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Intellectual property rights protection's role in reducing CO2 emissions and enabling the effectiveness of climate policies in developed and developing countries

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Abstract

This thesis investigates the role of intellectual property rights (IPR) protection in reducing CO2 emissions and enabling the effectiveness of climate policies, thereby contributing to the achievement of climate goals. In examining the relationship between IPR protection and CO2 emissions at the country level, this study distinguishes between *de jure* and *de facto* IPR protection and between developed and developing countries. By conducting regression analysis with panel data from 2008-2018 in a Driscoll-Kraay robust standard errors model, the research finds no clear evidence that IPR protection reduces CO2 emissions. Some indications arise for a potential CO2 emission reducing interaction effect of the combination of strong IPR protection and the implementation of climate policies, particularly in the power industry sector. This suggests that IPR frameworks may enhance the effectiveness of climate policies. However, due to its limitations, this study's findings should be interpreted with caution. Future research should address these limitations and focus on the longer-term impacts of IPR protection and its relationship with CO2 emissions in specific sectors to better understand the role of IPR protection in reducing CO2 emissions.

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1 INTRODUCTION

At present, there is a consensus at the global level that climate change is one of the greatest challenges of this century. However, the correct approach to tackle this problem and achieve the goals set in the Paris Agreement is not yet crystal clear. This thesis investigates the role of a country's framework of intellectual property rights (IPR) protection in reducing CO2 emissions and enabling the effectiveness of climate policies, thereby contributing to the achievement of climate goals. This research makes a distinction between developed and developing countries.

Climate change is caused by greenhouse gas emissions, of which CO2 is an important contributor. The majority of these emissions originate from human activities (Dong et al., 2022). Climate change poses risks of extreme weather events, such as sea level rise (Huang & Zhai, 2021) and extreme colds and heatwaves. The climate change mitigation efforts made so far have not been sufficient, as the most recent report by the Intergovernmental Panel on Climate Change (2023) warns that the goal of the Paris Agreement to limit temperature rise to 1.5°C compared to pre-industrial times is unlikely to be achieved. A drastic shift is needed, for which new know-how, skills, and technologies are necessary. Technology development is regarded by the United Nations Framework Convention on Climate Change (UNFCCC) as one of the primary solutions to address climate change (Moradi et al., 2022). Therefore, it is essential to acquire knowledge about how the development and dissemination of green innovations can be promoted, and, more importantly, whether this indeed leads to improved sustainable performance.

Intellectual property rights seem to play a significant role in this regard. Existing literature has extensively explored the relationship between the protection of intellectual property rights and innovation and technology transfers (Papageorgiadis & Sharma, 2016; Allred & Park, 2007; Kim, 2003; Maskus & Okediji, 2010). According to incentive theory, strong IPR protection allows inventors to enjoy the benefits of an innovation, thus creating a competitive advantage in investing in the development of innovations (Arrow, 1972; Gosseries et al., 2008; Vimalnath et al., 2022). However, there is not complete consensus on this mechanism, as evidence also suggests that open science systems may be advantageous (Carayannis et al., 2024), and that the overall effect of the intellectual property rights regime is highly overestimated and may have almost no impact

(Archibugi & Filippetti, 2014). The effectiveness of intellectual property rights protection in promoting innovations remains a point of discussion among scholars (Sweet & Maggio, 2015).

This is all the more the case regarding IPR protection's impact on *international* technology transfers, where there is considerable ambiguity in the evidence. Stronger intellectual property rights protection may reduce transaction costs, leading to efficient contracts and greater technology dissemination (Burrel et al., 2023; Yang & Maskus, 2009; Arora, 1996). On the other hand, strong intellectual property rights protection may act as a barrier to (duplicative) innovations and technology transfers by increasing market power and making reverse engineering more difficult (Falvey et al., 2006; Li & Chen, 2023; Kim, 2003). Additionally, evidence suggests that the relationship between IPR protection, innovation, and technology transfers may depend on the level of economic development, indigenous capabilities and absorptive capabilities of a country (Du et al., 2019; Athreye et al., 2023; Sweet & Maggio, 2015; Chen & Puttitanun, 2005). As a result, there would be heterogeneity in the relationship across developed and developing countries (Allred & Park, 2007).

This relationship matters for global efforts to mitigate climate change, as this struggle relies on green innovations and technology transfers. Empirical research has provided evidence that IPR protection has a positive impact on green technology development and climate change mitigation technology transfers (Liu & Zhong, 2024; Taghizadeh-Hesary et al., 2019; Vimalnath et al., 2022; Barton, 2007; Athreye et al., 2023). Separately, evidence has been found that green technology innovations lead to certain climate neutrality outcomes, such as resource efficiency and energy efficiency (Li & Chen, 2023; Cheng & Yao, 202). This combination of research provides grounds to believe that stronger IPR protection is associated with better climate outcomes. However, there is still no comprehensive research that directly examines the relationship between intellectual property institutions and actual CO2 emissions at the country level. Li and Chen (2023), for example, explicitly point out the need for research into the relationship between a country's IPR framework and its progress towards achieving specific carbon neutrality targets. This thesis aims to fill this research gap and builds on the proposition that the relationship could depend on the stage of development of a country. Additionally, the literature provides grounds for the idea that the effectiveness of climate policies is determined by a country's institutional quality (Stef et al., 2023; Bae et al., 2017; Gani, 2012), that intellectual property protection frameworks create a favourable

institutional environment for green technology innovation (Cao et al., 2023), and that IPR protection and climate policies are each other's key constraint on their impacts and therefore should be jointly addressed (Burell et al., 2023). Therefore, this research also examines the moderating effect of IPR protection on the impact of climate policies on CO2 emissions. The research question of this study is therefore:

What is the influence of intellectual property rights protection on CO2 emissions and on the effectiveness of climate policies in reducing CO2 emissions, and how do these relationships vary between developed and developing countries?

In addition to the fact that the direct relationship between intellectual property rights protection and CO2 emissions, as well as its impact on climate policies' effectiveness, has not been comprehensively examined at the country level before, this thesis also stands out from related studies by distinguishing between developed and developing countries. Furthermore, this study differentiates between *de jure* IPR protection and *de facto* IPR protection. This is relevant, because the presence of formal IPR protection regulations does not always align with the actual enforcement and perception of these frameworks.

This thesis is structured as follows. Section 2 conducts a literature review on climate change mitigation, the theoretical framework around intellectual property rights, empirical evidence on the relationship between intellectual property rights and climate neutrality, the heterogeneity across developed and developing countries, and the relationship between IPR frameworks and climate policies. Section 3 presents the data, variables and empirical method used. Section 4 presents the results of the regression models and their interpretation, as well as robustness checks. Section 5 will be a discussion on the research's implications and limitations and directions for future research. Lastly, section 6 will summarize the conclusions made.

2 LITERATURE REVIEW

2.1 Climate change mitigation

2.1.1 Climate risks and carbon neutrality goals

2.1.1.1 Climate risks

With a look at recent literature, it becomes clear that climate change is recognized in science as one of the most, if not the most, significant global challenges of the 21st century (Abudu et al., 2024; Cheng et al., 2023). Achieving sustainable human development through climate change mitigation has become a prominent international goal, given that climate change affects virtually all aspects of economic and social sustainability (Tan et al., 2022). Climate change is caused by greenhouse gas emissions, the vast majority of which originate from human activities (Dong et al., 2022).

The risks of climate change are mainly in the occurrence of extreme weather events. Extreme weather is more problematic than the mean climate state (Ren et al., 2022). It has already led in recent years to sea level rise, coral reefs degradation and monsoon precipitation decrease (Huang & Zhai, 2021), as well as glacier melting, floods, extreme colds and extreme heat waves (Dong et al., 2022). According to the IPCC report of 2023, this has caused hundreds of local species to be lost, and placed millions of people in acute food and water insecurity. The average global temperature in 2021 was about 1.11°C higher than in the preindustrial period in the late 19th century (Chen et al, 2023). Climate warming at the current pace will only increase the risk of amplified intensity and frequency of extreme events in the future (Huang & Zhai, 2021).

2.1.1.2 Mitigation efforts

The search to a global solution to climate change began as early as 1992 with the signing of the United Nations Framework Convention on Climate Change (UNFCCC). A very important step was taken in 2015 with the adoption of the Paris Agreement, which sets long-term goals to reduce climate change risks. The Agreement calls for a limit on global temperature rise of 1.5°C compared to preindustrial times. Achieving this goal requires greenhouse gas emissions to be reduced by 45% by 2030 and emissions to reach net zero by 2050.

Carbon emission reduction and carbon neutrality are the most appropriate ways to address climate change (Bhatia et al., 2024). It is therefore a global consensus that the focus should be on these strategies (Wu et al., 2022). Carbon neutrality, or 'net zero carbon emissions', means that the CO2 that is emitted, which need not be zero, is offset by carbon dioxide removal through capture and storage methods (Huang & Zhai, 2021). A large proportion of countries worldwide has already implemented net-zero goals. This has improved energy efficiency and technology deployment in many places and reduced rates of deforestation and emissions (IPCC, 2023). The largest decline in CO2 emissions was seen in April 2020 due to the lockdown measures against Covid-19 (Wu et al., 2022). However, according to these authors, to achieve the Paris Agreement goal of limiting temperature rise to 1.5°C, carbon emissions must decrease by 7.6% per year by 2030. This reduction is even greater than the Covid-19 emission dip.

The steps taken to date have not yet been sufficient. The IPCC's (2023) report points out that "global warming is more likely than not to reach 1.5°C even under the very low greenhouse gas emission scenario and likely or very likely to exceed 1.5°C under higher emissions scenarios." It also states that heatwaves and droughts will become more frequent, storms will intensify, and extreme sea level events will occur at least annually in more than half of the tide gauge locations by the year 2100. The message is that, despite the efforts already made by governments worldwide, the risks of climate change are very pressing and require more drastic action.

2.1.2 The need for knowledge and technologies

To combat climate change, a major transformation is needed (Leach et al., 2012). This transformation can only be achieved if the required know-how, skills and technologies are developed. The IPCC and the UNFCCC view technology development as one of the primary solutions for reducing greenhouse gas emissions (Moradi et al., 2022). These advances in technology should enable the achievement of green development (Cao et al., 2023) and can occur through innovation or the dissemination of existing knowledge and environmentally sound technologies (ESTs) (Zhuang, 2017). In particular, low-carbon technologies are a crucial component in reducing greenhouse gas emissions and combating climate change (Athreye et al., 2023). For this purpose, large-scale research programs and commercialization are necessary (Vimalnath et al., 2022).

A large amount of literature provides evidence that environment-related green technology innovation forms the 'breakthrough' for reducing carbon emissions (Dong et al., 2022). Green technology innovation is defined as technological innovation in energy conservation, pollution prevention, waste recycling, green product design, and environmental management (Huang et al., 2019). The IPCC report of 2023 highlights as a positive aspect in the current mitigation progress that options like solar energy, wind energy, urban green infrastructure, energy efficiency and improved forest and crop/grassland management have become technically viable and are becoming increasingly cost-effective (IPCC, 2023). This progress can be attributed to promoting research and development in green innovation. Recent literature demonstrates that these efforts are highly valuable because green technology innovation improves energy efficiency (Song et al., 2024) and carbon emission efficiency (Dong et al., 2022).

2.1.3 Green technology innovations in developing countries

However, these types of positive effects are mainly found in studies focusing on developed countries. Du et al. (2019) find that the impact of green technology innovations on CO2 emissions is heterogeneous, depending on a country's income level. In developing countries, so they indicate, the costs of applying green innovations in practice are high, due to poor productivity and low marketization level. Also, governments put their focus on improving economic living standards, rather than promoting green technology innovations into real applications (Du et al., 2019). Therefore, they argue that new mechanisms in green finance, governmental support and intellectual property rights are necessary to accelerate the diffusion and application of green technology in low-income countries. In line with this, the IPCC 2023 report concludes that "the adoption of low-emission technologies lags in most developing countries, particularly least developed ones, due to insufficient institutional and financial support, uncertainty over long-term additionality and trade-offs, weak governance, insecure land ownership, low incomes, lack of access to alternative sources of income, and the risk of reversal" (IPCC, 2023).

These differences between developed and developing countries result in widening disparities between them, especially considering that developing countries often bear the brunt of the negative impacts of climate change. Therefore, in Article 4.5, the UNFCCC calls for developed countries to "take all practicable steps to promote, facilitate, and finance, as appropriate, the transfer of

environmentally sound technologies and know-how to other parties, particularly developing country parties, to enable them to implement the provisions of the convention".

2.2 Intellectual property rights: theoretical framework

2.2.1 Intellectual property

Following the World Intellectual Property Organisation, intellectual property refers to creations of the mind. Rather than tangible physical objects, intellectual property goods include inventions, artistic creations, or brand names. In other words, it is what results from the intellectual efforts of an individual. Intellectual property goods are characterized by their vulnerability in terms of ownership. These creations are only valuable to the extent that exclusively the owner can reap the benefits from them. If others can exploit the good, there is no use in investing in the creation of the product. This is a critical issue, since intellectual property is non-rival as well as partially non-excludable (Kang & Seo, 2006).

Therefore, intellectual property is protected by intellectual property rights. There are four main types of intellectual property rights: patents, copyrights, trademarks and trade secrets. In this research, the most important intellectual property rights are patents. Patents are granted for inventions, typically for a period of 20 years (Kim et al., 2012). In this period, the owner can legally exclude others from making, using, or selling the invention.

2.2.2 De jure and de facto IPR protection

Intellectual property rights protection is legally shaped by the adoption of regulations by governments. By establishing laws and regulations that stipulate that certain rights may not be infringed, inventions and technologies that are, for instance, covered by patents are theoretically protected. However, as emphasized by Voigt (2013), it is important to distinguish between the mere adoption of formal legal regulations (*de jure*) and the actual stringency and level of enforcement of these regulations in practice (*de facto*) when assessing the influence of legal institutions (Papageorgiadis & McDonald, 2019). Papageorgiadis and McDonald (2019) reflect these categories with the terms 'law in the books' and 'law in practice'. Making this distinction is relevant because focussing only on the formal presence of regulations may not provide the complete picture.

There may be several reasons for this. One is that the adoption of legislation is a relatively 'simple' act that by itself may not have an immediate effect. The extent to what is formally prescribed on paper translates into practice as intended may depend on the government's capacities (Athreye et al., 2023) and willingness to enforce the rules. Political corruption may play a significant role in this regard. Additionally, there are economic institutions that play a significant role, such as the ease with which individuals are able to register their (IP) rights or uphold them in court. High costs related to this may diminish effective legal protection in practice. Also, changing informal institutions, which are embedded in norms and behaviours of individuals, is a relatively slow process compared to changing formal institutions (Papageorgiadis & McDonald, 2019). Papageorgiadis and McDonald argue that if transactions in an economy are largely determined by social protocols, the formal adoption of IPR rules and the suitable norms of behaviour in terms of IPR enforcement may diverge. The legitimacy of strong IPR protection regulations is then low because people are not used to the related 'modus operandi'.

A second reason relates to the channel through which IPR protection enhances innovation and technological transfers. As will be further elaborated on in subsequent sections, this particularly depends on the level of trust individuals have in the IPR protection frameworks. This perception may not only be influenced by the presence of formal regulations, but also by other factors, meaning that *de jure* IPR protection and individuals' perceptions of it may not always align. As shown by Khoury et al. (2014), the quality of IPR frameworks cannot always be based on objective information, but rather on an individual's interpretation of these institutions. According to Khoury et al. (2014), foreign inventors, less familiar with the ability of governments to actually commit to IPR protection in practice, may view governments' efforts to formally implement IPR protection regulations more positively than more sceptical domestic inventors. Outsiders may also place greater value on democratic political systems because it ensures fairness, while insiders may prioritize the formal stringency of regulations. Apart from the distinction between foreign and domestic inventors, this is an example illustrating that *de jure* IPR protection may not always align with *de facto* IPR protection.

2.2.3 Intellectual property rights and innovation

2.2.3.1 Commercialization of public goods

It is a widely recognized and research-proven view that intellectual property rights play an important role in the development of innovations (Papageorgiadis & Sharma, 2016; Allred & Park, 2007). The importance of legal entitlements such as patents and copyrights lies in the fact that knowledge and innovations, or more generally intellectual property, is a public good (Burrell et al., 2023). Unlike real property, what is typical about intellectual property is that one does not have exclusive control over the good and it can be used by multiple people at the same time (Gosseries et al., 2008). In other words, they are non-excludable and non-rival goods (Papageorgiadis & Sharma, 2016). This makes gains from innovations difficult to appropriate (Arrow, 1972).

