation systems at the regional, national, and union level warrants a holistic approach covering the public sector, academia, and civil society apart from private entities. Sound institutions can act as enablers and accelerators for firms and industries in the green transition process, hence we expect an attenuating effect on emissions conditional on firm attributes.

Controlling for firm characteristics as well as industry and phase fixed effects, we find strong support for our main hypothesis, *i.e.*, sound institutional attributes at the country level are associated with ebbing emissions for EU ETS participants. A robust set of ten institutional indicators exhibits strong association with emissions abatement. The choice of the institutional variables for the empirical analysis is also enhanced by factor analysis which reduces the number of potential covariates given the common underlying notions of the institutional variable in hand. All results underscore the importance of technological readiness, innovation capacity and skills in the emissions abatement effort. Firms operating within a set of supporting institutions are expected to reduce GHG emissions more efficiently controlling for firm and industry features.

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Figures

Figure 1. Emissions
The figure shows aggregate allocated and verified GHG emissions for the period 2005-2018.

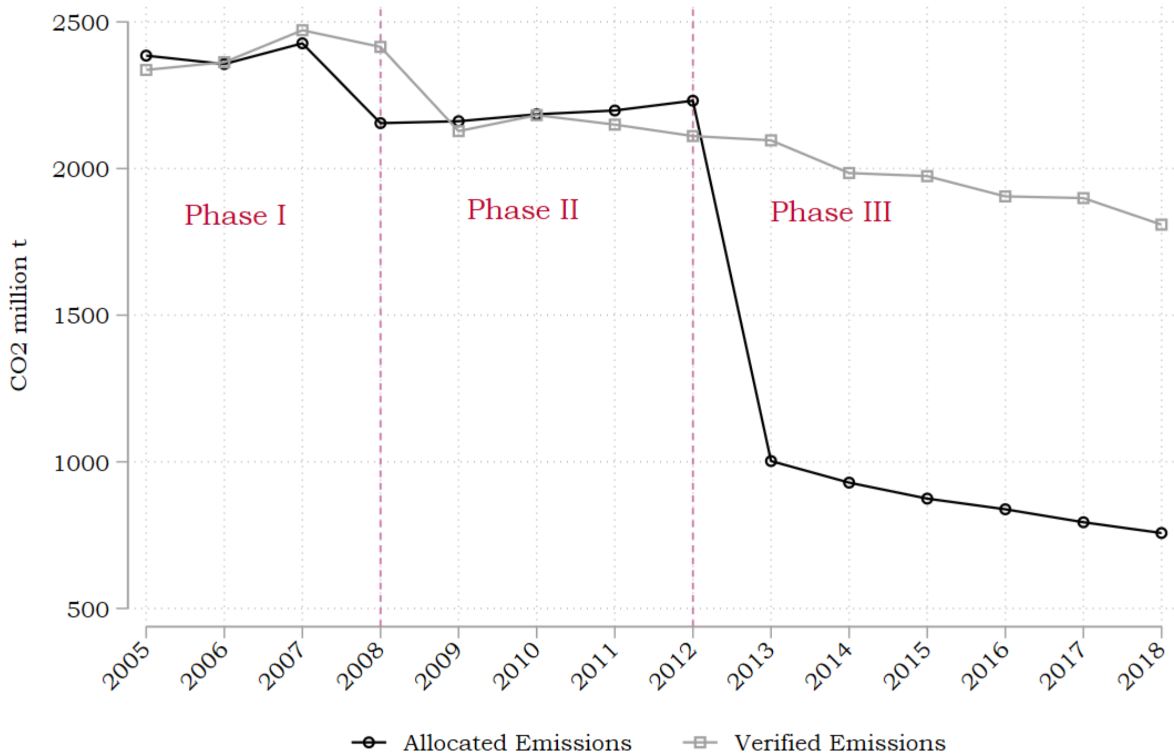


Figure 2. Emissions per country during Phase III
The figure shows percentage change in verified GHG emissions per country for the period 2013-2018.

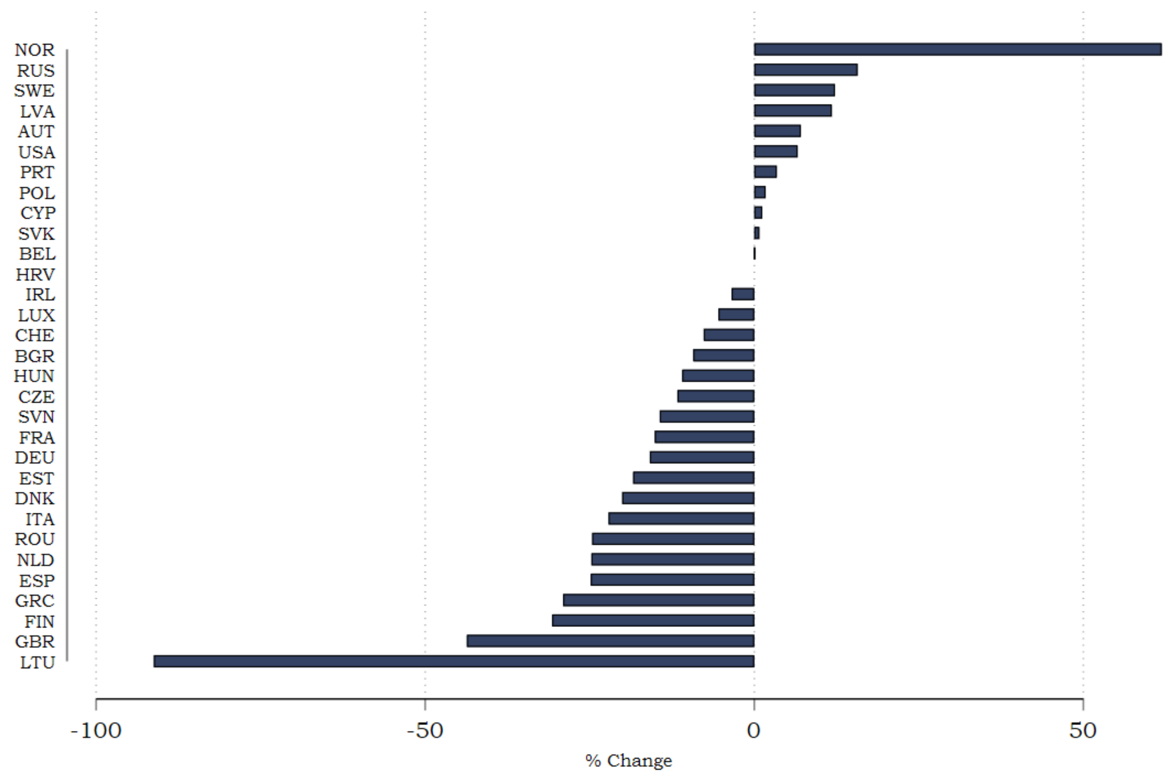


Figure 3. IMD indicators

The figure shows IMD Indicators for the countries that participate in EU ETS for the period 2005-2018.