Given the foregoing, a way is needed to ensure that an inventor enjoys the benefits of their invention. This is done by granting them exclusive rights to the good (Li & Chen, 2024; Schutz Veiga, 2023). IPR protection does that by preventing firms' innovations from being exposed (Teixeira & Ferreira, 2019) and giving them the power to prevent similar works from being produced (Gosseries et al., 2008), thus enabling the commercialization of their innovations (Teixeira & Ferreira, 2019).

2.2.3.2 Incentive theory

In this way, IPR protection addresses and corrects the market failure of the underproduction of knowledge due to the lack of profitability (Burrell et al., 2023; Gosseries et al., 2008). Innovators are incentivized to invest in the creation of innovations (Vimalnath et al., 2022). The fact that they can rely on obtaining the benefits of their creation will encourage their innovation activity (Papageorgiadis & Sharma, 2016). Through this mechanism, IPR protection can contribute to a competitive advantage, providing a stimulus for companies to remain progressive in developing innovations. This is also known as the incentive theory of intellectual property rights (Arrow, 1972; Gosseries et al., 2008; Vimalnath et al., 2022).

2.2.4 Intellectual property rights and technology transfers

2.2.4.1 Dissemination of knowledge

Not only may the creation of knowledge occur through domestic innovation in a specific location, it can also result from the spreading of knowledge from a place where innovation has occurred to another place where the knowledge is not yet present. In the literature, this is referred to as technology transfers or dissemination of knowledge. Climate change mitigation technologies are mostly developed in the more developed countries, while developing countries often do not have access to them due to the lack of innovative capabilities (Davies-Venn, 2023). Therefore, it is crucial that the mechanism of knowledge dissemination across countries functions effectively. Maskus (2004) elaborates on the channels through which technology transfers may take place. This may be through trade in goods, FDI, licensing, but also through imitation, reverse engineering or migration of students or scientists.

2.2.4.2 Reduced transaction costs

The relationship between the level of IPR protection and technology transfers has received much attention in the literature. It is argued that IPR stringency is an effective tool for facilitating technology transfers. This theory relies on the notion that the purpose of IPR protection is to reduce transaction costs (Yang & Maskus, 2009). It posits that firms tend to prefer transferring their technologies to countries where IPR protection is stronger (Burrell et al., 2023). According to Maskus (2004), intellectual property protection provides the legal framework to trust that proprietary characteristics of technologies can be revealed to the recipient without information leakage occurring in the open market, increasing the efficiency of contracts (Arora, 1996). If the receiving country's IPR protection is weak, companies will be less willing to contract and transact, opting to keep the knowledge to themselves. This suggests that IPR stringency in the receiving country is positively related to the spread of knowledge to that country.

The hypothesis that strictness on intellectual property rights increases the flow of knowledge to a country is also supported by empirical research (Cockburn et al., 2016; Montobbio et al., 2015; Eaton & Kortum, 1996). Maskus and Okediji (2010) indicate that this effect has been strengthened since the conclusion of the World Trade Organization (WTO) Agreement on Trade Related Aspects

of Intellectual Property Rights (TRIPS). Section 2.5.2 elaborates on the empirical evidence for the relationship.

2.2.4.3 IPR disparities as a barrier to technology transfers

The negative side of promoting strong IPR protection, however, is that overly restrictive IPR protection frameworks in the technology-exporting countries may act as barriers to technology transfers (Kim, 2003; Falvey et al., 2006; Li & Chen, 2023). In the case of informal dissemination of knowledge, this is because intellectual property rights give inventors control, and poorly enforced intellectual property rights provide the opportunity to imitate foreign technologies (Maskus, 2004). However, even in the case of formal transfers, IPR may pose an obstacle. As shown above, intellectual property rights protect one's proprietary knowledge, increasing the market power of intellectual property rights holders (Falvey et al., 2006). This grants them the opportunity to demand monopolistic rates for their innovations (Kujo, 2022). The resulting lower output and higher prices make the technologies inaccessible to the rest of the world (Falvey et al., 2006). This is especially the case for developing countries, placing firms from these locations at a competitive disadvantage (Yang & Maskus, 2009), since these countries often have a weak bargaining position due to inadequate IPR protection frameworks. These countries thus have an additionally strong interest in improving IPR protection to overcome disparities relative to technology-exporting countries.

The incentive theory together with the transaction costs theory leads, in the context of the presumed importance of green innovation and the dissemination of climate change mitigation technologies, to the following hypothesis:

> **H1**: A country's level of intellectual property rights protection is negatively related to its annual CO2 emissions.

2.3 Developed and developing countries

2.3.1 The innovative 'north' and the IP-importing 'south'

When it comes to views on the positive impact of stronger IPR frameworks, the literature makes a clear distinction between developed and developing countries, often divided into the innovative

north and the intellectual property-importing south (Lee et al., 2018). While developed countries have "spared no effort" to protect intellectual property rights, negotiations on the agreement on Trade Related Aspects of Intellectual Property (TRIPS) have been challenged by countries such as Korea, Brazil, Thailand, India and the Caribbean states (Auriol et al., 2023). They advocate for regulations such as patent pooling and even the revocation of patent rights on green technologies (Hall & Helmers, 2010). The United States, on the other hand, strongly opposes the weakening of existing international requirements, as Hall and Helmers (2010) point out. This contrast is largely due to the extreme concentration of technologies in the developed world. Kumar (2003) indicates that 94 percent of patents and 91 percent of technology fees receipts are accounted for by only ten developed countries. A strengthened IPR regime, according to Kumar (2003), would maintain and further develop these countries' technological domination over the world.

2.3.2 Heterogeneous optimal IPR levels

In high-income economies, stronger IPR protection increases innovation and technology diffusion. However, Falvey et al. (2006) demonstrates that this is not the case for other groups of countries. They find evidence that for middle-income countries, strengthening intellectual property rights has a dual effect. On the one hand, domestic innovation and technology diffusion through foreign patenting and international trade is encouraged, but on the other hand, this offsets the benefits of imitation that was possible with weaker IPR protection. In low-income countries, they find no effect on innovation and a negative effect on international trade (Falvey et al., 2006). The literature attributes the heterogeneity in effects to the fact that developing countries produce less drastic innovations (Allred & Park, 2007) and depend largely on incremental, adaptive and imitative research (Sweet & Maggio, 2015). With enhanced patent protection, the cost of technological inputs becomes too high (Glass, 2004). Due to smaller markets and lesser technological capabilities, and thus capacity to innovate, it may be that the optimal IPR protection is lower in the 'south' than in the 'north' (Chen & Puttitanun, 2005; Allred & Park, 2007). Hall and Helmers (2010) suggest that within developing countries there are two groups, namely emerging economies such as Brazil, China, India and Mexico, where stronger IPR protection has a positive impact on domestic innovations and transfers from the developed world, and a larger group of less-developed countries in which this effect is not found.

The question then arises how exactly this mechanism works, and what the underlying reason is for the cases in which stronger IPR protection does lead to domestic innovation and imported innovation. Breitwieser and Foster-McGregor (2012) indicate, for example, that strong IPR protection can indeed have benefits in developing countries, but only if research and development is highly productive and leads to cost reductions. This goes hand in hand with comprising a large share of the market of the product in question (Breitwieser & Foster-McGregor, 2012). The north does benefit from better IPR frameworks, because developed economies countries have access to research funds, complex technological systems, accompanying infrastructures, and renowned and well-equipped research institutions and qualified individual researchers (Raiser et al., 2017). This gives them a better capacity for research and development. In the countries without substantial experience and technological knowledge, just strengthening the IPR framework is not enough (Verspagen, 2003). Global IPR homogeneity is not desirable, according to Hudson and Minea (2013), because a given level of IPR protection does not have the same impact on high-income countries as it does on low-income countries. Sweet and Maggio (2015) therefore argue that IPR standards should be "development appropriate." Improving IPR frameworks should not be seen in isolation, but depends on a country's institutional environment (Lee et al., 2018).

2.3.3 The importance of improved IPR in developing countries

Yet, there are still reasons to advocate for improved IPR systems in developing countries. Firstly, stronger IPR protection is "one of the most promising potential positive effects" (Breitwieser & Foster-McGregor, 2012), because developed countries place great value on strong patent protection in recipient-countries. This was already elaborated on in section 2.2.4. In addition, it is argued that this will ensure that northern countries will develop more technologies that the south needs (Chen & Puttitanun, 2005). After all, those needs are different. Moreover, better IPR systems in the south could benefit the north as well, because weak IPR in developing countries lead developed countries to create more hard-to-imitate technologies, which causes less efficient research and development in the north (Taylor, 1993; Chen & Puttitanun, 2005).

Breitwieser and Foster-McGregor (2012) conclude that the incentives created by stronger IPR protection are not "clear cut" because they vary by country type and are dependent on interaction effects. Falvey et al. (2006) argue that the focus should not only be on drafting protective laws and

regulations, but rather on the technical and legal expertise underlying technology transfers. Finding a solution to climate change through a change of IPR frameworks tailored to different country characteristics, and not just those of the developed world, is all the more urgent, as it is developing countries experiencing the most severe repercussions of climate change (Hall & Helmer, 2010). These authors point out that these countries heavily rely on agriculture, which is vulnerable to climatic changes, experience higher impact on public health, face a higher risk of natural disasters and have the highest likelihood of political unrest and violent conflict. This adds to the relevance of comprehensive research on the heterogeneity of the impact of IPR frameworks on climate-related outcomes.

The foregoing leads to the following hypothesis:

> **H2:** To the extent that there is a negative relationship between the level of intellectual property rights protection and annual CO2 emissions, this relationship is stronger in developed countries than in developing countries.

2.4 Intellectual property rights and climate policies

2.4.1 Climate policies incentivizing green technologies

Climate policy interventions aim to improve, for instance, the efficient use of natural resources, ultimately reducing greenhouse gas emissions. In addition to directly addressing environmental issues, these policies also have indirect effects on climate change by providing incentives for the creation of new technologies and the diffusion of existing green technologies, as stated by Hall and Helmers (2010). There are various forms of regulatory climate policies. A prominent one is the cap-and-trade system, in which a limit is placed on total emissions and emission rights can be traded. Additionally, there are emission taxes, top-down regulations on emission performance standards, and policy interventions focusing on R&D incentive schemes (Hall & Helmers, 2010). This can take the form of subsidies or tax credits.

Dechezleprêtre et al. (2013) argue that domestic climate policies increase the demand for climate technologies. This is because regulatory stringency creates incentives to internalize the social costs of environmental degradation (Barbieri et al., 2023). Market-based instruments or the threat of

sanctions for violating regulations lead actors to act in line with the goals of these policies. This is done by investing in the creation or adoption of green technologies, while the incentives to develop carbon-intensive technologies decrease (Gray & Shadbegian, 1998). Popp (2010) argues that market-based R&D subsidies create incentives for the development of green technologies, while regulatory policies primarily induce the diffusion of technologies. For this reason, market-based incentives should be implemented in conjunction with regulatory policies (Hall & Helmers, 2010).

A caveat to the proposed positive effects of climate policies, according to Hall and Helmers (2010), could be that when international differences in environmental policies exist, this creates an incentive for polluting companies to conduct their activities elsewhere. Dean et al. (2009) find that high-pollution sectors in Hong Kong, Macao, Taiwan, Malaysia, Indonesia, and the Philippines avoid areas with high pollution taxes for their projects, but investors from the US, EU, and Japan do not. They therefore conclude that firms from developed economies employ more sustainable technologies and therefore respond less to environmental levies. So, if a negative relationship between climate policies and CO2 emissions is found in developing countries, according to this theory, it could be because companies are relocating to so-called 'pollution havens'.

2.4.2 Climate policies in conjunction with institutions

Literature suggests that the effect of climate policies depends on country characteristics. Section 2.5.4 elaborates on this, for instance by demonstrating that the efficiency of climate change policies is determined by the legal framework and enforcement of regulations (Bae et al., 2017). It seems necessary for climate change policies to be associated with improvements in general property rights protection and other institutional dimensions (Stef et al., 2023). In section 2.4.1 it is explained that climate policies certainly may work for CO2 emission reduction efforts, but it is also evident that they do not directly influence CO2 emissions. This, indeed, ultimately depends on people's behaviour. Therefore, there needs to be a 'playing field' in which people will actually and easily adjust their actions. Given the incentive theory as described in section 2.2.3, improvements in IPR protection could contribute to this. With a stronger IPR framework, actors may be more inclined to take steps toward innovations, thereby aligning with what regulatory climate policies prescribe. Additionally, for example, government investments in R&D will have more effect if one knows

that R&D may ultimately result in the appropriation of knowledge and technologies. This is achieved through an adequate IPR framework.

The foregoing leads to the following hypothesis:

> **H3**: To the extent that there is a negative relationship between the implementation of climate policies on annual CO2 emissions, the impact of climate policies gets stronger as the level of intellectual property rights protection increases.

2.5 Intellectual property rights and climate neutrality: empirical evidence

2.5.1 IPR fostering green innovation

A trend in literature has emerged in recent years where arguments are based on the positive impact of IPR systems on green innovation and sustainable development. Often, this is based on hypothetical theories, as described in section 2.2.3. Vimalnath et al. (2022) point out that there is a lack of evidence-based insights in this regard, hindering structured managerial and policy discussions on sustainability. Nevertheless, there is general consensus in the literature on the importance of IPR protection for green innovation. This is, in fact, also supported by empirical studies.

Liu and Zhong (2024) pose that intellectual property rights are recognized as catalysts for green innovation. The correlation between stringent IPR protection and investments in environmentally friendly technologies show that strong IPR protection stimulates research and development in sustainable solutions (Taghizadeh-Hesary et al., 2019). Additionally, Vimalnath et al. (2022) provide empirical evidence that the economic incentive argument of intellectual property rights is true, also with respect to green innovations. They therefore conclude that intellectual property rights are a crucial tool for innovation in green technology. Hao et al. (2021) show that while improving IPR protection reduces imitating innovation, it accelerates the transfer of tacit knowledge and technology, which fosters the technological progress, ultimately resulting in reduced carbon emissions.

From such empirical evidence, the policy implication consistently emerges that creating a robust IPR system should be prioritized. Liu and Zhong (2024), for example, conclude that an improved

IPR framework can constitute a "flourishing and dynamic environment". Hao et al. (2021) point out that Chinese governments urgently need to adopt a new approach in the intellectual property rights system by improving IPR policies and regulations, in order to break down the infringements on environmentally friendly innovations.

Yet, it must be noted once again that this does not represent the whole picture. Sweet and Maggio (2015) mention that the beforementioned positive impact does indeed exist with a world sample, but it is restricted to countries above a certain level of development. Chen and Puttitanun (2005) also provide evidence that the optimal level of IPR protection of a country depends on the degree of technological ability present, and it may have a U-shaped relationship with the level of economic development. For this reason, Sweet and Maggio (2015) mention that there is an urgency to tailor national IPR systems to what suits a country and its state of development.

2.5.2 IPR and climate change mitigating technology transfers

The global issue of climate change needs to be addressed collectively by the entire world. The problem, however, is that the necessary climate technology patents are held by a small group in the developed part of the world (Burell et al., 2023). Because of this 'effective monopoly' (Raiser et al., 2017), it is required that climate change mitigating technologies are disseminated, especially to developing countries (Srinivas, 2009). This is the way for countries that are not on the technological frontier to make the transition to a carbon neutral economy (Falvey et al., 2006).

There is plenty of empirical research proving that transferring countries do indeed rely on the trust that the formal intellectual property law system projects. Maskus and Penubarti (1995) provide evidence that exporting firms discriminate based on local patent laws in their sales decisions across export markets, leading them to the conclusion that IPR are indeed trade related. Sajid et al. (2024) find in their thematic analysis of qualitative data that developed countries often view weak IPR in developing countries as the most significant obstacle to technology transfer, because of the discrepancy in overprotection and underprotection that complicates negotiations. Barton (2007) shows that stronger protection helps developing countries because firms from developed countries are then more willing to enter into clean energy technology transfers. Other examples include Park and Lippoldt (2008) who find that a patent rights index is positively associated with inward FDI for developed, developing and least developed countries, and for developing countries especially

when it comes to high-tech products. Maskus (1998) also finds that FDI from the US is positively related to patent strength in developing countries, and Contractor (1980) finds evidence that weak IPR protection in technology-recipient countries is associated with lower quality of transferred technologies (Maskus, 1998).