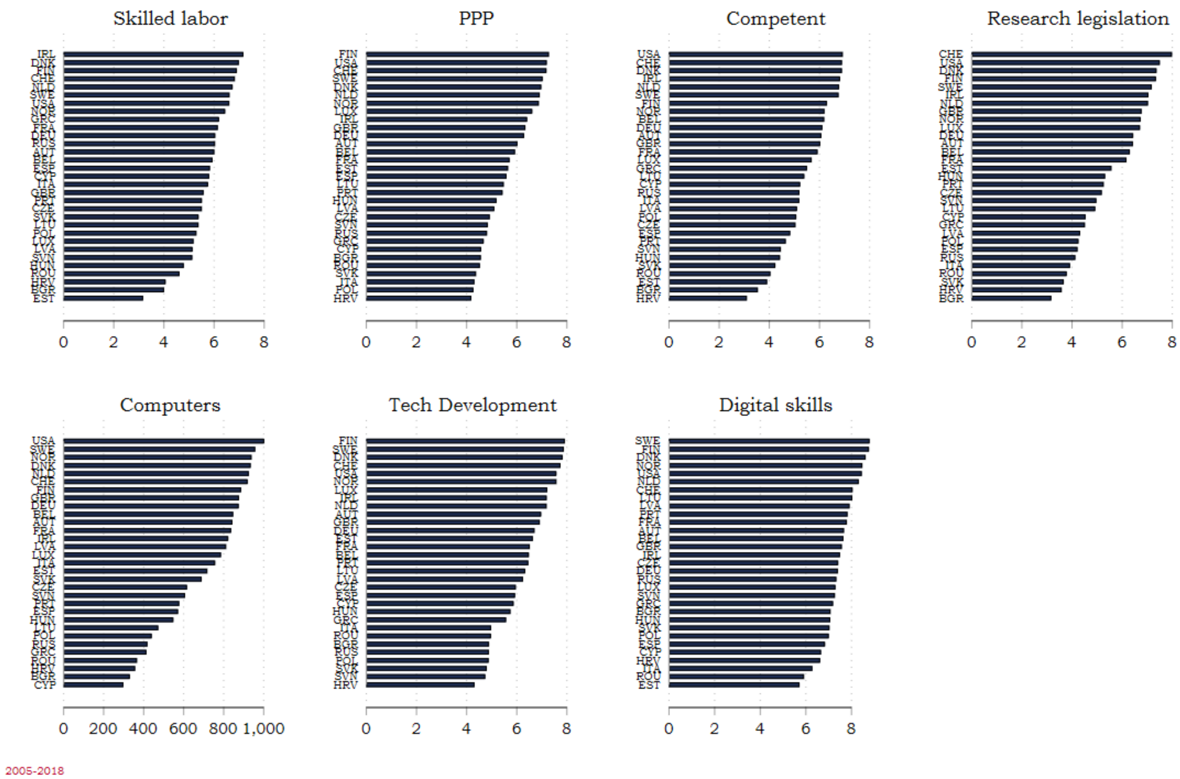


Figure 4. WEF indicators
The figure shows WEF indicators for the countries that participate in EU ETS for the period 2005-2018.

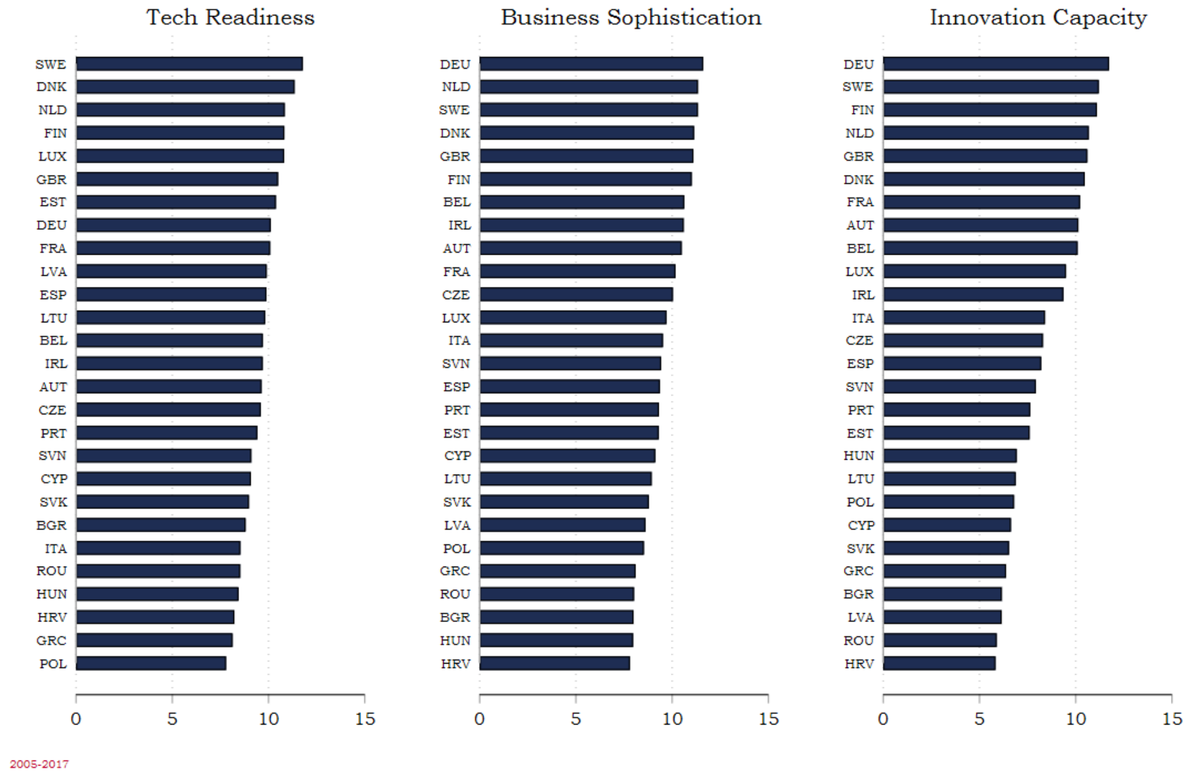
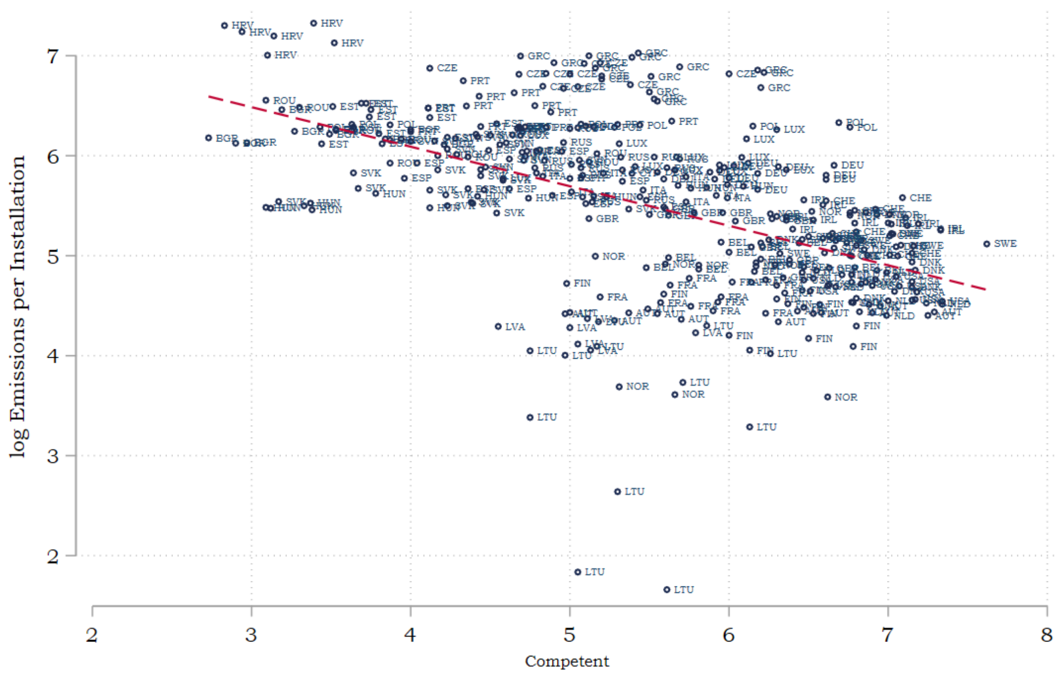