These studies do not all specifically touch on the dissemination of climate-related technologies. The study by Athreye et al. (2023) does. As was done in the present study, they distinguish between *de jure* and *de facto* IPR protection. They find that strong *de jure* IPR protection has a significant positive impact on climate mitigating technology transfers. This does differ between countries. In OECD countries, the influence of *de jure* and *de facto* IPR protection is complementary, but in non-OECD countries, only *de jure* IPR protection causes an increase in technology transfers. This may indicate that transferring countries do indeed rely on the trust that the formal intellectual property law system projects.

2.5.3 IPR and carbon neutrality outcomes

The previous two sections showed that stronger intellectual property rights protection is positively associated with green innovation and climate change mitigating technology transfers. The question of this thesis is then whether these mechanisms also lead to better outcomes in CO2 emissions. There is no comprehensive research yet that examines the relationship between IPR institutions and CO2 performance at the country level (Cao et al., 2023). However, research from recent years has explored relationships related to this, providing grounds to believe that stronger IPR protection in a country mitigates its CO2 emissions.

Li and Chen (2023) find empirical evidence that a higher index of intellectual property rights has a positive impact on the resource efficiency index in the advanced G7 countries. Resource efficiency, according to Li and Chen (2023), is a crucial factor to achieve carbon neutrality goals. In contrast, no effect was found for emerging countries (E7). The authors conclude that advanced economies succeed in stimulating innovation and adopting resource-efficient technologies. Trade in green utilities did however demonstrate a positive impact on resource efficiency in both country groups. Hao et al. (2021) also conclude that in China, with the continuous improvement of IPR frameworks, international trade leads to a reduction in CO2 emissions. Cao et al. (2023) also focus their research on China. They find empirical evidence that IPR protection exacerbates the carbon

emission reduction effects of technological innovations, specifically in wind power, solar energy, hydropower, marine energy, biomass energy and energy storage. They conclude that a robust IPR system is a requirement for China to reduce carbon emissions. Similar results have been found regarding renewable energy capabilities (Lin & Zhu, 2019), energy intensity (Cheng & Yao, 2021), energy expenditures (Li & Chen, 2024) and the carbon performance index (He et al., 2021; Xu et al., 2021). Pan et al. (2023) find that the Chinese policy of National Intellectual Property Rights Demonstration Cities (NIPRDC) improved urban air quality. All these studies solely relate to China.

Stef et al. (2023) examine the relationship between conscious government policies for environmentally sound and sustainable economic growth, political institutions, and CO2 emissions. With data from 136 countries, they find that effective climate policies must be associated with improvements in the protection of general property rights (the rule of law) to reduce CO2 emissions. In addition, there is country-level evidence that, regardless of IPR, green technology innovation fosters carbon emission efficiency in developed countries, and has a direct mitigating effect on carbon emissions (Dong et al., 2022).

All these researchers concur in urgently calling for more attention to IPR protection's role in the path to achieving carbon neutrality goals. Cao et al. (2023) emphasize that more empirical evidence is needed on the carbon mitigating effects of these mechanisms.

2.5.4 Climate change policies and IPR protection

The literature provides empirical evidence supporting the statement that climate policies promote green technologies and lead to better climate outcomes. Fisher-Vanden et al. (2004) find that increased energy prices lead to a decrease in energy intensity, as resources are redirected towards R&D expenditure. Similarly, Popp (2002) identifies a positive relationship between energy prices and innovation, Jaffe and Palmer (1997) demonstrate an association between the costs of complying with environmental regulations and innovation, and Veugelers (2012) concludes that fiscal incentives are crucial in promoting sustainable technology transfers. These studies demonstrate that market-based policy instruments can play a significant role in achieving climate goals by creating obvious economic incentives. Dechezleprêtre et al. (2013) provide evidence that climate policies, as an index of six different policy categories, have a positive impact on climate

change mitigating technology transfers. Additionally, Verdolini and Bosetti (2017) show that stricter environmental policies lead to more inward clean technology transfers, with market-based policies being particularly influential. However, they note that the positive influence of environmental policies is limited to OECD countries.

In line with this, literature suggests that the effect of climate policies depends on country characteristics. Bae et al. (2017) demonstrate that the efficiency of climate change policies is partly determined by the legal framework and the enforcement of regulations. Gani (2012) find evidence that countries with high institutional quality have lower CO2 emissions per capita. Building on this literature, Stef et al. (2023) show that it is necessary for climate change policies to be associated with improvements in the protection of property rights and other institutional dimensions. Although this relates more to the overall rule of law in a country, not necessarily the IPR framework, it does provide a foundation for the argument that enabling factors related to institutional quality exist for the effectiveness of climate policies. In their conclusion, supported by empirical results, Cao et al. (2023) focus on the assertion that IPR protection specifically acts as a moderating variable creating a favourable institutional environment for green and low-carbon technology innovation. This would enhance the effectiveness of climate policies. Additionally, Burell et al. (2023) touch upon this moderating effect, particularly for developing countries, but from the opposite perspective. They argue that IPR protection is not the key constraint hindering developing countries in the use of green technologies, but rather, it lies in the demand side. Improved IPR protection would only play a positive role once the costs of green technologies are reduced. Therefore, the focus should be on demand-side policies that reduce costs.

3 DATA AND METHODS

3.1 Data and variable specification

3.1.1 Dependent variable: per capita CO2 emissions (*CO2*)

The outcome variable of interest in this research is total annual CO2 emissions in megatonnes (Mt) per capita at the country level. The data for this variable is sourced from the Emissions Database for Global Atmospheric Research (EDGAR). The European Commission publishes an annual report by its Joint Research Centre (JRC) based on data from the EDGAR and the International Energy Agency (IEA). The report uses data for all countries and all anthropogenic sectors from 1970 to 2022 (European Commission, 2023). The emission values in the EDGAR dataset are calculated by multiplying activity and technology mix data of each country by country-specific emission factors and reduction factors for installed abatement systems (European Commission, 2023). The emission factors used are the global default values recommended by the IPCC in 2006 (IPCC, 2006). The dataset of this study contains 1,908 observations of this variable over the period from 2008 to 2018. By using per capita CO2 emissions, population size differences are accounted for. In the EDGAR, data is also available for annual CO2 emissions in seven different sectors. In this study, CO2 emissions in the power industry, transport and industrial processes sectors will be used as outcome variables for robustness. This will be returned to in section 4.2.3.

3.1.2 Key independent variables

3.1.2.1 Intellectual property rights protection: *IPRP*

The variable on the IPR framework is operationalized in various ways in this study. In the first model, the International Property Rights Index is used, which is annually published by the Property Rights Alliance. The most recent report includes 125 countries, collectively representing 93.4% of the world population and 97.5% of world GDP (Levy-Carciente, 2023). The International Property Rights Index assesses the institutional state of property rights and is subdivided into three components: legal and political environment, physical property rights, and intellectual property rights. This thesis uses the component of intellectual property rights. It consists of the items 'protection of intellectual property rights', 'patent protection', 'trademark protection', and 'copyright protection'. In the first investigated relationship, the variable *IPRP* assesses the overall state of the

IPR framework of a country. The scores of the items are scaled by the International Property Agency to range between 0 and 10. The variable consists of 1,221 observations over the period 2008 to 2018.

As elaborated on in section 2.2.2, it is crucial to distinguish between *de jure* and *de facto* IPR protection when measuring the impact of IPR protection institutions, since the presence of formal regulations may not always be congruent with the actual enforcement and effectiveness of these regulations in practice. IPR protection's relationship with green innovation and the dissemination of technologies depends on the level of trust in the legal framework. This may not only be determined by the presence of strong regulations, but also by the subjective perception that individuals have of the IPR framework, which may be dependent on other factors.

3.1.2.2 Strength of patent law: *De jure*

The commonly used measure of IPR protection in the literature is the GP index, created by Ginarte and Park (1997) (Cao et al., 2023; Athreye et al., 2023; Chen & Puttitanun, 2005; Allred & Park, 2007). In this study, this index is used for *de jure* IPR protection (*De jure)*. The GP index measures the strictness of patent law through five different components, namely extent of coverage, membership in international patent agreements, provision for loss of protection, enforcement mechanisms, and duration of protection. These fived dimensions range from 0 to 1, resulting in a total index ranging from 0 to 5. The index is available for every five years from 1960 to 2015. However, starting from 2021, Prof. Walter G. Park continued his work in partnership with the Property Rights Agency (Kazakou & Park, 2021). The new International Patent Index is released every two years. This index is the same as the original GP index, however, a dimension of patent applications has been added. Since this does not correspond with the earlier indexes, for this thesis, the index is recomputed without this dimension. Consistent with Athreye et al. (2023), the years in between each five years during the period from 1960 to 2015 were filled with linear interpolation in order to obtain a continuous variable, as well as the years between 2015 and 2021, together with the missing year 2022. Therefore, 50 missing years were filled by the linear interpolation of 14 observations to obtain a continuous variable from 1960 to 2023. For this study, only the years in the period 2008-2018 are used. There are 1,342 observations of the *De jure* variable in this time period.

Although it has become the standard measure in the research field on IPR protection, it also has its limitations. Sweet and Maggio (2015) point out that this is a measure for the strength of patent protection, and not for the quality of patent systems. There may be disparities there, for example, because countries frequently sign international treaties that they then do not adhere to, or because the index does not consider whether IPR protocols are actually respected and whether they are part of the main IPR statutes, or are deeply buried in laws (Sweet & Maggio, 2015). Jandhyala (2015) also argues that formal IPR policies are imperfectly correlated with their effectiveness, leading to differences in the *de facto* protection of intellectual property between countries with the same regulations, as explained in section 2.2.2. For the same reason, Athreye et al. (2023) distinguish between *de jure* and *de facto* IPR protection in their research, where the former concerns the strictness of patent law (GP index) and the latter concerns patent enforcement.

3.1.2.3 Perception of IPR protection: *De facto*

The operationalization of the *De facto* variable is conducted using citizens' perceptions of IPR protection. The data originates from the question in the Executive Opinion Survey as part of The Global Competitiveness Report by the World Economic Forum: "In your country, to what extent is intellectual property protected?" The values of the data range from 1 to 7. The responses to this question reflect the respondent's practical experiences, rather than solely the existence of laws and regulations. Therefore, it can be considered a measure of *de facto* IPR protection. The dataset consists of 1,804 observations over the period from 2008 to 2018. This item is also part of the intellectual property component of the International Property Rights Index by the Property Rights Alliance.

3.1.2.4 Climate change policies: *Policy*

The investigation of the impact of a high-quality IPR protection framework as an enabling factor for the effectiveness of climate change policies is conducted with an interaction term with a variable on adopted climate change-related policies (*Policy*). For the operationalization of this variable, alignment is sought with the common method in the literature (Athreye et al., 2023; Verdolini & Bosetti, 2017; Nesta et al., 2014; Johnstone et al., 2010). This is done by creating dummy variables for the adoption of environmental, energy, and climate policies listed by the International Energy Agency (IEA) in six categories. These categories are information and education, economic instruments, policy development and reforms, research, development and deployment (RD&D),

regulatory instruments, and voluntary approaches. Each dummy variable receives a value of 1 as from the year that a country adopted a policy in the respective category. The dummy variables collectively form a count variable by summing the scores in all categories, so that the *Policy* variable ranges from 0 to 6. This data was obtained from the authors of the paper by Athreye et al. (2023). The dataset of the present study contains 858 observations of the *Policy* variable over the period from 2008 to 2018.

The limitations of this approach, as also acknowledged by other users, is that it does not allow for distinction based on the stringency of policies and the level of actual enforcement of the policy (Verdolini & Bosetti, 2017; Johnstone et al., 2010). The rationale for this method on the other hand, as indicated by Verdolini and Bosetti (2017), is that governments do not simply come to the adoption of environmental measures, but that there is a lengthy decision-making process involved, including the voting of parties and the support of the public opinion. Therefore, it is considered a credible measure of the "magnitude of commitments of different countries" (Verdolini & Bosetti, 2017).

3.1.3 Control variables

3.1.3.1 Diffusion of climate change mitigation technologies: *DiffCCMTcap*

In the theoretical framework it is explained that climate change mitigation technologies are needed to limit CO2 emissions. These technologies do not necessarily have to be invented domestically but can also be transferred internationally. Therefore, the diffusion of technologies is a better measure of the number of patented technologies in a country than solely the amount of domestically created technologies. Climate change mitigation technologies consist of technologies related to energy transmission, generation and distribution, wastewater treatment and waste management, energy efficient ICT, capture and storage of greenhouse gas emissions, transportation, buildings, and the production and processing of foods. The *DiffCCMTcap* variable measures the number of inventions that seek patent protection through, national, regional or international routes in a given jurisdiction. This way, the amount of available climate change mitigation technologies in a country is represented, including both domestic and foreign inventions. This variable originates from the OECD Intellectual Property database. The data was divided by total population to obtain a per

capita measure of climate change mitigation technology diffusion. The *DiffCCMTcap* variable consists of 704 observations in the 2008-2018 time period.

3.1.3.2 Economic development: *GDPcap*

GDP per capita at current US dollars as a measure of economic development is included as a control variable. Economic development is very likely to influence per capita CO2 emissions. This relationship is in industrial activities using fossil fuels, but also in increased per capita (energy) consumption in more developed countries. On the other hand, economic development may be negatively related to CO2 emissions because institutional reforms and technological progress follows from economic development (Cao et al., 2023). The proposition that environmental pollution and economic development are related in an inverted u-shape also underlies the well-known environmental Kuznets-curve (Grossman & Krueger, 1993). The data of the *GDPcap* variable is sourced from the World Bank national accounts database. The balanced database of this study of the period 2008-2018 contains 1,859 observations.

3.1.3.3 Trade openness: *Trade*

The country's openness to trade is included as a control variable, as there may be a negative relationship between barriers and restrictions to trade and the transfer of technologies (Athreye et al., 2023). Openness to trade may enhance intercountry collaboration in technological advances, but on the other hand it may enlarge the scale of production of a country, leading to higher emissions (Dong et al., 2022). The data of this variable comes from the Fraser Institute database of economic freedom. It is an index ranging from 0 to 10 capturing the freedom to trade internationally. The index consists of two dimensions. The tariff dimension contains the items 'revenue from trade taxes', 'mean tariff rate' and 'standard deviation of tariff rates'. The regulatory trade barriers dimension contains the items 'non-tariff trade barriers' and 'compliance costs of importing and exporting' (Gräbner-Radkowitsch et al., 2018). There are 1,507 observations in the period 2008-2018 in this study.

3.1.3.4 Urbanization: *Urb*

The urban population as a percentage of total population is used to control for the level of urbanization. Research suggests that urbanization is positively related to CO2 emissions. Urban lifestyles are associated with high consumption patterns compared to rural lifestyles (Zhou et al., 2019). Urbanization also increases infrastructure development and transportation activities,

increasing fuel demand and pollution, according to Muhammad et al. (2020). Literature suggests that when controlling for macro-economic factors influencing CO2 emissions, urban population together with GDP per capita and energy consumption should be considered the main determinant of CO2 emissions (Gaies et al., 2022). The data for this variable originates from the United Nations Conference on Trade and Development (UNCTAD) database. The are 1,848 observations for this variable in the balanced dataset.

3.1.3.5 Energy intensity: *Ei*

CO2 emissions are assumed to be positively related to energy consumption (Waheed et al., 2019), because a large part of consumed energy comes from burning fossil fuels, which result in high CO2 emissions. The energy intensity variable measures the proportion of total primary energy consumption per GDP, so that it represents the amount of energy used to produce a unit of economic output. It may be the case that in countries where technology has become cleaner and more efficient, the energy intensity is less positively related to CO2 emissions. The energy intensity variable has 1,793 observations in the 2008-2018 period. The measure unit is in million metric tons of oil equivalent, and the data is sourced from the International Energy Agency.

3.1.3.6 Research & Development: *RD*

RD is used as a control variable to include the impact of the promotion of new technology creation (Cao et al., 2023). Innovation may not only be enhanced by a strong IPR framework, but also by the fact that large amounts of financial means are made available, for instance by governments, for research and development. *RD* represents the percentage of research and development expenditures per total GDP. The variable has 935 observations in the dataset from 2008 to 2018 and is sourced from the World Development Indicators dataset.

3.1.4 Descriptives

The regression analysis is conducted with a balanced dataset covering the time period from 2008 to 2018. For the relationships with *IPRP* as the operationalization of IPR protection (eq. 1 & 3), the dataset contains observations of in total 50 countries, of which 35 are OECD-member countries and 15 are non-OECD countries. The relationship that distinguishes between *de jure* and *de facto* IPR protection (eq. 2) is investigated with 33 OECD countries and 14 non-OECD countries,

creating a total of 44 countries. The measurement and source of each variable of this study are presented in Table 1.