Figure 5. IMD indicators and firms' emissions

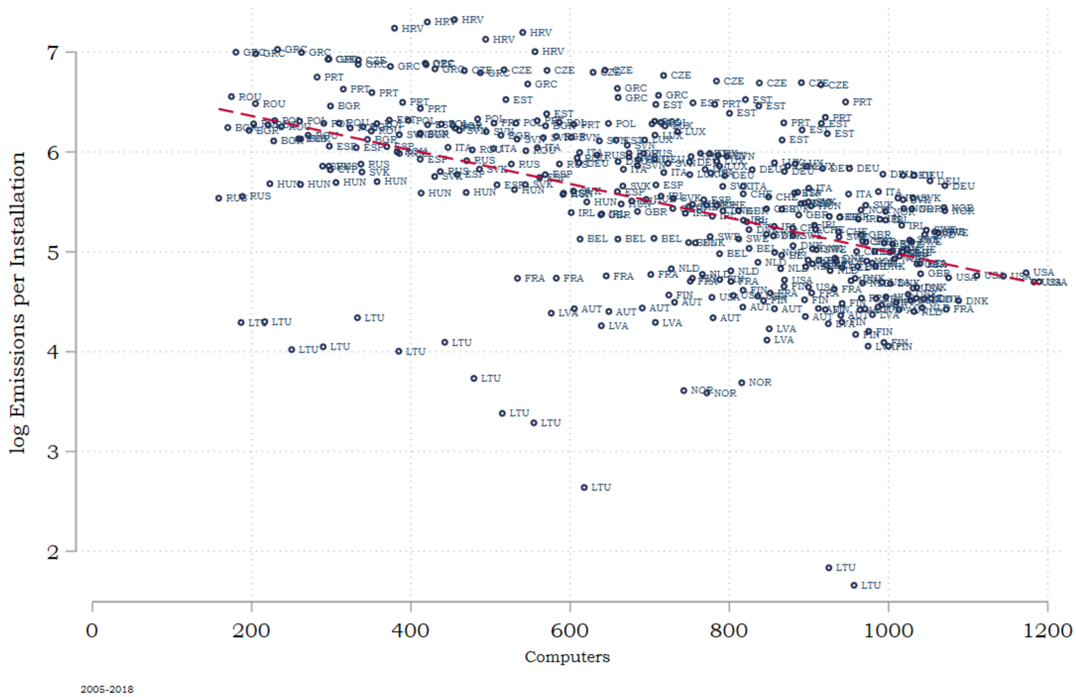
The figure shows scatterplots of selected indicators from the of IMD World Competitiveness Ranking for the countries that participate in EU ETS for the period 2005-2018.

Skilled labour

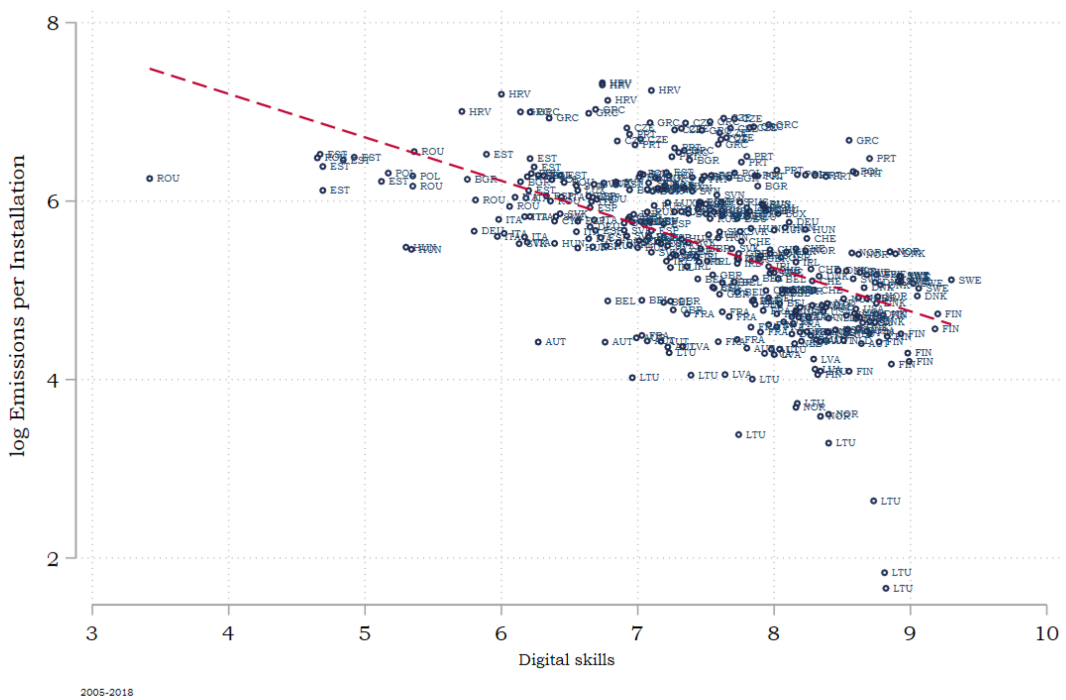
Competent



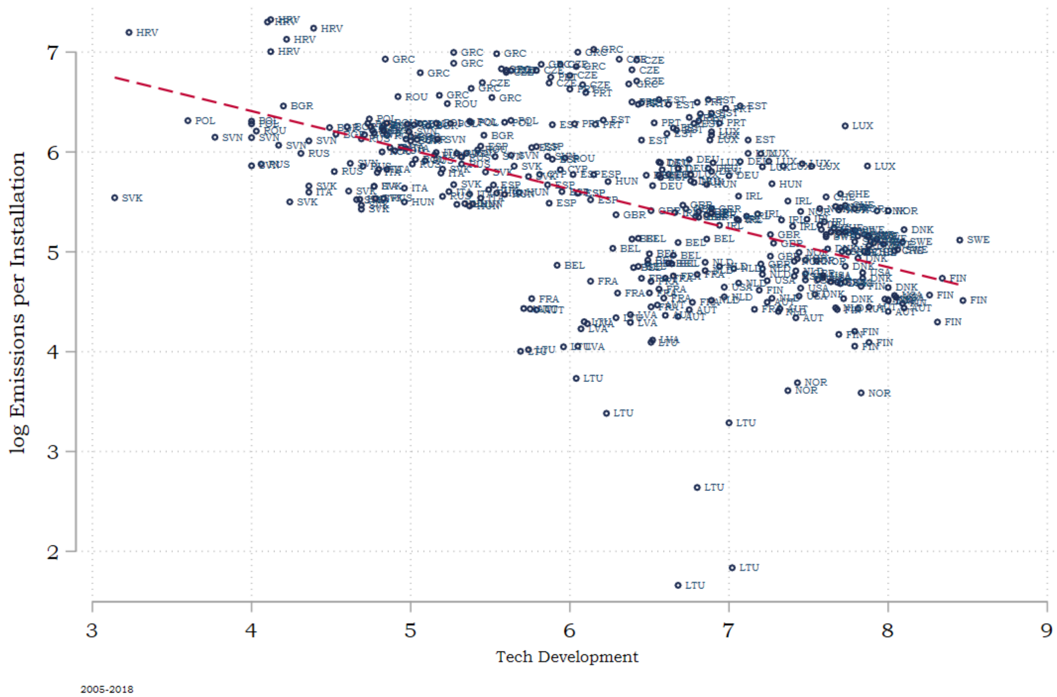
Computers



Digital skills



Tech development



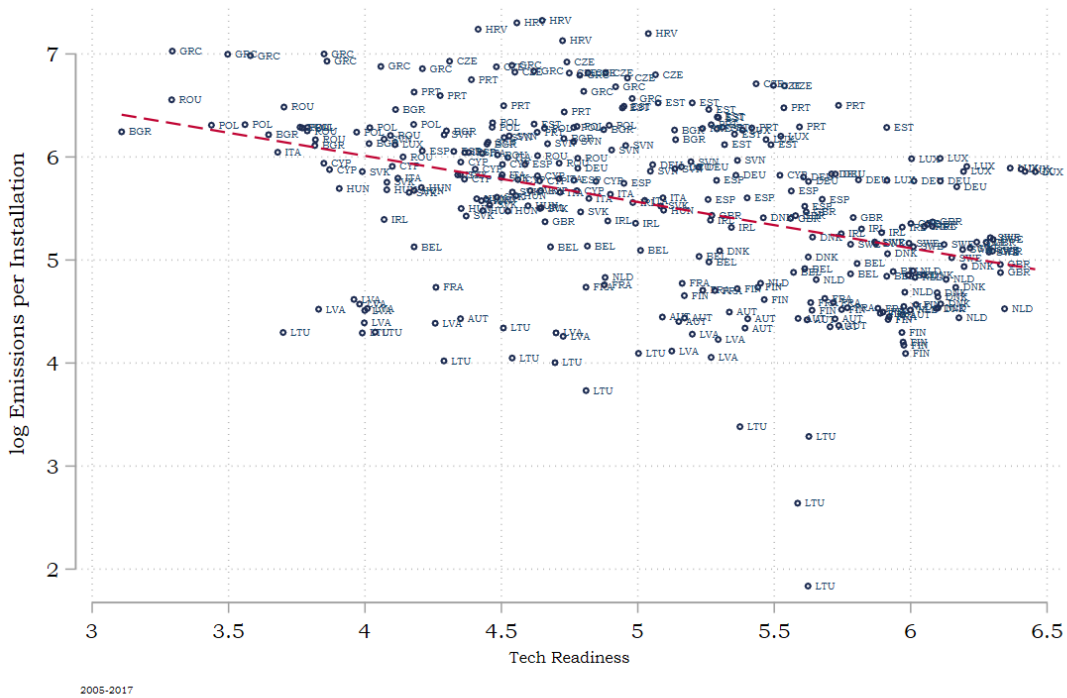
PPP

Research legislation

Figure 6. WEF indicators and firms' emissions

The figure shows scatterplots of selected indicators from the WEF World Competitiveness Ranking for the countries that participate in EU ETS for the period 2005-2017.

Technological readiness



Business sophistication

Innovation capacity

Figure 7. Coefficient plots from regression analysis for each phase period.