TABLE 1: Variable measurement and source

Variables	Acronym	Measurement	Source
Per capita CO2 emissions	*CO2*	CO2 emissions in Mt per capita	EDGAR
IPR protection	*IPRP*	IPR index category of International Property Rights Index	Property Rights Alliance
Climate change policies	*Policy*	Count of dummies of implemented climate change policy categories	International Energy Agency
Perception of IPR protection	*De facto*	Survey question "In your country, to what extent is intellectual property protected?" from 0 to 7.	Global Competitiveness Report
Strength of patent law	*De jure*	GP-index	Ginarte & Park (1997) and Property Rights Alliance
Diffusion of climate change mitigation technologies	*DiffCCMTcap*	Amount of (foreign) inventions seeking patent protection per capita	OECD IP database
GDP per capita	*GDPcap*	GDP per capita at current US dollars	World Bank
Trade openness	*Trade*	Freedom to trade internationally index from 0 to 10	Fraser Institute
Urbanization	*Urb*	Percentage of urban population per total population	UNCTAD
Energy intensity	*Ei*	Total primary energy consumption in million metric tons of oil equivalent per GDP	EIA
Research & Development	*RD*	Percentage of research and development expenditures per total GDP	World Development Indicators

In Table 2, the summary statistics of the variables are presented. These statistics show that the average CO2 emissions per capita is 4.67 Mt for the full sample. On average, there appears to be a significant difference in the amount of per capita CO2 emissions between OECD countries (8.64 Mt) and non-OECD countries (3.63 Mt). The significant difference between these samples is also present for *IPRP*, *Policy*, *De facto* and *De jure* and most of the control variables. This confirms the relevance of differentiating between the OECD countries and non-OECD countries when analysing the relationships of interest.

Before conducting the regression models of this study, the data was standardized. The variables that consist of indices or ratios were standardized to a mean of approximately zero and a standard

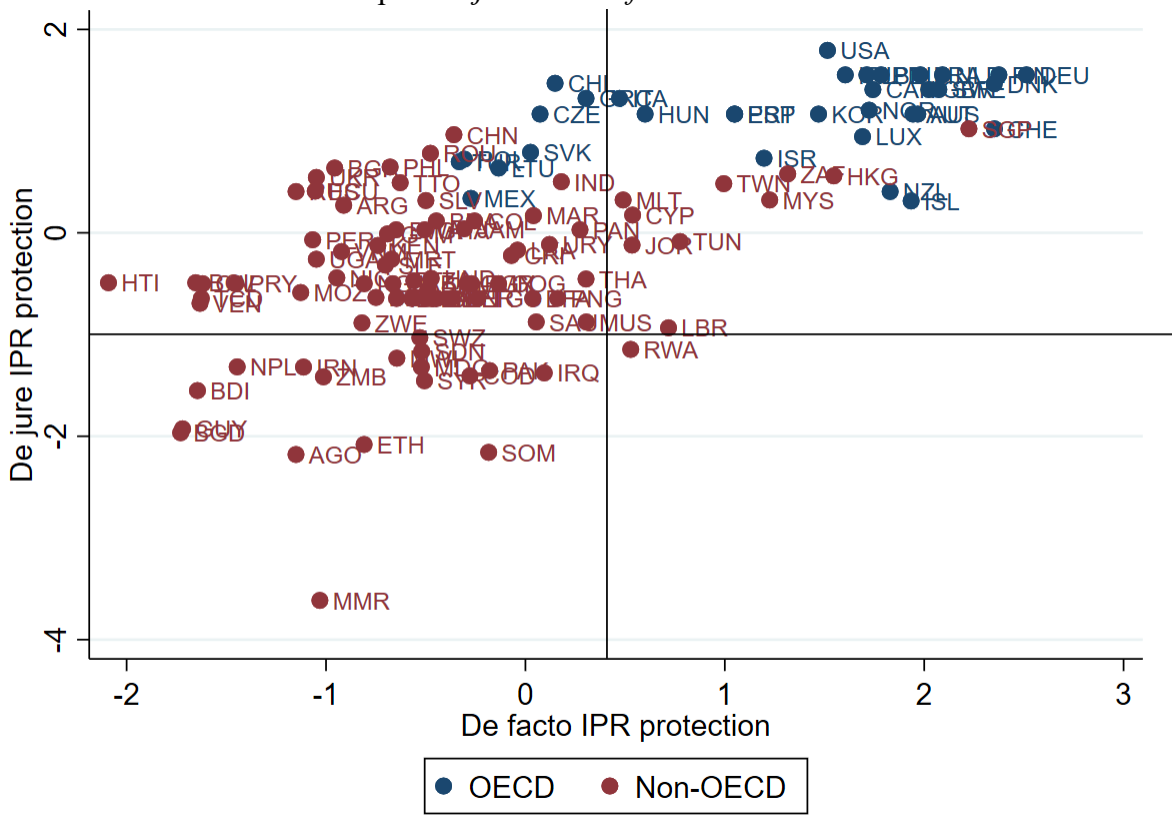
deviation of approximately one. This solves the incomparability of the different scales of the variables. The variables that are not in a scale are min-max normalized to a scale from zero to one. The standardized version of the data is presented in Table 6 in the appendix.

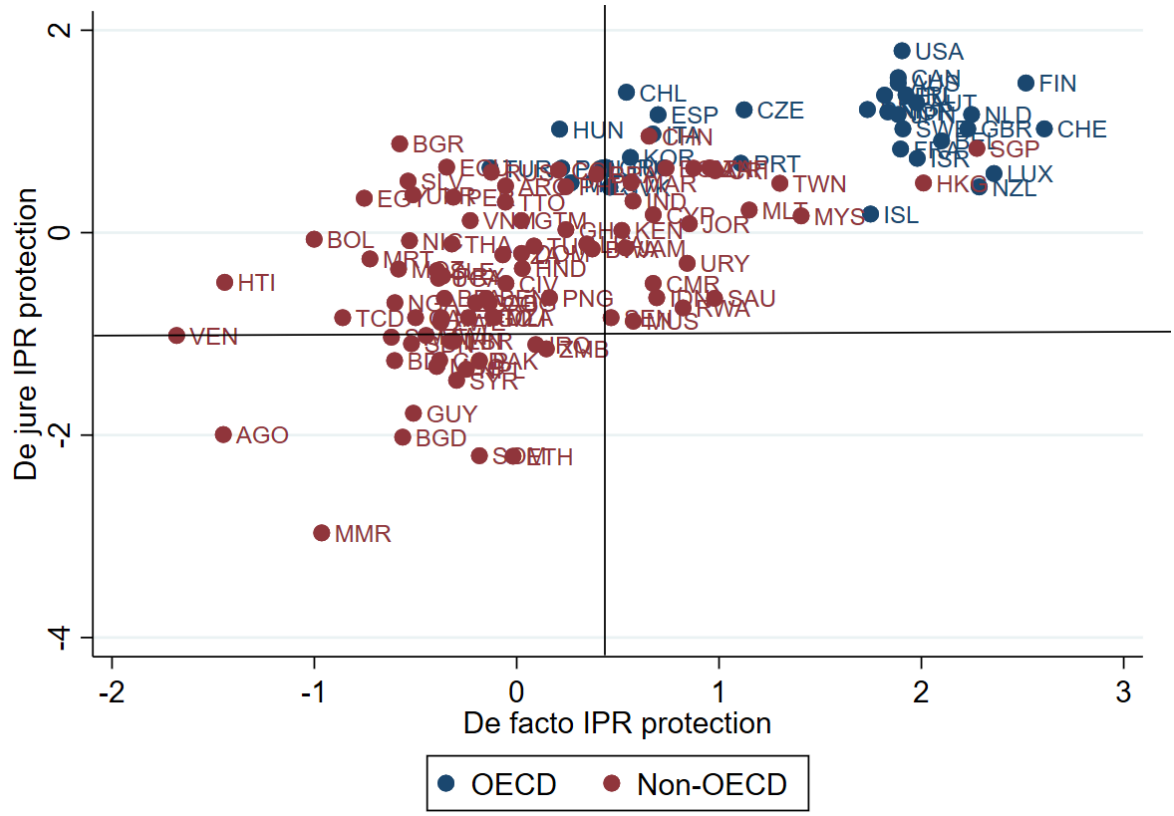
Table 7 in the appendix presents a matrix of the correlation between each variable by full sample, and OECD and non-OECD subsamples. The correlations between *De facto* and *De jure* are shaded. The inclusion of these two measures of IPR protection may cause identification issues if they are highly correlated. The correlation matrix reveals that there is a correlation of 0.600 in the full sample, 0.389 in the OECD subsample and 0.315 in the non-OECD subsample. Graph 1, presented below, displays a correlation scatterplot of the two variables in 2008 and 2018. From this graph it follows that, overall, there is a trend in which countries with stronger IPR laws also have stronger *de facto* IPR protection. However, there is also a large portion of the countries that have a relatively strong *de jure* IPR protection but a relatively weak *de facto* IPR protection system. These countries are in the upper left part of the scatterplot. On the other hand, there are no countries that have a weak *de jure* framework but a strong *de facto* IPR framework, which seems logical. From the correlation coefficients and the correlation scatterplot follows that the variables do not measure the same effect and that they can be included in the same equation without a great threat of identification issues.

TABLE 2: Descriptive statistics of non-standardized data by full sample and OECD membership

Variables	N	mean	sd	min	max
Full sample					
CO2	1,908	4.666	5.927	0.026	43.03
IPRP	1,221	5.342	1.669	1.200	9.100
Policy	858	3.202	2.445	0.000	6.000
De facto	1,804	$-3.69e^{-10}$	3.802	1.065	1.575
De jure	1,342	3.324	0.864	0.200	4.878
DiffCCMTcap	704	2,648	10,253	1.000	126,097
GDPcap	1,859	13,684	19,570	194.7	123,679
Trade	1,507	6.409	1.232	2.090	9.419
Urb	1,848	57.51	22.47	10.12	100
Ei	1,793	76.60	306.5	0.0201	3,459
RD	935	1.056	1.019	0.018	4.776
OECD					
CO2	396	8.640	4.108	3.596	23.11
IPRP	396	7.206	1.121	4.200	9.100
Policy	396	4.962	1.733	0.000	6.000
De facto	396	4.973	0.947	2.594	6.580
De jure	363	4.279	0.347	3.417	4.878
DiffCCMTcap	385	3,245	8,177	1.000	39,560
GDPcap	396	39,384	23,614	8,496	123,679
Trade	396	7.588	0.722	5.429	9.352
Urb	396	77.22	11.36	52.21	98.00
Ei	396	158.5	393.1	1.911	2,455
RD	385	1.902	1.007	0.307	4.776
Non-OECD					
CO2	1,512	3.625	5.891	0.0260	43.03
IPRP	825	4.591	1.199	1.200	8.700
Policy	462	1.693	1.896	0.000	6.000
De facto	1,408	3.473	0.842	1.575	6.278
De jure	979	2.970	0.718	0.200	4.417
DiffCCMTcap	319	2,063	11,923	1.000	126,097
GDPcap	1,463	6,830	10,654	194.7	98,041
Trade	1,111	6.043	1.124	2.090	9.419
Urb	1,452	52.13	21.75	10.12	100.0
Ei	1,397	54.83	275.1	0.0205	3,459
RD	550	0.457	0.437	0.0184	2.597

GRAPH 1: Correlation scatterplot *de jure* and *de facto* IPRP in 2008 and 2018





3.2 Model specification and estimation identification

3.2.1 Equations and model specification

In this study, three different relationships are investigated: the impact of IPR protection on CO2 emissions, the difference in impact of *de facto* and *de jure* IPR protection, and the interaction effect of IPR protection on the relationship between climate-related policies and CO2 emissions. The regression models used to estimate these relationships are conducted with the full sample of countries, as well as with the subsamples of OECD and non-OECD countries only to examine the heterogeneity in effects between developed and developing countries.

The first equation (1) is as follows:

$$CO2_{ct} = \beta_0 + \beta_1 IPRP_{ct} + \beta_2 Policy_{ct} + \beta_3 Control_{ct} + \varepsilon_{ct} \quad (1)$$

In equation 1, *CO2* means CO2 emissions per capita in megatons, *IPRP* denotes the level of IPR protection, and *Policy* stands for the adoption of climate-related policies. *Control* refers to the control variables *DiffCCMTcap*, *GDPcap*, *Trade*, *Urb*, *Ei*, *RD*. ε_{ct} indicates the error term. Subscripts *c* and *t* indicate country and year. In this relationship, the coefficient of interest is β_1. The β_2 coefficient serves as a reference for the moderating effect of IPR protection on the impact of climate policies, included in equation 3.

The second equation (2) distinguishes between *de jure* and *de facto* IPR protection:

$$CO2_{ct} = \beta_0 + \beta_1 De\ jure_{ct} + \beta_2 De\ facto_{ct} + \beta_3 Policy_{ct} + \beta_4 Control_{ct} + \varepsilon_{ct} \quad (2)$$

De jure means the strength of intellectual property protection laws and regulations. *De facto* indicates the actual enforcement of intellectual property rights in practice. The coefficients of main interest are β_1 and β_2. The same control vector is used as in equation 1.

With equation 3, it is attempted to investigate the impact of the IPR protection framework as an enabling or enhancing factor for the effectiveness of climate policies. This is done by estimating the coefficient of the interaction term between the two variables:

$$CO2_{ct} = \beta_0 + \beta_1 IPRP_{ct} + \beta_2 Policy_{ct} + \beta_3 IPRP_{ct} \times Policy_{ct} + \beta_4 Control_{ct} + \varepsilon_{ct} \quad (3)$$

In this relationship, the coefficient of interest is β_3, as it captures the extent to which the IPR protection framework affects the effectiveness of climate policies to mitigate a country's CO2 emissions. The control vector is the same as in equations 1 and 2.

This study uses the Driscoll-Kraay (1998) approach to avoid incorrect estimations due to slope heterogeneity and cross-sectional dependence (Wang et al., 2022). The Discroll-Kraay robust standard errors technique can be used for both short- and long-run panels and it accounts for heteroskedasticity, serial correlation, slope heterogeneity and cross-sectional dependence (Viglioni, 2024). In the following section it is substantiated why this is the most suitable modelling technique for the present study. The preliminary tests in section 3.2.2 reveal that a two-way fixed effects model is most appropriate, compared to a pooled OLS approach. However, since it is expected that most variation in the variables is across countries instead of over time, as follows from Graph 2, a Discroll-Kraay model without country fixed effects, but with time fixed effects, will be conducted as a benchmark regression. This way, it is clarified whether there is indeed an effect if cross-country variance is allowed to play a role, which is eliminated by using a two-way fixed effects model.

The benchmark regression equations, in which time fixed effects are included, are as follows:

$$CO2_{ct} = \beta_0 + \beta_1 IPRP_{ct} + \beta_2 Policy_{ct} + \beta_4 Control_{ct} + v_t + \varepsilon_{ct} \quad (1.1)$$

$$CO2_{ct} = \beta_0 + \beta_1 De\ jure_{ct} + \beta_2 De\ facto_{ct} + \beta_3 Policy_{ct} + \beta_4 Control_{ct} + v_t + \varepsilon_{ct} \quad (2.1)$$

$$CO2_{ct} = \beta_0 + \beta_1 IPRP_{ct} + \beta_2 Policy_{ct} + \beta_3 IPRP_{ct} \times Policy_{ct} + \beta_4 Control_{ct} + v_t + \varepsilon_{ct} \quad (3.1)$$

In this equation, v_t captures time-specific effects that are constant across countries and vary over the years.

Including both time and country fixed effects in the model, as indicated by the estimation tests, results in the following equations:

$$CO2_{ct} = \beta_0 + \beta_1 IPRP_{ct} + \beta_2 Policy_{ct} + \beta_4 Control_{ct} + u_c + v_t + \varepsilon_{ct} \quad (1.2)$$

$$CO2_{ct} = \beta_0 + \beta_1 De\ jure_{ct} + \beta_2 De\ facto_{ct} + \beta_3 Policy_{ct} + \beta_4 Control_{ct} + u_c + v_t + \varepsilon_{ct} \quad (2.2)$$

$$CO2_{ct} = \beta_0 + \beta_1 IPRP_{ct} + \beta_2 Policy_{ct} + \beta_3 IPRP_{ct} \times Policy_{ct} + \beta_4 Control_{ct} + u_c + v_t + \varepsilon_{ct} \quad (3.2)$$

The two-way fixed effects model captures cross-country heterogeneity that is constant over time, and time-specific heterogeneity that is constant over countries. u_c and v_t indicate country and year fixed effects.