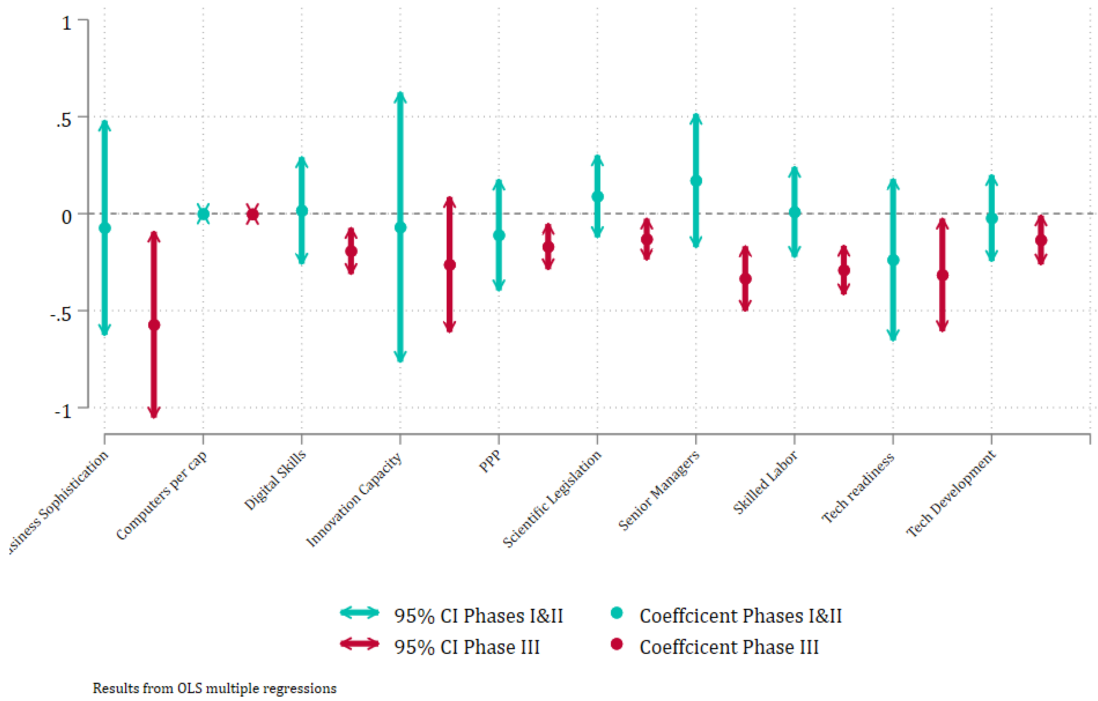


Table 1. EU-ETS summary statistics

The table reports basic summary statistics for the EU-ETS sample. Definitions for all variables are in Table A1 of the Appendix. The sample period is 2005-2018.

	Obs.	Mean	St.Dev	Min	Max
Allocated	11,578	1,965.956	256.273	0.001	144,000
Verified	11,578	2,474.378	287.361	0.004	150,000
Verified Installation	11,578	348.424	70.01	0.003	22,764.85
Excess	11,578	508.422	-4.204	-48,800	137,000
Excess % allocated	11,578	7,735.743	-5.145	-99.995	1.12e+07
Excess % verified	11,578	-716.335	-5.424	-2,210,000	99.999
Installations	11,578	9.875	3	1	343
State	11,578	0.216	0	0	1
Public	11,578	0.296	0	0	1
Phase I	11,578	0.219	0	0	1
Phase II	11,578	0.368	0	0	1
Phase III	11,578	0.413	0	0	1
EU28	11,578	0.894	1	0	1

Table 2. Summary statistics
The table reports basic summary statistics for the final sample. Definitions for all variables are in Table A1 of the Appendix. The sample period is 2005-2018 upon data availability.

	Obs.	Mean	Median	St.Dev	Min	Max
Allocated	1,863	1,715.371	226.27	5,538.131	0.025	75,720.05
Verified	1,863	2,343.799	337.042	6,393.09	0.037	72,436.55
Verified Installation	1,863	319.624	74.618	772.154	0.031	10,222.78
Excess	1,863	628.428	8.422	3,442.813	-13,500	42,250.3
Excess % allocated	1,863	175.353	10.22	714.606	-90.757	8,641.9
Excess % verified	1,863	1.659	9.272	74.194	-981.892	98.856
Installations	1,863	12.77	4	31.595	1	285
State	1,863	0.252	0	0.434	0	1
Public	1,863	0.322	0	0.467	0	1
Phase I	1,863	0.025	0	0.155	0	1
Phase II	1,863	0.218	0	0.413	0	1
Phase III	1,863	0.757	1	0.429	0	1
EU28	1,863	1	1	0	1	1
Size	1,863	20.311	20.217	2.157	14.801	26.95
Total assets change	1,863	7.034	-.373	43.152	-69.32	320.844
ROE	1,863	4.537	1.43	15.633	-82.72	66.64
Intangible	1,863	15.503	15.344	3.749	0	25.126
Cash flow	1,863	589.185	36.722	2,584.973	-860.558	45,235.63
GDP growth	1,863	0.029	0.027	0.035	-0.146	0.349
GFCF	1,863	20.13	20.284	2.76	11.074	37.286
Business R&D	1,863	1.274	1.38	0.657	0.11	2.67
Rate	1,863	-0.945	-1.05	1.32	-3.86	7.23
Liquid liabilities	1,630	97.502	89.873	71.153	29.777	699.197
Financial development	1,170	131.285	121.548	56.579	22.593	309.213
Stock markets	1,863	5.528	5.77	1.389	1.86	7.77
Research legislation	1,863	5.552	6.14	1.406	2.08	8.2
Competent	1,863	5.673	5.88	0.792	2.73	7.62
PPP	1,817	5.612	5.77	0.977	2.78	8.07
Computers	1,863	860.805	921.66	189.703	117.01	1087.99

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Digital skills	1,863	7.366	7.26	0.849	3.42	9.3
Skilled labour	1,863	5.958	5.97	0.83	2.47	8.09
Tech development	1,863	6.261	6.5	0.99	3.14	8.47
Technological readiness	1,631	5.478	5.71	0.614	3.291	6.457
Business sophistication	1,607	4.981	5.056	0.628	3.467	6.26
Innovation capacity	1,607	4.544	4.832	0.89	2.913	5.787

Table 3. Baseline regressions

The table reports coefficient estimates and t-statistics (in parentheses) from estimations using the country indicator variables. Columns (1)-(7) use the IMD indicators as dependent variables and columns (8)-(10) use the WEF indicators as dependent variables. Definitions for all variables are in Table A1. Estimation method is OLS with phase and industry fixed effects, and robust standard errors The sample period is 2005-2018 for columns (1) -(7) and 2005-2017 for columns (8)-(10). The lower part of the table also reports the number of observations and the adjusted R-squared. The ***, **, and * marks denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Skilled labour	-0.258***									
	(0.053)									
Competent		-0.269***								
		(0.074)								
Computers			-0.002***							
			(0.000)							
Digital skills				-0.176***						
				(0.055)						
PPP					-0.144***					
					(0.055)					
Research legislation						-0.099**				
						(0.049)				
Tech development							-0.113**			
							(0.057)			
Technology readiness								-0.314***		
								(0.120)		
Business sophistication									-0.529***	
									(0.189)	
Innovation capacity										-0.312**
										(0.157)