3.2.2 Justification of estimation approach

Since it is expected that there are country level characteristics that are not controlled for by the control variables having an impact on CO2-emissions, it is suitable for this analysis to use a country fixed effects approach, as described in the foregoing section. A fixed effects model captures the influence of constant unobservable country characteristics. Examples that may be relevant in this study are quality of government institutions, cultural attitudes toward climate change, and the development of education and research. Controlling for these characteristics reduces omitted variable bias. However, it should be noted that the visualization of the variables over time, as presented in Graph 2, reveals that the variation in the data is for a large part across entities. This is especially the case for the dependent variable *CO2* and the independent variables *De jure* and *Policy*, but also for other variables. This has important implications when using a fixed effects approach, since the variation across countries will be absorbed, leaving only the little variation over time in a specific country to estimate the effect with. Therefore, including country fixed effects is not ideal for this analysis. For this reason, the two-way fixed effects specification follows a one-way fixed effects estimation, controlling only for time-invariant effects and allowing for variation between countries. This will be a pooled OLS estimation instead of a random effects specification, due to the unrealistic assumption of the random effects specification that the unobserved country characteristics are uncorrelated with the regressors.

To confirm the foregoing, several statistical tests were conducted to identify the most suitable estimation approach. The results of these estimation identification tests are presented in Table 8 in the appendix. Firstly, the White test was used to assess the presence of heteroskedasticity, and the

Woolridge test was used to test for serial correlation. These tests indicate the presence of heteroskedasticity and serial correlation in the data of all equations at the $p<0.01$ significance level.

Because heteroskedasticity and serial correlation were found, the Wald test for time fixed effects was performed on robust standard errors models. This test reveals that adding time fixed effects provides a better model. A joint F-test, testing whether all u_i are equal to zero, demonstrates that adding country fixed effects is necessary for each equation. Since Stata suppresses this test when conducting a robust standard errors model, as it becomes too difficult to calculate the robust form of the statistic when there are more than a few panels, the test statistics relate to regular fixed effects models. These tests suggest including both time and country fixed effects in the model.

The Breusch-Pagan LM test was used to investigate whether a random effects model would fit the data better than a pooled OLS model. The null hypothesis that the variances across entities are zero is rejected at the 1% significance level for each equation, indicating that random effects are preferred over pooled OLS. However, as described above, it was not chosen to use a random effects specification due to the unrealistic assumptions of this model. Next, the choice for the best estimation method was based on the overidentification test described by Arellano (1993). This test is equivalent to the Hausman test when testing for model specification but, unlike the Hausman test, is also applicable to models with robust standard errors. The test results suggest a fixed effects specification for each equation.

These tests confirm that, indeed, including two-way fixed effects is most suitable for this analysis. On the other hand, as explained earlier, including country-fixed effects is not ideal because there is only marginal variation over time in the data. Therefore, the two-way fixed effects approach is combined with a pooled OLS model with time-fixed effects.

3.2.3 Slope heterogeneity and cross-sectional dependence tests

It is crucial to test for slope heterogeneity and cross-sectional dependence in panel data. Since it is common for countries to have distinct characteristics, slopes are usually heterogeneous (Viglioni et al., 2024). If slope heterogeneity is not accounted for, the estimates will be biased (Li et al., 2021). Cross-sectional dependence is present when the data of one country is correlated with the data of another country. This may be caused by common unobserved factors that influence the

dependent variable (Cheng & Yao, 2021). Cross-sectional dependence should not only be taken into account to avoid biased estimates, but it also has implications for the unit root tests to be used. The first-generation Im-Pesaran-Shin (IPS) test is not robust to cross-sectional dependence. Therefore, in the presence of cross-sectional dependence and slope heterogeneity, the cross-sectionally augmented Im-Pesaran-Shin (CIPS) test is recommended (Li et al., 2021).

The slope heterogeneity test introduced by Pesaran and Yamagata (2008) is used. The results of this test are presented in Table 9 in the appendix. The null hypothesis of slope homogeneity is rejected for each equation at the 1% significance level, except for the non-adjusted delta in equation 3, with significance at the 5% level. The test was also conducted with HAC standard errors as introduced by Blomquist and Westerlund (2013) to account for the heteroskedasticity and autocorrelation that is present in the data. This test also indicates slope heterogeneity at 1% significance, suggesting a model specification that suits the heterogeneity across countries.

To assess the issue of cross-sectional dependence, the Pesaran (2004) cross-sectional dependence test was conducted. This technique is efficient in handling cross-sectional dependence issues in panel data with finite cross-sectional units and short time periods (Li et al., 2021). The cross-sectional dependence test indicates strong cross-sectional dependence for all variables at the 1% significance level, as presented in Table 10 in the appendix.

From these preliminary test follows that heteroskedasticity, serial correlation, slope heterogeneity and cross-sectional dependence are present in the panel data. Therefore, the Driscoll-Kraay approach is suitable for this study. The Driscoll-Kraay robust standard errors technique can be used for both short- and long-run panels and it accounts for heteroskedasticity, serial correlation, slope heterogeneity and cross-sectional dependence (Viglioni, 2024).

3.2.4 Panel unit root tests

To avoid misleading results, it should be confirmed that the panel data is stationary. As mentioned above, the first-generation unit root test is not suitable in the presence of cross-sectional dependence. Therefore, the CIPS test as suggested by Pesaran (2007) was conducted. This test is robust to cross-sectionally dependent panels and allows for varying slope coefficients across cross-sectional units (Li et al., 2021). The CIPS test is conducted at level and at first difference, both with

and without time trend. The results are presented in Table 11 in the appendix. The variables *De jure*, *Trade*, *Ei*, and *DiffCCMTcap* are stationary at level, some of them after adding a time trend. The variables *CO2*, *IPRP*, *GDPcap*, *Urb* and *RD* are stationary at first difference. *De facto* and *Policy* appear to be non-stationary, based on the CIPS-test.

Structural breaks may mislead unit root tests to accept the null hypothesis of unit root when the data is in fact stationary. To assess the issue of structural breaks in these variables regarding non-stationarity, the unit root test with structural breaks suggested by Karavias and Tzavalis (2014) was conducted for *De facto* and *Policy*. It was specified in this test that the errors are cross-sectionally dependent. The results in Table 12 in the appendix suggest that the null hypothesis that all panel time series are unit root processes must be rejected for both variables. The test reveals that there is a structural break in 2011 for *De facto* and in 2009 for *Policy*. This will be accounted for in the models by adding dummy variables that have the value 1 when the year is higher than or equal to 2009 and 2011 respectively. From these tests it can be concluded that the variables are integrated over time. In the Driscoll-Kraay robust standard errors models, all variables are used at first difference level for consistency.

4 RESULTS

4.1 Baseline results

Table 3 shows the results of the Driscoll-Kraay robust standard errors estimations of equations 1.1 and 1.2. Models 1 and 2 show the full sample estimates. The variables *IPRP* and *Policy* do not exhibit significant results, neither with nor without country fixed effects. The same goes for the OECD and non-OECD subsamples, apart from the *Policy* variable showing a significantly positive coefficient on CO2 emissions in non-OECD countries in model 6. Furthermore, it is notable that the relationship between energy intensity is highly significant and strongly positive in all models, especially in the OECD subsample (β=0.779 & 0.743; $p<0.01$). Lastly, the results indicate a significantly positive relationship between the incoming diffusion of climate change mitigation technologies (*DiffCCMTcap*) and CO2 emissions in non-OECD countries, in contrast to what was expected.

Table 4 shows the results of the Driscoll-Kraay robust standard errors estimations of equations 2.1 and 2.2, in which *De jure* and *De facto* are used to make the distinction between the effects of IPR law stringency and IPR enforcement. In contrast to what was expected, *de jure* IPR protection shows a significantly positive effect on CO2 emissions in models 1 and 5. However, this effect disappears when country fixed effects are included. In the OECD subsample, no statistically significant effect was found at all. The same holds for *de facto* IPR protection in all models. Model 2 provides evidence for a negative relationship between R&D expenditures (*RD*) and CO2 emissions. However, this effect was not present in the other models.

The estimation results presented in Table 5 are in line with what was found in the estimation results of the other equations. In equations 3.1 and 3.2, an interaction term of *Policy* and *IPRP* was added to investigate the effect of IPR protection as a factor enhancing the effect of climate policies. Models 1 and 2, in which the full sample is used, provide evidence of a significantly negative interaction effect between IPR protection and climate policies on CO2 emissions (β= -0.00264; $p<0.05$ & β= -0.00203; $p<0.05$). This indicates that the combination of strong IPR protection and the implementation of climate policies has a stronger CO2 emission mitigating effect than the sum of their separate effects. This would suggest that the presence of a strong IPR protection framework adds to the CO2 emission mitigating effect of climate policies. However, such an individual effect was not found.

TABLE 3: Driscoll-Kraay robust standard errors estimation results of equations 1.1 and 1.2 by full sample and OECD membership

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample		**OECD**		**Non-OECD**	
IPRP	-0.00173	-0.00259	-0.000385	-0.000696	-0.00173	-0.00298
	(0.00407)	(0.00357)	(0.00375)	(0.00317)	(0.00346)	(0.00390)
Policy	0.00182	0.000117	0.00199	-0.000933	0.00345	0.00508**
	(0.00129)	(0.00125)	(0.00170)	(0.00194)	(0.00219)	(0.00162)
DiffCCMTcap	0.00373	-0.00109	-0.0163	-0.0194	0.0437**	0.0476***
	(0.0201)	(0.0190)	(0.0226)	(0.0252)	(0.0169)	(0.0127)
GDPcap	0.00729	0.00189	0.0141	0.00754	0.0987	0.125*
	(0.0203)	(0.0152)	(0.0211)	(0.0131)	(0.0718)	(0.0599)
Trade	-0.000943	-0.000907	-0.000178	-0.000616	-0.00208	-0.00185
	(0.00302)	(0.00186)	(0.00334)	(0.00253)	(0.00314)	(0.00471)
Urb	-0.0468	-0.0319	-0.0426	-0.0161	0.0120	-0.0618
	(0.0336)	(0.120)	(0.0574)	(0.159)	(0.0492)	(0.332)
Ei	0.365***	0.387***	0.779***	0.743***	0.195**	0.216***
	(0.0463)	(0.0473)	(0.0932)	(0.106)	(0.0639)	(0.0500)
RD	-0.000845	-0.00366**	0.00128	-0.00386	0.00616	0.00910
	(0.00135)	(0.00118)	(0.00274)	(0.00279)	(0.0127)	(0.0119)
Constant	-0.00729***	-0.0072049***	-0.0074443**	-0.0073261***	-0.0066118***	-0.00569
	(0.000368)	(0.0009339)	(0.000202)	(0.0012514)	(0.0006054)	(0.00466)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Observations	470	470	340	340	130	130
Number of countries	47	47	34	34	13	13
R-squared	0.301	0.323	0.367	0.415	0.364	0.354

Note: Dependent variable is *CO2.* All variables are at first difference. Driscoll and Kraay robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

TABLE 4: Driscoll-Kraay robust standard errors estimation results of equations 2.1 and 2.2 by full sample and OECD membership

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample		**OECD**		**Non-OECD**	
De jure	0.0111**	0.00858	0.00316	0.000855	0.0160*	0.0304
	(0.00488)	(0.00571)	(0.00617)	(0.00852)	(0.00829)	(0.0189)
De facto	0.000647	0.00143	-0.00204	-0.000719	0.00635	0.00400
	(0.00209)	(0.00103)	(0.00296)	(0.00239)	(0.00412)	(0.00779)
Policy	0.00140	0.000228	0.00241	-0.00160	0.00387*	0.0144***
	(0.00156)	(0.00142)	(0.00458)	(0.00505)	(0.00175)	(0.00323)
DiffCCMTcap	0.00111	-0.00432	-0.0242	-0.0268	0.0441**	0.0738*
	(0.0254)	(0.0198)	(0.0286)	(0.0280)	(0.0158)	(0.0326)
GDPcap	0.00493	0.000272	0.0151	0.00900	0.0927	-0.0536
	(0.0207)	(0.0136)	(0.0225)	(0.0128)	(0.0767)	(0.129)
Trade	2.22e-05	1.30e-05	0.000871	0.000626	-0.000971	0.00374
	(0.00303)	(0.00168)	(0.00356)	(0.00248)	(0.00330)	(0.00902)
Urb	-0.0404	-0.0453	-0.0303	-0.0123	0.0272	0.235
	(0.0363)	(0.128)	(0.0610)	(0.168)	(0.0396)	(0.320)
Ei	0.351***	0.379***	0.787***	0.757***	0.164**	0.00198
	(0.0448)	(0.0471)	(0.0974)	(0.102)	(0.0546)	(0.0544)
RD	-0.000250	-0.00376***	0.00273	-0.00336	0.00345	-0.00507
	(0.00194)	(0.00109)	(0.00405)	(0.00323)	(0.0110)	(0.0192)
Constant	-0.00732***	-0.00712***	-0.00766***	-0.00743***	-0.00705***	0.00293
	(0.000403)	(0.00122)	(0.000553)	(0.00160)	(0.000396)	(0.00540)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Observations	440	440	320	288	108	108
Number of countries	44	44	32	32	12	12
R-squared	0.298	0.318	0.361	0.415	0.396	0.380

Note: Dependent variable is *CO2*. All variables are at first difference. Driscoll and Kraay robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

TABLE 5: Driscoll-Kraay robust standard errors estimation results of equations 3.1 and 3.2 by full sample and OECD membership

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample		**OECD**		**Non-OECD**	
IPRP	-0.000766	-0.00183	0.00202	0.00126	-0.000727	-0.00248
	(0.00403)	(0.00362)	(0.00536)	(0.00506)	(0.00377)	(0.00423)
Policy	0.00174	0.000172	0.000330	-0.00214	0.00265	0.00465**
	(0.00189)	(0.00161)	(0.00404)	(0.00398)	(0.00218)	(0.00160)
IPRP x Policy	-0.00264**	-0.00203**	-0.00343	-0.00272	0.00278	0.00126
	(0.000830)	(0.000826)	(0.00402)	(0.00406)	(0.00263)	(0.00228)
DiffCCMTcap	0.00382	-0.000928	-0.0164	-0.0194	0.0436**	0.0477***
	(0.0189)	(0.0186)	(0.0223)	(0.0250)	(0.0164)	(0.0124)
GDPcap	0.00815	0.00255	0.0147	0.00798	0.102	0.126*
	(0.0206)	(0.0149)	(0.0221)	(0.0131)	(0.0728)	(0.0618)
Trade	-0.000881	-0.000815	-1.96e-05	-0.000411	-0.00231	-0.00199
	(0.00300)	(0.00183)	(0.00357)	(0.00279)	(0.00332)	(0.00474)
Urb	-0.0450	-0.0316	-0.0410	-0.0152	0.0125	-0.0499
	(0.0318)	(0.118)	(0.0572)	(0.159)	(0.0488)	(0.329)
Ei	0.365***	0.386***	0.774***	0.739***	0.188**	0.214***
	(0.0469)	(0.0473)	(0.0983)	(0.113)	(0.0649)	(0.0520)
RD	-0.000674	-0.00351**	0.00142	-0.00372	0.00626	0.00902
	(0.00126)	(0.00125)	(0.00289)	(0.00295)	(0.0128)	(0.0120)
Constant	-0.0073086***	-0.0072149***	-0.007406***	-0.0072985***	-0.0066183***	-0.0058585***
	(0.0003754)	(0.0009302)	(0 .00023)	(0.0012668)	(0.0006217)	(0.004621)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Observations	470	470	340	340	130	130
Number of countries	47	47	34	34	13	13
R-squared	0.302	0.324	0.369	0.416	0.367	0.355

Note: Dependent variable is *CO2*. All variables are at first difference. Driscoll and Kraay robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

4.2 Robustness

4.2.1 Lagged variable approach

It is to be expected that changes in IPR protection frameworks do not directly affect the amount of CO2 emissions in the same year. Inventions and technologies take a certain period of time to be marketed or implemented as established products. Therefore, the analysis is conducted again with the explanatory variables lagged by one year. This accounts for the possible time lags between the variables and their impacts on CO2 emissions, consistent with literature on related models (Li & Chen, 2023; Athreye et al., 2023). Simultaneously, this helps with mitigating endogeneity issues because the potential presence of reverse causality is eliminated with the use of lagged variables. It could be the case that countries in which CO2 emission performances are weak are more likely to address this by improving IPR frameworks and adopting climate policies. This lagged approach is useful and common when an exogenous instrumental variable is not available (Wang & Bellemare, 2019). However, it does not address the potential influence of unobserved factors, which leaves the way open for omitted variable bias.

This results in the following equations.

$$CO2_{ct} = \beta_0 + \beta_1 IPRP_{ct-1} + \beta_2 Policy_{ct-1} + \beta_4 Control_{ct(-1)} + v_t + \varepsilon_{ct} \quad (1.3)$$

$$CO2_{ct} = \beta_0 + \beta_1 De\ jure_{ct-1} + \beta_2 De\ facto_{ct-1} + \beta_3 Policy_{ct-1} + \beta_4 Control_{ct(-1)} + v_t + \varepsilon_{ct} \quad (2.3)$$

$$CO2_{ct} = \beta_0 + \beta_1 IPRP_{ct-1} + \beta_2 Policy_{ct-1} + \beta_3 IPRP_{ct-1} \times Policy_{ct-1} + \beta_4 Control_{ct(-1)} + v_t + \varepsilon_{ct} \quad (3.3)$$

Again, the time fixed effects approach will be followed by a two-way fixed effects approach:

$$CO2_{ct} = \beta_0 + \beta_1 IPRP_{ct-1} + \beta_2 Policy_{ct-1} + \beta_4 Control_{ct(-1)} + u_c + v_t + \varepsilon_{ct} \quad (1.4)$$

$$CO2_{ct} = \beta_0 + \beta_1 De\ jure_{ct-1} + \beta_2 De\ facto_{ct-1} + \beta_3 Policy_{ct-1} + \beta_4 Control_{ct(-1)} + u_c + v_t + \varepsilon_{ct} \quad (2.4)$$

$$CO2_{ct} = \beta_0 + \beta_1 IPRP_{ct-1} + \beta_2 Policy_{ct-1} + \beta_3 IPRP_{ct-1} \times Policy_{ct-1} + \beta_4 Control_{ct(-1)} + u_c + v_t + \varepsilon_{ct} \quad (3.4)$$

The same control variables as in the baseline regressions are used. However, not all of them are lagged by one year. Control variables *DiffCCMTcap* and *RD* are lagged because it is expected that there is a delay in their relationship with CO2 emissions, and there may be a reverse channel in these relationships as well. Since this is not expected for *GDPcap*, *Trade*, *Urb* and *Ei*, the non-lagged versions are used as control variables. Therefore, the -1 lag is in brackets in the equations above. u_c and v_t again capture country and time fixed effects.

Tables 13 to 15 in the appendix present the estimation results of the Driscoll-Kraay robust standard errors models with lagged variables. Table 13 shows that using 1-year lags did not alter results of *IPRP* and *Policy* compared to Table 3 in the sense that still no significantly negative estimation coefficients were found, in contrast to what was hypothesized. The IPR protection variable again showed negative signs and the climate policy variable showed positive signs, except for the non-OECD subsample. What changed compared to the results in Table 4 is that there is no significantly positive effect of *Policy* found in model 6.

Table 14 presents the estimation results of equations 2.3 and 2.4. Compared to the estimation coefficients of Table 4, more evidence was found for a positive relationship between *de jure* IPR protection and CO2 emissions, in contrast to what was hypothesized. In models 1 to 4, significantly positive coefficients of approximately 0.0165 were found with the full sample and the OECD countries subsample. The variable did not exert a significant effect in the non-OECD countries subsample, while this in fact was the case in model 5 of the non-lagged estimation (Table 4) . In the full sample, adding country fixed effects (model 2) altered the significance level of the coefficient from $p<0.01$ to $p<0.1$ and in the OECD subsample from $p<0.01$ to $p<0.05$.

The coefficients of *De facto* switched from positive to negative signs in the full sample models compared to the non-lagged estimation results in Table 4. Additionally, the negative coefficient in model 6 ($\beta= -0.00366$) was significant at the $p<0.1$ level. This provides some evidence for a lagged negative relationship between *de facto* IPR protection. However, this is not supported by the other models.

In the model presented in Table 15, no significant effects of interest were found. The lagged *IPRP* variable seems to have no relationship with CO2 emissions. The same holds for the interaction effect of IPR protection and the implementation of climate change policies on CO2 emissions.

4.2.2 De facto IPRP as Patent Enforcement Index

The *de facto* IPR protection variable is operationalized in this study as citizens' perceptions of the extent to which intellectual property rights are protected. This was chosen as the main operationalization of this variable because of the high number of countries for which this variable is available. However, it may not be the most optimal measurement of *de facto* IPR protection as it is a survey item based on people's subjective valuations. Also, it does not allow for nuances. It is a broad question on the general level of IPR protection. Therefore, the main results of this study are compared with the estimation results when a different operationalization is used for this variable.

This operationalization is based on the Patent Enforcement Index (Papageorgiadis & Sofka, 2020). This index relates to the transaction costs of upholding patent rights and consists of the dimensions servicing costs, property rights protection costs, and monitoring costs. This can be thought of as a measure of *de facto* IPR protection because it provides insight into the ease with which patent rights can be enforced, according to Papageorgiadis and Sofka (2020). The aggregate score is an unweighted average of the three components with a maximum of 10. The dataset contains observations from 51 countries in the period from 1998 to 2017. Since this extended time period is also available for all the other variables, but not for the main operationalization of *De facto*, using this dataset also allows for investigating whether there is a different relationship between IPR protection and CO2 emissions over a longer period of time, as compared to the period 2008-2018.

The results of this estimation model are presented in Table 16. Where the original models still provided evidence for a significantly positive relationship between *De jure* and *CO2* in the full sample and the non-OECD sample, this is no longer the case in this robustness model. All coefficient signs of *De jure* in Table 16 are negative. In model 2, this effect is significant at the $p<0.05$ level. Additionally, no evidence was found in the original model for a significant relationship between *De facto* and *CO2*. However, this robustness model provides an indication of

a positive relationship in the full sample with coefficients of 0.0150 without country fixed effects and 0.0140 with the inclusion of country fixed effects (both at $p<0.05$). It is notable that the signs of these two versions of IPR protection switch between significantly positive and negative, as will also be evident from later robustness estimations. This could indicate that collinearity between these variables is still a problem in this study. It seems that from all the models combined, no definitive conclusion can be drawn about the relationship of these variables with CO2 emissions. Furthermore, Table 16 provides marginal evidence for a negative relationship between patent seeking (*DiffCCMT*) and CO2 emissions. Negative effects of this variable were found in the full sample and non-OECD subsample without country-fixed effects at the $p<0.1$ significance level.

4.2.3 Separate CO2 emission categories

It could be the case that that there are specific sectors in which CO2 emission levels may vary more across countries or are more dependent on institutions like IPR protection frameworks compared to other sectors. For instance, in the agriculture sector it is mostly other greenhouse gasses, like methane and nitrous oxide that pose a threat for climate change challenges. CO2 emissions in agriculture come from soil tillage and burning crop residues. From a layman's point of view, it seems unlikely that these activities can be made more climate friendly by using technologies developed through improved IPR systems, compared to activities in other sectors. For robustness, three categories of CO2 emissions that are expected to be the most related to IPR protection are chosen as dependent variables to compare their relationships with IPR protection with that of total CO2 emissions.

The first sector is power industry. This refers to power and heat generation plants. It is expected that the amount of CO2 emissions in this sector is highly dependent on IPR frameworks, as innovations in for instance solar and wind power, but also carbon capture and storage technologies are very important determinants of reduced net CO2 emissions. The second sector is transport. This refers mobile combustion by road, rail, shipping, and aviation vehicles. The emissions from burning fuels in transportation are a big driver of climate change. Technology development can improve energy efficiency in these vehicles and can create a shift towards electrical vehicles. The last CO2 emission category is processes. This refers to emissions from the industrial process of

producing cement, iron and steel, aluminium, chemicals, etc. Improved technologies may contribute to optimized processes and greener alternatives, like using hydrogen as fuel.

Tables 17 to 19 present the results for CO2 emissions in the power industry sector as the outcome variable. In equation 1 (Table 17) nothing changed regarding the effect of *IPRP* compared to the main results. Still, negative coefficients emerged from the regression analysis without any significance. Table 18 shows that the significantly positive effect of *De jure* in the full sample without country fixed effects found in the main analysis (Table 4) is not present in the power industry sector. Similar to the main analysis, no significant relationship between *de facto* IPR protection and CO2 emissions was found. The results indicate a negative interaction effect of *IPRP* and *Policy* in the full sample at the $p<0.05$ level. This effect is not present in the subsamples.

What is striking is that *Policy* shows a significant positive relationship in the full sample and non-OECD sample. This is unexpected, since the purpose of climate policies is to mitigate pollution and climate change. The positive relationship could be due to a reverse causality issue, in which countries with high CO2 emissions switch to implementing policies. Another issue could be that countries with already improved emission performance implemented their policies before 2008. The fact that first differences were used in this study removes the impact of these policies, because there is little or no growth in the implementation of climate policies in those countries.

Tables 20 to 22 present the results for CO2 emissions in the transportation sector as the outcome variable. This alteration to the main analysis again does not change the impression of the main analysis. No significant effect of *IPRP* emerged from this robustness analysis (Table 20). The same goes for *De facto*. There is still evidence for a positive relationship between *de jure* IPR protection and CO2 emissions (Table 21). Also, no significant interaction effect was found (Table 22). In this model with CO2 emissions in transportation as a dependent variable however, *Policy* appears to have a significantly negative effect in the OECD subsample in all three equations. Additionally, different from other models, *DiffCCMT* exerts a significantly negative effect in the full sample and OECD subsample, especially in the estimation of equation 2. This provides an indication that green innovation may be an important determinant of reduced CO2 emissions in the transport sector.

The analysis on CO2 emissions in the industrial processes sector provides evidence for a negative effect of *IPRP* (Table 23). Model 2 presents a coefficient of -0.00595 (full sample) and model 4 presents a coefficient of -0.00887 (OECD sample), both at the $p<0.05$ significance level. In all models, *De jure* and *De facto* do not exert any significant effects (Table 24). Also, no interaction effect is found between *Policy* and *IPRP* (Table 25).

5 DISCUSSION

5.1 Hypotheses evaluation

In section 2 of this thesis, based on existing literature, three hypotheses were developed regarding the relationships between IPR protection frameworks, climate policies and CO2 emissions. These hypotheses were tested using the empirical analysis described in section 3 and the subsequent results described in section 4.

Hypothesis 1 posits that a country's level of IPR protection is negatively related to its annual CO2 emissions. This proposition stems from the incentive theory and the theory of reduced transaction costs in technology transfers. The empirical analysis of this study does not provide evidence that this relationship exists. None of the baseline regression models show a significant relationship between the general measure of IPR protection and CO2 emissions. The robustness estimation of CO2 emissions in the processes sector does in fact provide some marginal indication of a negative impact of overall intellectual property protection. When distinguishing between *de jure* and *de facto* IPR protection, indications emerge for a positive effect of *de jure* IPR protection on CO2 emissions. This effect is found in the full sample and non-OECD country sample in the non-lagged model, and also found in the full sample and OECD country sample in the lagged variables model. The lagged model can be considered the better fitting model due to the potential delay in the hypothesized effect and the elimination of reverse causality issues. Moreover, the relationship is highly significant in the lagged variables model without country fixed effects and exists also with the inclusion of country fixed effects, whereas it is only moderately significant in the non-lagged model and does not exist when country fixed effects are included. The reason for the observed positive relationship, which is not in line with hypothesis 1, could stem from a possible association between strong *de jure* IPR frameworks and a country's level of economic development and industrialization. This is also reflected in the fact that the significant relationship is not found in the non-OECD sample in the lagged model and becomes less significant with the inclusion of country fixed effects. The positive impact of economic activity and industrialization on CO2 emissions, which according to the estimation results is not captured by GDP per capita and the level of urbanization in this analysis, would then be more present than the potential negative

relationship between IPR protection and CO2 emissions through green innovation and technology transfers. Overall, the hypothesis that there is a negative relationship between a country's IPR protection framework and its annual CO2 emissions cannot be accepted. The only support for this proposition is found in the robustness model of CO2 emissions in the industrial processes sector.

Hypothesis 2 posits that, to the extent that there is a negative relationship between the level of IPR protection and annual CO2 emissions, this relationship is stronger in developed countries than in developing countries. Unfortunately, hypothesis 1 cannot be accepted based on this analysis, thus compromising the interpretation of hypothesis 2. As indicated, it did show that a clear distinction can be made between the OECD sample and the non-OECD sample in terms of the apparent positive relationship between *de jure* IPR protection and CO2 emissions. This difference could stem from the level of development and industrialization that could be associated with stronger IPR regulations and higher CO2 emissions, as it was interpreted in the paragraph above. Furthermore, the robustness model in which CO2 emissions in the processes sector act as a dependent variable is the only model that provides some support for hypothesis 1, adding relevance to the evaluation of hypothesis 2. It showed a negative relationship between general IPR protection frameworks and CO2 emissions from industrial processes in the full sample and the OECD subsample. This suggests that IPR protection can contribute to optimized processes through, for instance, energy-efficient technologies and greener fuel alternatives in OECD countries and not in non-OECD countries, which is in line with hypothesis 2. However, this conclusion about the *industrial* sector is not in line with the idea described earlier that IPR regulation may be associated with higher economic development and *industrialization*, leading to higher CO2 emissions. The failure to find significant relationships in the non-OECD sample, both in the case of *de jure* IPR protection and overall IPR protection, could also be due to power issues in the data. The model in question had 288 and 340 observations from 32 and 34 countries respectively for the OECD sample and 108 and 130 observations from 12 and 13 countries respectively for the non-OECD sample. Overall, the analysis does not provide strong evidence supporting hypothesis 2, partly due to the lack of finding significant relationships related to hypothesis 1.

Lastly, marginal support was found for the proposition that the combination of the implementation of climate policies and the presence of a strong IPR protection framework exerts a negative

interaction effect on the amount of CO2 emissions, as was laid down in hypothesis 3. This means that the negative effect of these two factors combined would be stronger than each of the individual effects added up. This could then be interpreted as IPR protection frameworks being an enabling factor for the effectiveness of climate policies, or vice versa. Although it did not demonstrate a significant relationship between climate policies and CO2 emissions, the non-lagged Driscoll-Kraay robust standard errors model showed a significantly negative interaction effect of IPR protection and climate policies in the full sample. This effect was not present in the subsamples. In the lagged variables model, no significant interaction effect was found. The robustness checks in which CO2 emissions from separate sectors functioned as the dependent variable provided more proof for a negative interaction effect of IPR protection and climate policies. In the power industry sector, significantly negative interaction effects were found in the full sample and the OECD-country subsample. Other than what was expected, climate policies exerted a significantly positive individual impact on CO2 emissions from the power industry sector in the full sample and, with even more significance, in the non-OECD subsample. In the transport sector model, no interaction effect was found. In contrast to the power industry sector, climate policy implementations were shown to be negatively related to CO2 emissions in the transport sector in the full sample and the OECD subsample. No significant interaction effect was found in the industrial processes sector either. In this model, negative individual effects of climate policies were found in the full sample and the non-OECD subsample. Overall, some indications for a negative interaction effect of IPR protection and climate policies emerged from the analyses. This may suggest that the negative effects of these variables on CO2 emissions only emerge the more they are both present. However, the analyses did not provide sufficient evidence to support hypothesis 3.

5.2 Academic contribution

Climate change is one of the biggest global challenges today, largely driven by greenhouse gas emissions. As a result, many scientists have made efforts to investigate the ways to tackle this issue. It has been shown that intellectual property rights are a significant determinant of green innovation and environmentally sound technology transfers. These two concepts are also mentioned by the IPCC and UNFCCC as part of the primary solution for reducing greenhouse gas emissions. Also, empirical research has shown that these green innovation and technology transfers can be related

to better carbon neutrality outcomes. However, the crucial question remains about the original determinant of this relationship. The question still needs to be addressed whether improvements in IPR protection influence greenhouse gas performance. After all, this is a variable that governments can directly influence. This study fills this research gap by investigating whether IPR protection has a negative impact on CO2 emissions and whether strong IPR frameworks are an enabling factor for the effectiveness of climate policies. In addition, the literature has frequently highlighted that improvements in IPR frameworks do not have the same effects worldwide. Several studies have pointed out that there could be heterogeneous optimal IPR levels, depending on a country's degree of economic development and technological capabilities. This research builds on this idea and distinguishes between OECD and non-OECD countries to test the validity of this proposition in the context of the relationship between IPR protection and CO2 emissions. Furthermore, this research stands out compared to other studies on IPR protection by addressing the difference between *de jure* and *de facto* IPR protection. Recently, there has been more attention to the fact that these two concepts are not perfectly correlated, and that the mere presence of formal legal regulation does not provide the complete picture. The research design of this thesis takes the academic world a step further in understanding the path to CO2 emission reductions worldwide.