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Size	0.287***	0.304***	0.296***	0.295***	0.312***	0.301***	0.300***	0.296***	0.307***	0.297***
	(0.029)	(0.030)	(0.029)	(0.030)	(0.030)	(0.030)	(0.030)	(0.033)	(0.033)	(0.033)
Total assets change	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Intangible	-0.090***	-0.096***	-0.094***	-0.095***	-0.104***	-0.097***	-0.098***	-0.094***	-0.098***	-0.096***
	(0.017)	(0.017)	(0.017)	(0.017)	(0.018)	(0.017)	(0.017)	(0.019)	(0.019)	(0.020)
ROE	-0.008***	-0.007***	-0.007**	-0.007**	-0.007**	-0.007**	-0.007**	-0.005*	-0.006*	-0.006*
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Cash flow	-0.000*	-0.000*	-0.000*	-0.000*	-0.000*	-0.000*	-0.000*	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Rate	0.104***	0.112***	0.019	0.136***	0.107***	0.110***	0.102***	0.095**	0.091*	0.111**
	(0.037)	(0.036)	(0.045)	(0.037)	(0.038)	(0.037)	(0.037)	(0.046)	(0.047)	(0.045)
GDP growth	1.680	1.877	2.485*	2.543*	2.890**	2.417*	2.312*	1.857	1.830	2.172*
	(1.367)	(1.372)	(1.392)	(1.395)	(1.326)	(1.382)	(1.380)	(1.424)	(1.300)	(1.309)
GFCF	-0.056***	-0.056***	-0.054***	-0.049***	-0.045**	-0.043***	-0.042**	-0.046**	-0.062***	-0.046**
	(0.017)	(0.017)	(0.017)	(0.017)	(0.018)	(0.017)	(0.017)	(0.018)	(0.019)	(0.019)
Business R&D	-0.054	0.007	0.159	0.015	0.016	0.008	-0.035	-0.001	0.198	0.184
	(0.086)	(0.091)	(0.104)	(0.093)	(0.095)	(0.104)	(0.094)	(0.106)	(0.144)	(0.174)
Stock market	-0.046	0.004	-0.022	-0.068*	-0.048	-0.034	-0.040	-0.003	0.025	-0.004
	(0.040)	(0.042)	(0.040)	(0.040)	(0.043)	(0.044)	(0.043)	(0.047)	(0.049)	(0.052)
Constant	10.187***	9.468***	9.209***	9.533***	8.619***	8.529***	8.748***	9.411***	11.246***	9.472***
	(0.831)	(0.815)	(0.790)	(0.816)	(0.727)	(0.756)	(0.788)	(0.856)	(1.150)	(0.894)
Observations	1,863	1,863	1,864	1,863	1,817	1,863	1,863	1,631	1,607	1,607
Adjusted R-squared	0.236	0.231	0.233	0.229	0.227	0.226	0.226	0.227	0.232	0.223
1 SD effect	-0.214	-0.213	-0.379	-0.149	-0.141	-0.139	-0.112	-0.193	-0.332	-0.278

Table 4. GMM estimations

The table reports coefficient estimates and t-statistics (in parentheses) using the country indicator variables lagged two periods as instruments. Columns (1)-(7) use the IMD indicators as dependent variables and columns (8)-(10) use the WEF indicators as dependent variables. Definitions for all variables are in Table A1. Estimation method is two stage GMM with phase and industry fixed effects, and robust standard errors. The sample period is 2005-2018 for columns (1)-((7) and 2005-2017 for columns (8)-(10). The lower part of the table also reports the number of observations and the adjusted R-squared. The ***, **, and * marks denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Skilled labour	-0.352***									
	(0.000)									
Competent		-0.538***								
		(0.000)								
Computers			-0.002***							
			(0.000)							
Digital skills				-0.219***						
				(0.000)						
PPP					-0.203***					
					(0.005)					
Research legislation						-0.114*				
						(0.064)				
Tech development							-0.122*			
							(0.077)			
Technology readiness								-0.384***		
								(0.005)		
Business sophistication									-0.606***	
									(0.003)	
Innovation capacity										-0.372**
										(0.034)

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Size	0.275***	0.302***	0.287***	0.288***	0.305***	0.298***	0.298***	0.294***	0.315***	0.304***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Total assets change	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000
	(0.525)	(0.310)	(0.532)	(0.403)	(0.428)	(0.486)	(0.459)	(0.801)	(0.658)	(0.651)
Intangible	-0.083***	-0.088***	-0.095***	-0.094***	-0.103***	-0.098***	-0.100***	-0.096***	-0.106***	-0.103***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ROE	-0.008***	-0.008***	-0.007***	-0.007***	-0.007**	-0.007**	-0.007***	-0.005*	-0.005*	-0.005*
	(0.004)	(0.005)	(0.009)	(0.009)	(0.016)	(0.012)	(0.010)	(0.099)	(0.092)	(0.097)
Cash flow	-0.000**	-0.000**	-0.000*	-0.000*	-0.000*	-0.000*	-0.000*	-0.000	-0.000	-0.000
	(0.038)	(0.031)	(0.099)	(0.077)	(0.060)	(0.074)	(0.065)	(0.158)	(0.102)	(0.124)
Rate	0.114***	0.108***	0.009	0.150***	0.093**	0.106***	0.101***	0.088*	0.078	0.104**
	(0.002)	(0.004)	(0.839)	(0.000)	(0.016)	(0.005)	(0.008)	(0.066)	(0.117)	(0.028)
GDP growth	0.666	0.543	2.960**	2.490*	2.205*	2.388*	2.419*	1.851	1.399	1.538
	(0.606)	(0.681)	(0.021)	(0.054)	(0.100)	(0.062)	(0.058)	(0.152)	(0.291)	(0.250)
GFCF	-0.062***	-0.063***	-0.052***	-0.046***	-0.040**	-0.044**	-0.043**	-0.049***	-0.064***	-0.046**
	(0.000)	(0.000)	(0.003)	(0.007)	(0.028)	(0.012)	(0.014)	(0.009)	(0.001)	(0.017)
Business R&D	-0.002	0.080	0.172*	0.050	0.060	0.054	0.002	0.060	0.249*	0.251
	(0.985)	(0.390)	(0.096)	(0.590)	(0.539)	(0.622)	(0.984)	(0.581)	(0.095)	(0.178)
Stock market	-0.047	0.096*	-0.029	-0.079**	-0.029	-0.030	-0.042	-0.004	0.038	0.008
	(0.238)	(0.083)	(0.468)	(0.047)	(0.507)	(0.523)	(0.339)	(0.935)	(0.455)	(0.877)
Constant	11.021***	10.632***	9.771***	10.103***	8.557***	8.793***	9.031***	9.940***	10.070***	8.745***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Obs.	1,786	1,786	1,786	1,786	1,786	1,786	1,786	1,537	1,537	1,537
Adj. R-squared	0.235	0.229	0.236	0.231	0.227	0.227	0.228	0.223	0.225	0.222
1 SD effect	-0.292	-0.426	-0.379	-0.186	-0.198	-0.160	-0.121	-0.236	-0.381	-0.331
Sargan-Hansen	3.174	0.702	12.25	2.053	0.589	0.076	0.392	0.035	0.013	0.055
Anderson CC	389.2	295	570.9	606.6	557	528	613.2	510.4	343.1	364.1

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Endogeneity Test Statistic	5.504	6.326	0.755	2.542	0.927	0.315	0.199	4.714	0.054	0.151