The analysis of this thesis offers virtually no support for the proposition that IPR protection leads to reduced CO2 emissions. In contrast, there are indications that strong *de jure* IPR protection has a positive impact on CO2 emissions, but this is likely due to an association between IPR law implementations and for instance economic development and industrialization. Mainly due to the lack of a negative relationship between IPR protection and CO2 emissions, it also cannot be concluded that this relationship is stronger in developed countries. For both the positive impact of *de jure* IPR protection and the negative impact of general IPR protection, no significant effect was found in developing countries. Finally, some evidence follows from the analysis that there is a negative interaction effect between IPR protection and climate policies implementation on CO2 emissions. This provides, although only marginally, an indication that the combination of a strong IPR protection framework and climate policy implementation enables both these variables to reduce CO2 reductions.

5.3 Policy implications

This study aimed to determine the extent to which government efforts to counter climate change through the implementation of legal frameworks and climate policies are effective. After all, these institutions can be adjusted relatively easily by the executive and legislative powers. If it would turn out that the presence of these institutions is associated with reduced CO2 emissions, it would be valuable for governments to focus on their implementation.

The present empirical analysis does not indicate that strong IPR protection has a significant CO2 emission-reducing effect, even though this could be well-argued based on theory and related empirical research. It is likely that this is due to the limitations of this research, which will be described in the following section. Additionally, a clear difference between developed and developing countries in the examined relationship was not found. However, there is some indication that the presence of strong IPR frameworks and the implementation of climate policies could reinforce each other in their potential CO2 emission-mitigating effect. The reason that the separate impacts were not found could then be that both are dependent on the presence of the other variable, as an enabling factor. This provides an, although based on this research still only marginal, indication that it would be valuable for governments to focus on a balanced implementation of IPR protection frameworks and climate policies.

5.4 Limitations

Despite efforts in this thesis to make careful choices to conduct the most appropriate analysis of the relationship under study, there are several limitations to this research. It is inherently challenging to choose the right estimation model for the variables on legal institutions at the country level in this study because most of the variation occurs across countries rather than over time. This issue is also addressed in section 3.2.1 with reference to Graph 2. This characteristic makes it difficult to capture the true effects in a model. An important initial consideration is that omitted variable bias poses a threat when studying country-level institutions, as unobserved factors that vary across countries can influence the results. This bias occurs when variables that affect the dependent variable are left out of the model, potentially leading to incorrect estimates of the relationship between the variables under study. It is to be expected that both CO2 emissions and

the quality of a country's legal system are correlated with country-specific characteristics. This may include factors such as, for instance, the level of industrialization, level of education, and cultural or historical factors. Furthermore, Sun et al. (2024) mention the example that the quality of export products is associated with the extent to which countries sign bilateral agreements with high requirements on, for instance, intellectual property rights (Horn et al., 2010). Higher amounts of export are likely to be associated with higher CO2 emissions, shaping another potential omitted variable. Therefore, including country fixed effects in the model is the methodologically most correct approach, as also followed from the estimation tests described in section 3.2.2. Country fixed effects control for all time-invariant differences between countries and thus help reduce the impact of omitted variable bias and allow for a more accurate estimation of the relationship between legal institutions and the dependent variable. The problem with using country fixed effects on the other hand, is that they eliminate variation between countries, where, as noted above, most of the variation in legal institutions exists. As a result, the studied effect largely disappears in the analysis because the model with country fixed effects primarily captures variation within a country over time. This trade-off makes it difficult to fully understand the impact of legal institutions. Therefore, both models without country-fixed effects and with fixed-effects were used. However, it follows from the foregoing that neither are optimal for estimating the relationship of interest. It would be very valuable to use an instrumental variable for IPR protection in this analysis, making the estimations without country fixed effects less likely to be biased and allowing for a more reliable estimation of the impact of cross-country variation in IPR frameworks. Unfortunately, this instrumental variable is difficult to imagine, nor does the literature offer any leads on this.

Secondly, there are various limitations regarding the time period in which and over which the effect might occur. It is to be expected that the effect of IPR protection on CO2 emissions has a much longer delay than specified in these models. It is conceivable that innovation processes take many years to lead to a measurable outcome. The measurement moment starts with the implementation of strong IPR regulations. According to incentive theory, this should provide a stimulus for innovation, but before that will happen, individuals must first have the perception that intellectual property is adequately protected in the country. Then, the innovation process in which inventions are made and technologies are developed takes a long time. After that, the trajectory begins in which the innovations are widely used in practice and can make a significant difference regarding

the level of CO2 emissions. The relationship between IPR framework improvements and CO2 emissions may thus cover a large span of time, rather than being present within a single year. In addition, a later time period than that between 2008 and 2018 might be more relevant for this study. The attention to climate change has been growing over the years and has only become an issue of primary concern for many governments in the most recent years. It was also not until 2015 that the Paris Agreement, which set concrete climate goals, was adopted. Therefore, the measurement of how countries are achieving these goals might be better done using data on more recent years as well. Finally, the period before 2008 is also relevant to include, as the data shows that many countries had already implemented their climate policies before this time. Therefore, the dummy-count variable used for this purpose no longer changes for these countries in the present analysis, resulting in no measurable effect when using country fixed effects, even though precisely these countries had already made significant progress in addressing climate change. This leads to a distorted picture of the relationship with CO2 emissions. This is particularly the case in OECD countries.

Relating to this, using first differences for all variables in this analysis forms a limitation. Due to non-stationarity issues in the data, the change in the value of the relevant variable between two consecutive years was used. This means that only the variation over time is used in the model, even when country fixed effects are not included, while the dataset is characterized by the fact that there is only minimal variation over time. Thus, a significant part of the assessed effect is removed. Moreover, precisely those countries that already scored high in the IPR index and the climate policies count since 2008 will show less upward change. When using first differences, these countries will then receive a low value or even zero, which contrasts with reality. If these countries tend to have low CO2 emissions, it distorts the picture of the relationship studied in the pooled model, which was primarily meant to assess the cross-country variation. The regression estimations were also performed with the variables at level, but since this does not lead to substantially different results and moreover is methodologically not the right approach, this was not included in the thesis. The only difference was that all control variables showed effects at the $p<0.01$ significance level. However, the variables of primary interest did not. The conclusion must be drawn that the data is simply not optimal for deriving realistic insights when the methodologically most appropriate method is used.

A final limitation is that power issues in the data for non-OECD countries cause the analysis to be suboptimal. This makes it difficult to draw reliable conclusions about the heterogeneity in effects between developed and developing countries.

5.5 Directions for future research

From the theoretical argumentation and the related empirical research, it follows that there are strong indications for a CO2 emission-reducing impact through improvements in intellectual property rights protection frameworks. The fact that climate change poses a major threat to humanity and nature currently makes the further research efforts in this direction of great importance.

It follows from the limitations mentioned in the previous section that certain methodological aspects leave room for an improved and more reliable analysis. It is likely that the relationship would be better estimated by considering a much longer delay in the effect and by examining a longer time period. Additionally, better controls for endogeneity would be valuable to better estimate the effect of cross-country variation in IPR institutions. Finding an instrumental variable for the strength and quality of IPR protection would enhance the possibilities in this regard.

Furthermore, it would be valuable to focus the research on this relationship on specific sectors that are relevant. The main analysis of this thesis was conducted on total CO2 emissions, while on the other hand, it is also indicated that some sectors are a lot less related to improvements in green innovation and CO2 emission reductions than other sectors. Focusing on individual sectors could also be more relevant for policy implications, as they could then possibly be better targeted. The fact that the climate policies variable in the main models regarding total CO2 emissions shows no significant effect is an indication that it would be better to examine individual sectors, since it stands to reason that there should be some relationship between climate policies and CO2 emissions. This relationship was in fact found for CO2 emissions in the individual sectors, as shown in the robustness estimations. These improved models should be combined with an improved lagged approach and more suitable time period, as those issues have not yet been covered in this thesis.

Also, more knowledge about how inventors perceive the IPR system could improve the measure of *de facto* IPR protection. Indeed, individuals' perceptions of the framework is the variable most related to incentive theory and the theory of reduced transaction costs. Academics must move away from the idea that only the mere implementation of formal regulations or the signing of international treaties brings about a significant change in human behavior.

Finally, it seems valuable to conduct further research on the interaction effect between IPR protection frameworks and climate policies. From this analysis and from the theoretical framework, it seems that these concepts can reinforce each other's impact on a more sustainable world. However, it has not yet become clear what the individual effects look like and what the underlying mechanisms of a potential interaction effect are.

6 CONCLUSION

Climate change poses a major threat to life on earth, and we are still searching for approaches to tackle this issue. From the literature, it can be concluded that improved IPR frameworks could play an important role in this regard. IPR protection is associated with promoting green innovation and the transfer of climate change mitigating technologies. In this thesis, these mechanisms are explained based on incentive theory and transaction costs theory. Subsequently, green innovation and climate change mitigating technologies can be associated with improved climate outcomes. However, no research exists yet that examines the direct relationship between IPR frameworks and actual CO2 emissions. This thesis fills this research gap by examining the role of IPR frameworks in pursuing CO2 emission reductions and enabling the effectiveness of climate policies. This study distinguishes between *de jure* and *de facto* IPR protection and between OECD countries and non-OECD countries.

The regression analysis using a Driscoll-Kraay robust standard errors estimation with panel data from the period 2008-2018 offers no indication that IPR protection exerts a CO2 reducing effect. While there are indications of a positive relationship between *de jure* IPR protection and CO2 emissions, it is likely that this arises from a positive association between *de jure* IPR frameworks and a country's level of economic development and industrialization. This research does not unambiguously show that the optimal level of IPR protection is heterogeneous across developed and developing countries. Lastly, there are indications for a CO2 emission reducing interaction effect of the combination of strong IPR protection and the implementation of climate policies. This means that IPR protection frameworks could be an enabling factor for the effectiveness of climate policies, or vice versa. This effect was found with respect to total CO2 emissions and CO2 emissions in the power industry sector.

This research provides a marginal indication that it would be valuable for governments to focus on a balanced implementation of IPR protection frameworks and climate policies. However, in drawing implications from this study, its limitations must be considered. Using a country fixed effects model is necessary to control for the influence of country-specific characteristics. However, most of the variation in the variables used is between countries and hardly over time, which eliminates much of the effect in a two-way fixed effects approach, especially for those countries

that have already taken steps in IPR protection improvements and climate policy implementations before 2008. This makes both a one-way and two-way fixed effects approach suboptimal. Additionally, the effect studied is expected to only exist with much more delay than within the same year. Moreover, the period after 2018 is important for this relationship as well, given the increasing attention to addressing climate change. Future research should aim at a better estimation of the investigated relationship because, based on literature and related empirical research, there is still reason to expect that IPR improvements may have a CO2 reducing effect. This should be done by considering a much longer delay in the relationship and by using better controls for endogeneity that allow for an estimation of cross-country variation. In addition, future research should focus more on the individual sectors where the relationship may exist to varying degrees. Lastly, this thesis provides an initial starting point for future research to explore the importance of a combined improvement of IPR protection frameworks and implementation of climate policies.

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8 APPENDIX

8.1 List of tables

TABLE 6: Descriptive statistics of standardized data by full sample and OECD membership

Variables	N	mean	sd	min	max
Full sample					
CO2	1,908	0.108	0.138	0.000	1.000
IPRP	1,221	$4.41e^{-10}$	1.000	-2.181	2.186
Policy	858	$-4.31e^{-09}$	1.000	-1.310	1.145
De facto	1,804	$-3.69e^{-10}$	1.000	-2.091	2.608
De jure	1,342	$3.14e^{-09}$	1.000	-3.614	1.797
GDPcap	1,859	0.110	0.159	0.000	1.000
Trade	1,507	$-1.12e^{-09}$	1.000	-3.567	2.379
Urb	1,848	$1.26e^{-10}$	1.000	-2.109	1.891
Ei	1,793	0.023	0.091	0.000	1.000
RD	935	$6.22e^{-10}$	1.000	-1.011	3.658
DiffCCMT	704	0.084	0.149	0.000	1.000
OECD					
CO2	396	0.200	0.096	0.083	0.537
IPRP	396	1.053	0.671	-0.745	2.186
Policy	396	0.720	0.709	-1.310	1.145
De facto	396	1.099	0.889	-1.135	2.608
De jure	363	1.105	0.402	0.107	1.797
GDPcap	396	0.317	0.191	0.0672	1.000
Trade	396	0.893	0.586	-0.858	2.324
Urb	396	0.877	0.506	-0.236	1.802
Ei	396	0.046	0.114	0.001	0.710
RD	385	0.800	0.965	-0.729	3.555
DiffCCMT	385	0.127	0.180	0.002	1.000
Non-OECD					
CO2	1,512	0.084	0.137	0.000	1.000
IPRP	825	-0.505	0.691	-2.181	1.947
Policy	462	-0.617	0.775	-1.310	1.145
De facto	1,408	-0.309	0.790	-2.091	2.324
De jure	979	-0.410	0.831	-3.614	1.264
GDPcap	1,463	0.053	0.0862	0.000	0.792
Trade	1,111	-0.318	0.921	-3.567	2.379
Urb	1,452	-0.239	0.968	-2.109	1.891
Ei	1,397	0.017	0 .082	0.000	1.000
RD	550	-0.590	0.418	-1.006	1.466
DiffCCMT	319	0.033	0.071	0.000	0.444

Note: The full sample *CO2*, *GDPcap, Ei* and *diffCCMT* data were normalized so that these variables have a minimum of 0 and a maximum of 1. The full sample data of the other variables was standardized so that the variables have a mean of 0 and a standard deviation of 1.

TABLE 7: Correlation matrix by full sample and OECD membership

Variables	*CO2*	*IPRP*	*De jure*	*De facto*	*Policy*	*DiffCCMTcap*	*GDPcap*	*Trade*	*Urb*	*Ei*	*RD*
Full sample											
CO2	1.000										
IPRP	0.462	1.000									
De jure	0.576	0.813	1.000								
De facto	0.502	0.873	0.600	1.000							
Policy	0.545	0.656	0.667	0.566	1.000						
DiffCCMTcap	0.432	0.400	0.342	0.331	0.183	1.000					
GDPcap	0.648	0.783	0.627	0.758	0.574	0.307	1.000				
Trade	0.465	0.710	0.638	0.670	0.292	0.337	0.623	1.000			
Urb	0.574	0.565	0.621	0.492	0.552	0.258	0.592	0.447	1.000		
Ei	0.204	0.171	0.270	0.148	0.297	0.186	0.133	0.050	0.118	1.000	
RD	0.328	0.755	0.598	0.700	0.399	0.574	0.666	0.443	0.488	0.258	1.000
OECD											
CO2	1.000										
IPRP	0.368	1.000									
De jure	0.244	0.568	1.000								
De facto	0.384	0.877	0.389	1.000							
Policy	0.157	0.552	0.416	0.386	1.000						
DiffCCMTcap	0.399	0.223	0.175	0.138	0.196	1.000					
GDPcap	0.453	0.715	0.233	0.748	0.362	0.062	1.000				
Trade	0.421	0.588	0.277	0.620	0.162	0.165	0.458	1.000			
Urb	0.257	0.447	0.103	0.429	0.100	0.230	0.397	0.308	1.000		
Ei	0.361	0.243	0.373	0.108	0.197	0.284	0.085	0.233	0.130	1.000	
RD	0.216	0.603	0.343	0.563	0.159	0.534	0.384	0.259	0.374	0.219	1.000
Non-OECD											
CO2	1.000										
IPRP	0.376	1.000									
De jure	0.369	0.655	1.000								
De facto	0.414	0.751	0.315	1.000							
Policy	0.439	0.279	0.428	0.238	1.000						
DiffCCMTcap	0.296	0.543	0.307	0.471	-0.219	1.000					
GDPcap	0.786	0.554	0.404	0.553	0.066	0.762	1.000				
Trade	0.305	0.538	0.436	0.501	-0.305	0.411	0.511	1.000			
Urb	0.523	0.387	0.450	0.307	0.344	0.240	0.558	0.236	1.000		
Ei	0.130	0.112	0.257	0.082	0.530	0.188	0.043	-0.085	0.058	1.000	
RD	0.161	0.535	0.467	0.464	0.301	0.583	0.433	0.088	0.342	0.570	1.000