Table 5. Phase III regressions

The table reports coefficient estimates and t-statistics (in parentheses) from estimations using the country indicator variables for Phase III. Columns (1)-(7) use the IMD indicators as dependent variables and columns (8)-(10) use the WEF indicators as dependent variables. Definitions for all variables are in Table A1. Estimation method is OLS with industry fixed effects, and robust standard errors. The sample period is 2013-2018 for columns (1) -(7) and 2013-2017 for columns (8)-(10). The lower part of the table also reports the number of observations and the adjusted R-squared. The ***, **, and * marks denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Skilled labour	-0.291***									
	(0.064)									
Competent		-0.334***								
		(0.085)								
Computers			-0.002***							
			(0.000)							
Digital skills				-0.192***						
				(0.060)						
PPP					-0.170***					
					(0.060)					
Research legislation						-0.131**				
						(0.054)				
Tech development							-0.136**			
							(0.064)			
Technology readiness								-0.316***		
								(0.148)		
Business sophistication									-0.572***	
									(0.244)	
Innovation capacity										-0.262**
										(0.177)

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Size	0.314***	0.336***	0.326***	0.327***	0.332***	0.334***	0.334***	0.338***	0.346***	0.338***
	(0.033)	(0.033)	(0.033)	(0.033)	(0.034)	(0.033)	(0.033)	(0.038)	(0.038)	(0.038)
Total assets change	0.001	0.002	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Intangible	-0.016***	-0.112***	-0.113***	-0.114***	-0.117***	-0.115***	-0.117***	-0.122***	-0.123***	-0.123***
	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.022)	(0.022)	(0.022)
ROE	-0.009***	-0.008***	-0.008**	-0.008**	-0.008**	-0.008**	-0.008**	-0.007*	-0.007*	-0.007*
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Cash flow	-0.000*	-0.000*	-0.000	-0.000	0.000	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Rate	0.120***	0.126***	0.020	0.162***	0.112**	0.124***	0.112**	0.106*	0.097*	0.125**
	(0.042)	(0.042)	(0.050)	(0.043)	(0.044)	(0.043)	(0.044)	(0.057)	(0.057)	(0.055)
GDP growth	6.270***	6.892***	7.707***	8.015****	8.277***	8.192***	8.189***	7.022***	6.018***	6.829***
	(1.898)	(1.887)	(1.950)	(2.045)	(1.990)	(2.004)	(2.014)	(2.040)	(1.999)	(2.045)
GFCF	-0.052**	-0.053**	-0.054**	-0.043**	-0.047**	-0.048**	-0.046**	-0.045*	-0.068***	-0.046*
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.024)	(0.025)	(0.024)
Business R&D	-0.034	0.087	0.240**	0.086	0.104	0.154	0.073	0.059	0.319	0.215
	(0.107)	(0.107)	(0.120)	(0.110)	(0.111)	(0.125)	(0.113)	(0.129)	(0.195)	(0.207)
Stock market	-0.050	0.004	-0.022	-0.077*	-0.043	-0.037	-0.048	-0.005	0.030	-0.014
	(0.046)	(0.048)	(0.046)	(0.046)	(0.049)	(0.049)	(0.049)	(0.058)	(0.060)	(0.060)
Constant	9.903***	9.341***	9.283***	9.250***	8.548***	8.242***	8.478***	9.095***	10.084***	8.486***
	(0.777)	(0.748)	(0.752)	(0.780)	(0.728)	(0.710)	(0.748)	(0.975)	(1.258)	(0.914)
Obs.	1,411	1,411	1,412	1,411	1,411	1,411	1,411	1,179	1,179	1,179
Adj. R-squared	0.263	0.259	0.259	0.254	0.252	0.251	0.251	0.245	0.246	0.243
1 SD effect	-0.303	-0.275	-0.338	-0.267	-0.177	-0.192	-0.137	-0.179	-0.352	-0.229

Table 6. Regressions with factors

The table reports coefficient estimates and t-statistics (in parentheses) from estimations using the factors instead of the country indicator. Definitions for all variables are in Table A1. Estimation method is OLS in columns (1)-(3) and two stage GMM in columns (3)-(6), with phase and industry fixed effects, and robust standard errors. The sample period is 2005-2018 upon availability of the data. The lower part of the table also reports the number of observations and the adjusted R-squared. The ***, **, and * marks denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	OLS	2-step GMM	2-step GMM	2-step GMM
Factor $(t-1)$	-0.035	-5.517**	-0.247***	-0.023	-0.988**	-0.332***
	(0.076)	(2.308)	(0.051)	(0.832)	(0.011)	(0.000)
Size	0.320***	0.324***	0.303***	0.318***	0.338***	0.296***
	(0.030)	(0.030)	(0.030)	(0.000)	(0.000)	(0.000)
Total assets change	0.001	0.001	0.001	0.001	0.000	0.001
	(0.001)	(0.001)	(0.001)	(0.306)	(0.932)	(0.251)
Intangible	-0.111***	-0.113***	-0.099***	-0.114***	-0.141***	-0.094***
	(0.018)	(0.017)	(0.017)	(0.000)	(0.000)	(0.000)
ROE	-0.007**	-0.007**	-0.007***	-0.007**	-0.008**	-0.007***
	(0.003)	(0.003)	(0.003)	(0.015)	(0.012)	(0.008)
Cash flow	-0.000*	-0.000*	-0.000*	-0.000**	-0.000	-0.000**
	(0.000)	(0.000)	(0.000)	(0.047)	(0.128)	(0.028)
Rate	0.115***	0.084**	0.118***	0.108***	-0.339*	0.134***
	(0.038)	(0.042)	(0.037)	(0.005)	(0.071)	(0.000)
GDP growth	2.932**	2.932**	2.092	2.408*	2.949*	0.743
	(1.344)	(1.359)	(1.337)	(0.077)	(0.057)	(0.596)
GFCF	-0.045**	-0.031	-0.054***	-0.043**	0.031	-0.050***
	(0.018)	(0.019)	(0.018)	(0.019)	(0.405)	(0.006)
Business R&D	-0.056	0.023	0.049	-0.047	-0.688***	0.106
	(0.103)	(0.099)	(0.091)	(0.660)	(0.009)	(0.259)
Stock market	-0.066	-0.043	-0.116***	-0.067	0.172	-0.148***
	(0.050)	(0.043)	(0.041)	(0.308)	(0.117)	(0.001)
Constant	7.889***	5.693***	8.391***	7.774***	5.702***	8.430***
	(0.726)	(1.215)	(0.693)	(0.000)	(0.000)	(0.000)

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Obs.	1,813	1,813	1,813	1,749	1,749	1,749
Adj. R-squared	0.224	0.227	0.237	0.225	-0.145	0.235
Sargan-Hansen				0.008	1.957	3.649
Anderson CC				383.9	26.34	390.5
Endogeneity Test Statistic				0.184	10.93	4.287

Appendix

Table A1. Variable definitions and sources

Variable	Definition and source
	Panel A. Firm emissions and related variables **Source: EU-ETS**
Allocated	Allocated emissions in metric tons CO2 equivalent (aggregated across all firm installations).
Verified	Verified emissions measured in metric tons CO2 equivalent (aggregated across all firm installations).
Verified Installation	Allocated emissions in metric tons CO2 equivalent per firm installations.
Excess	The per-firm excess emissions calculated as: Verified − Allocated.
Excess % allocated	The per-firm excess emissions in percentage terms, calculated as: (Verified − Allocated) / Allocated.
Excess % verified	The per-firm excess emissions in percentage terms, calculated as: (Verified − Verified) / Verified.
Installations	The number of firm's GHG emitting installations.
State	A dummy variable indicating stated-owned firms and, accordingly, it takes the value 1 when the government has a stake of 5 percent or more, and 0 otherwise.
Public	A dummy variable indicating publicly listed firms and, accordingly, it takes the value 1 for a publicly-listed firm, and 0 otherwise.
Phase I	Phase I of the EU ETS and, accordingly, it takes the value 1 for years from 2005 to 2007, and 0 otherwise
Phase II	Phase II of the EU ETS and, accordingly, it takes the value 1 for years from 2008 to 2012, and 0 otherwise.
Phase III	Phase III of the EU ETS and, accordingly, in our sample it takes the value 1 for years from 2013 to 2018, and 0 otherwise.
EU28	Takes the value 1 for firms headquartered with the EU-28 zone, and 0 otherwise.
	Panel B. Financial variables **Source: Orbis**
Total assets	Total assets in millions
Total assets change	Percentage change in total assets between years t and t-1
Intangible	Intangible assets in millions
ROE	The ratio of income before interests and taxes to book value of equity
Cash flow	Operating income before depreciation divided by beginning of the year net assets.
	Panel C. Macroeconomic variables **Source: Eurostat, OECD, World Bank**
GDP growth	The country growth in GDP between years t and t-1
Rate	Country short term interest rates (average of commercial banks)

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GFCF	Gross fixed capital formation as a percentage of GDP. Gross fixed capital formation includes land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings.
Business R&D	Business R&D as a percentage of GDP
Liquid liabilities	Ratio of liquid liabilities to GDP. Liquid liabilities are also known as broad money, or M3. They are the sum of currency and deposits in the central bank (M0), plus transferable deposits and electronic currency (M1), plus time and savings deposits, foreign currency transferable deposits, certificates of deposit, and securities repurchase agreements (M2), plus travelers checks, foreign currency time deposits, commercial paper, and shares of mutual funds or market funds held by residents.
Financial development	Sum of private-sector credit and value of all listed stocks, divided by the country's GDP

Panel D. National indicators
Source: WEF, IMD

Technological readiness	9th pillar from WEF Global Competitiveness Indicator Report
Business sophistication	11th pillar from WEF Global Competitiveness Indicator Report
Innovation capacity	12th pillar from WEF Global Competitiveness Indicator Report
Research legislation	Scientific research legislation: Laws relating to scientific research do encourage innovation
Competent	Competent senior managers: Competent senior managers are readily available
PPP	Public-private partnerships: Public and private sector ventures are supporting technological development
Computers	Number of computers per 1000 people/ Source: Computer Industry Almanac
Digital skills	Digital/Technological skills are readily available
Skilled labour	Skilled labor is readily available
Tech development	Development and application of technology are supported by the legal environment
Stock markets	Stock markets provide adequate financing to companies

Table A2. Pearson correlation coefficients

The table reports Pearson correlation coefficients. p-values are reported in parentheses. Definitions for all variables are in Table A1.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) Technological readiness	1.000										
(2) Business sophistication	0.990	1.000									
	(<0.001)										
(3) Innovation capacity	0.980	0.990	1.000								
	(<0.001)	(<0.001)									
(4) Skilled labor	-0.050	-0.050	-0.030	1.000							
	(<0.001)	(<0.001)	(<0.001)								
(5) PPP	0.040	0.040	0.070	0.450	1.000						
	(-0.01)	(-0.01)	(<0.001)	(<0.001)							
(6) Competent	0.080	0.090	0.120	0.760	0.650	1.000					
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)						
(7) Research legislation	0.090	0.100	0.140	0.450	0.850	0.770	1.000				
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)					
(8) Computers	0.310	0.300	0.320	0.350	0.500	0.610	0.580	1.000			
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)				
(9) Tech Development	0.080	0.080	0.110	0.550	0.910	0.760	0.890	0.560	1.000		
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)			
(10) Digital skills	-0.110	-0.150	-0.140	0.630	0.620	0.690	0.660	0.390	0.740	1.000	
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)		
(11) Verified installation	-0.040	-0.030	-0.040	-0.110	-0.160	-0.160	-0.170	-0.180	-0.180	-0.170	1.000
	(-0.01)	(-0.02)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	

Table A3. Factor Analysis – Eigenvalues and cumulative variation

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor1	15.143	3.265	0.449	0.449
Factor2	11.877	10.309	0.352	0.801
Factor3	1.568	0.077	0.046	0.847
Factor4	1.491	0.371	0.044	0.891
Factor5	1.120	0.240	0.033	0.924
Factor6	0.880	0.220	0.026	0.951
Factor7	0.660	0.225	0.019	0.970
Factor8	0.435	0.143	0.013	0.983
Factor9	0.291	0.030	0.009	0.992
Factor10	0.262	0.127	0.008	0.999

Table A4. Factor Analysis – Factor Loadings

Variable	Factor1	Factor2	Factor3	Uniqueness
Skilled labor			0.754	0.311
Attracting and retaining talent	0.797			0.305
Brain Drain	0.847			0.213
Foreign highly skilled personnel	0.690			0.486
Entrepreneurship				0.337
Competent Senior Managers	0.638		0.509	0.151
PPP	0.875			0.157
Institutions Pillar		0.995		0.004
Infrastructure Pillar		0.999		0.004
Macroeconomic environment Pillar		1.000		0.005
Health and primary education Pillar		1.002		0.006
Higher Education Pillar		1.000		0.003
Goods Market Pillar		1.000		0.002
Labour Market Pillar		0.998		0.004
Financial Markets Pillar		0.996		0.006
Technological readiness Pillar		0.998		0.010
Market Size Pillar		0.986		0.019
Business Sophistication Pillar		0.997		0.002
Innovation Pillar		0.981		0.016
GCI		1.000		0.000
Government decisions	0.834			0.162
Legal and regulatory framework	0.854			0.160
Adaptability of government policy	0.786			0.244
Transparency	0.917			0.145
Funding for technological development	0.881			0.103
Scientific research Legislation	0.906			0.130
IP	0.832			0.073
Knowledge Transfer	0.872			0.166
Development and Application of Technology	0.906			0.063
Computers in use				0.443
Communications Technology	0.536		0.407	0.324
Computers per Capita	0.539			0.358

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Digital Skills	0.504	0.549	0.194
Finance Skills	0.712	0.447	0.144
Stock Market	0.809		0.270
Stock Market Capitalization	0.612		0.463
Venture Capital	0.799		0.319

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