TABLE 8: Estimation identification tests on heteroskedasticity, serial correlation, time fixed effects, entity fixed effects, RE vs OLS, and RE vs FE

	White-test		**Woolridge-test**		**Wald-test time FE**	
	X^2	**p-value**	F	**p-value**	F	**p-value**
Eq 1	285.0488	0.0000	50.617	0.0000	17.11	0.0000
Eq 2	290.2185	0.0000	46.689	0.0000	13.66	0.0000
Eq 3	302.3458	0.0000	49.576	0.0000	17.25	0.0000
	All $u_i = 0$		**Breusch-Pagan LM-test**		**Overidentifying-test**	
	F	**p-value**	X^2	**p- value**	X^2	**p- value**
Eq 1	169.96	0.0000	2016.05	0.0000	23.235	0.0031
Eq 2	172.67	0.0000	1831.86	0.0000	22.022	0.0088
Eq 3	175.02	0.0000	2018.84	0.0000	23.028	0.0061

TABLE 9: Slope heterogeneity tests

	Pesaran-Yamagata test				**Blomquist-Westerlund**			
	Δ	**p-value**	*adj.* Δ	**p-value**	Δ **(HAC)**	**p- value**	*adj.* Δ **(HAC)**	**p-value**
Eq 1	4.340	0.000	8.458	0.000	2.669	0.008	5.201	0.000
Eq 2	2.963	0.003	7.000	0.000	2.015	0.044	4.760	0.000
Eq 3	2.084	0.037	5.036	0.000	11.975	0.000	28.940	0.000

TABLE 10: Cross-sectional dependence test

	Pesaran CD-test	
Variables	***CD***	**p-value**
CO2	61.306	0.000
IPRP	83.56	0.000
De jure	516.642	0.000
De facto	117.044	0.000
Policy	251.628	0.000
DiffCCMTcap	34.427	0.000
GDPcap	481.973	0.000
Trade	233.447	0.000
Urb	462.085	0.000
Ei	254.648	0.000
RD	39.834	0.000

TABLE 11: Panel unit root test

	CIPS			
Variables	**Level**		**1st difference**	
	No trend	Trend	No trend	Trend
CO2	-1.712	-2.187	-2.693***	-2.963***
IPRP	-1.919	-2.439	-2.834**	-2.767***
De jure	-1.259	-2.844***		
De facto	-1.256	-1.622	-1.811	-1.679
Policy	0.408	-0.237	0.503	0.032
GDPcap	-1.096	-1.955	-2.451***	-3.219***
Trade	-2.201***	-2.637**		
Urb	-0.605	-0.849	-1.166	-3.329***
Ei	-2.199***	-2.404		
RD	-1.876	-1.905	-2.590***	-3.064***
DiffCCMT	-2.080**	-2.284		

Note: *** p<0.01, ** p<0.05, * p<0.1.

TABLE 12: Panel unit root test with structural breaks

	No trend		**Trend**		
Variables	***Statistic***	**p-value**	***Statistic***	**p-value**	**Break**
De facto	-6.9948	0.0000	2.9660	1.0000	2011
Policy	-3.7994	0.0001	-8.4359	0.0000	2009

TABLE 13: Driscoll-Kraay estimation results of equations 1.3 and 1.4 with lagged variables by full sample and OECD membership

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample		**OECD**		**Non-OECD**	
IPRP (1 year lag)	-0.000466	-0.00100	-0.00286	-0.00289	-0.000609	-0.00128
	(0.00137)	(0.00133)	(0.00190)	(0.00219)	(0.00867)	(0.00657)
Policy (1 year lag)	0.00215	0.000382	0.00289	0.000300	-0.00254	-0.00128
	(0.00202)	(0.00190)	(0.00188)	(0.00174)	(0.00463)	(0.00376)
DiffCCMTcap (1 year lag)	0.0133	0.0228**	0.0141	0.0378**	-0.0293	-0.0290
	(0.0152)	(0.00867)	(0.0155)	(0.0141)	(0.0226)	(0.0257)
GDPcap	-0.00505	-0.000406	-0.00248	0.00759	0.149	0.177*
	(0.0194)	(0.0167)	(0.0197)	(0.0151)	(0.109)	(0.0864)
Trade	-0.00241	-0.00193	-0.000538	-0.000509	-0.00380	-0.00355
	(0.00278)	(0.00175)	(0.00410)	(0.00296)	(0.00251)	(0.00519)
Urb	-0.0485	-0.0861	-0.0893	-0.194	0.0589	0.375*
	(0.0378)	(0.134)	(0.0587)	(0.142)	(0.0424)	(0.200)
Ei	0.327***	0.354***	0.843***	0.892***	0.124***	0.142***
	(0.0560)	(0.0622)	(0.120)	(0.0697)	(0.0352)	(0.0224)
RD (1 year lag)	-6.04e-05	-0.00341	8.46e-05	-0.00498	0.0145	0.0173
	(0.00135)	(0.00232)	(0.00287)	(0.00360)	(0.0176)	(0.0135)
Constant	0.00300***	0.00333**	-0.0031141**	0.00394**	-0.000609	-0.00368
	(0.000366)	(0.00128)	(0.0006024)	(0.00141)	(0.00867)	(0.00313)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Observations	423	423	306	306	117	117
Number of countries	47	47	34	34	13	13
R-squared	0.197	0.2096	0.286	0.336	0.275	0.275

Note: Dependent variable is *CO2.* All variables are at first difference. *IPRP, Policy, RD* and *DiffCCMTcap* are lagged by one year. Driscoll and Kraay robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

TABLE 14: Driscoll-Kraay estimation results of equations 2.3 and 2.4 with lagged variables by full sample and OECD membership

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample		**OECD**		**Non-OECD**	
De jure (1 year lag)	0.0171***	0.0145*	0.0169***	0.0176**	0.0153	0.0115
	(0.00334)	(0.00762)	(0.00407)	(0.00679)	(0.0125)	(0.0146)
De facto (1 year lag)	-0.00389	-0.00366*	-0.00327	-0.00206	0.000456	8.56e-05
	(0.00294)	(0.00191)	(0.00292)	(0.00130)	(0.00217)	(0.00176)
Policy (1 year lag)	0.00153	-0.000143	0.00204	-0.00266	-0.00316	-0.00216
	(0.00350)	(0.00320)	(0.00311)	(0.00313)	(0.00320)	(0.00317)
DiffCCMTcap (1 year lag)	0.0121	0.0210**	0.0154	0.0437**	-0.0385*	-0.0374*
	(0.0151)	(0.00818)	(0.0157)	(0.0171)	(0.0204)	(0.0192)
GDPcap	-0.0113	-0.00436	-0.00443	0.00992	0.112	0.124
	(0.0199)	(0.0152)	(0.0215)	(0.0156)	(0.107)	(0.0874)
Trade	-0.00222	-0.00221	-0.000708	-0.000705	-0.00241	-0.00330
	(0.00225)	(0.00146)	(0.00345)	(0.00292)	(0.00296)	(0.00534)
Urb	-0.0482	-0.125	-0.0819	-0.236	0.0789	0.541*
	(0.0454)	(0.127)	(0.0642)	(0.149)	(0.0430)	(0.284)
Ei	0.336***	0.376***	0.831***	0.890***	0.127**	0.144***
	(0.0421)	(0.0481)	(0.134)	(0.0714)	(0.0424)	(0.0208)
RD (1 year lag)	-0.00547	-0.00994*	-0.00318	-0.00974*	-0.00875	-0.0102
	(0.00552)	(0.00472)	(0.00595)	(0.00446)	(0.00995)	(0.0103)
Constant	0.00359***	0.00433***	0.00306***	0.00448***	-0.0036754	-0.00564
	(0.000566)	(0.00103)	(0.000707)	(0.00129)	(0.0031293)	(0.00427)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Observations	396	396	288	288	108	108
Number of countries	44	44	32	32	12	12
R-squared	0.212	0.227	0.289	0.343	0.299	0.287

Note: Dependent variable is *CO2.* All variables are at first difference. *IPRP, Policy, RD* and *DiffCCMTcap* are lagged by one year. Driscoll and Kraay robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

TABLE 15: Driscoll-Kraay estimation results of equations 3.3 and 3.4 with lagged variables by full sample and OECD membership

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample		**OECD**		**Non-OECD**	
IPRP (1 year lag)	0.000575	-4.37e-05	-0.00114	-0.00127	-0.00281	-0.00392
	(0.00192)	(0.00238)	(0.00500)	(0.00574)	(0.00738)	(0.00533)
Policy (1 year lag)	0.00206	0.000485	0.00172	-0.000672	-0.00154	0.000142
	(0.00197)	(0.00184)	(0.00136)	(0.00167)	(0.00496)	(0.00433)
IPRP x Policy (1 year lag)	-0.00320	-0.00280	-0.00245	-0.00225	-0.00379	-0.00451
	(0.00343)	(0.00345)	(0.00551)	(0.00529)	(0.00361)	(0.00300)
DiffCCMTcap (1 year lag)	0.0134	0.0232**	0.0139	0.0377**	-0.0300	-0.0303
	(0.0138)	(0.00811)	(0.0161)	(0.0142)	(0.0234)	(0.0255)
GDPcap	-0.00639	-0.00144	-0.00293	0.00722	0.149	0.178*
	(0.0186)	(0.0163)	(0.0194)	(0.0152)	(0.112)	(0.0905)
Trade	-0.00227	-0.00176	-0.000650	-0.000567	-0.00331	-0.00291
	(0.00292)	(0.00188)	(0.00430)	(0.00307)	(0.00219)	(0.00455)
Urb	-0.0486	-0.0921	-0.0881	-0.196	0.0576	0.307
	(0.0365)	(0.131)	(0.0616)	(0.141)	(0.0454)	(0.219)
Ei	0.332***	0.360***	0.848***	0.897***	0.138***	0.160***
	(0.0552)	(0.0599)	(0.123)	(0.0699)	(0.0394)	(0.0213)
RD (1 year lag)	-0.000504	-0.00388*	-0.000122	-0.00522	0.0136	0.0172
	(0.00135)	(0.00206)	(0.00316)	(0.00339)	(0.0180)	(0.0132)
Constant	0.00304***	0.00339**	0.00315***	0.00398**	0.00121	-0.00272
	(0.000351)	(0.00125)	(0.000576)	(0.00137)	(0.00246)	(0.00301)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Observations	423	423	306	306	117	117
Number of countries	47	47	34	34	13	13
R-squared	0.200	0.212	0.287	0.336	0.280	0.281

Note: Dependent variable is *CO2*. All variables are at first difference. *De jure, De facto, Policy, RD* and *DiffCCMTcap* are lagged by one year. Driscoll and Kraay robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

TABLE 16: Robustness test results: Patent Enforcement Index as *De facto*

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample		**OECD**		**Non-OECD**	
De jure	-0.00673	-0.00990**	-0.00916	-0.00808	-0.00692	0.00407
	(0.00409)	(0.00410)	(0.00832)	(0.0118)	(0.00458)	(0.00692)
De facto	0.0150**	0.0140**	0.0154	0.0167	0.00432	-0.000395
	(0.00667)	(0.00622)	(0.0107)	(0.0197)	(0.00574)	(0.0183)
Policy	0.00599***	0.00436*	0.0115**	0.00114	0.00771**	0.00790
	(0.00184)	(0.00230)	(0.00513)	(0.00958)	(0.00298)	(0.00704)
DiffCCMTcap	-0.0728*	0.0346	-0.134	-0.279	-0.0437*	0.0435
	(0.0363)	(0.0352)	(0.241)	(0.436)	(0.0219)	(0.0457)
GDPcap	-0.0305	-0.0151	-0.0269	-0.0564	0.211	0.287*
	(0.0230)	(0.0269)	(0.0184)	(0.0416)	(0.128)	(0.157)
Trade	-0.00832**	-0.00882**	-0.0113*	-0.00860	-0.00246	-0.000958
	(0.00384)	(0.00351)	(0.00632)	(0.00868)	(0.00598)	(0.0124)
Urb	0.0226	-0.0854	-0.00377	-0.0158	0.106**	0.0657
	(0.0277)	(0.110)	(0.0347)	(0.129)	(0.0441)	(0.0915)
Ei	0.617***	0.780***	1.745***	2.101***	0.297***	0.166**
	(0.0931)	(0.0960)	(0.155)	(0.275)	(0.0653)	(0.0765)
RD	-0.00595	-0.00874	-0.00262	-0.00980	-0.00788	-0.0259
	(0.00847)	(0.00828)	(0.0103)	(0.0106)	(0.0149)	(0.0194)
Constant	0.00189*	0.00346	0.00157	0.00132	-0.0175	-0.00256
	(0.00104)	(0.00205)	(0.00112)	(0.00322)	(0.0113)	(0.00439)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Observations	703	703	519	519	184	184
Number of countries	43	43	31	31	12	12
R-squared	0.257	0.257	0.302	0.273	0.431	0.353

Note: Dependent variable is *CO2*. *De facto* operationalized by Patent Enforcement Index for robustness. All variables are at first difference. Driscoll-Kraay robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Extended time period between 1998-2017 used.

TABLE 17: Robustness test results: power industry sector CO2 emissions as *CO2* (eq. 1.1 and 1.2)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample		**OECD**		**Non-OECD**	
IPRP	-0.00737	-0.00651	-0.00486	-0.00280	-0.00938	-0.0102
	(0.00857)	(0.00737)	(0.00913)	(0.00818)	(0.0133)	(0.0110)
Policy	0.0147***	0.0145***	0.00870	0.00380	0.0213***	0.0284***
	(0.00439)	(0.00403)	(0.00504)	(0.00449)	(0.00578)	(0.00468)
DiffCCMTcap	0.0200	0.0170	0.0142	0.0194	0.0254	0.0284
	(0.0334)	(0.0341)	(0.0273)	(0.0390)	(0.0551)	(0.0529)
GDPcap	-0.0448	-0.0461	-0.0278	-0.0299	0.267*	0.418**
	(0.0413)	(0.0502)	(0.0459)	(0.0543)	(0.141)	(0.139)
Trade	-0.00195	-0.00206	-0.000421	-0.00180	-0.00616	-0.00719
	(0.00966)	(0.00446)	(0.00956)	(0.00504)	(0.0146)	(0.0111)
Urb	0.0274	-0.215	-0.0388	-0.333	0.278***	0.393
	(0.123)	(0.377)	(0.148)	(0.437)	(0.0764)	(0.444)
Ei	0.641***	0.734***	1.582***	1.565***	0.219**	0.290***
	(0.0751)	(0.0870)	(0.231)	(0.195)	(0.0828)	(0.0685)
RD	0.00953	0.00770	0.0100	0.00587	0.0251	0.0304
	(0.00528)	(0.00610)	(0.00872)	(0.00743)	(0.0304)	(0.0285)
Constant	-0.0120304 ***	-0.0095994***	-0.0104***	-0.00760*	-0.0137***	-0.0160**
	(0.0011851)	(0.0032693)	(0.00104)	(0.00364)	(0.00139)	(0.00596)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Observations	470	470	340	340	130	130
Number of countries	47	47	34	34	13	13
R-squared	0.151	0.384	0.169	0.189	0.257	0.259

Note: Dependent variable is *CO2*, operationalized as per capita CO2 emissions in power industry sector for robustness. All variables are at first difference. Driscoll-Kraay robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

TABLE 18: Robustness test results: power industry sector CO2 emissions as *CO2* (eq. 2.1 and 2.2)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample		**OECD**		**Non-OECD**	
De jure	0.0192	0.0277	-0.0156	-0.00454	0.0665*	0.0623
	(0.0153)	(0.0180)	(0.0150)	(0.0189)	(0.0339)	(0.0341)
De facto	6.90e-06	0.00351	-0.00147	0.00242	0.0121	0.0120
	(0.00458)	(0.00396)	(0.00579)	(0.00656)	(0.0218)	(0.0189)
Policy	0.0171***	0.0192***	0.0135	0.00971	0.0232***	0.0289***
	(0.00498)	(0.00368)	(0.0140)	(0.0110)	(0.00448)	(0.00310)
DiffCCMTcap	0.0115	0.00883	-0.00449	0.00473	0.0271	0.0361
	(0.0484)	(0.0406)	(0.0456)	(0.0506)	(0.0610)	(0.0645)
GDPcap	-0.0523	-0.0547	-0.0259	-0.0297	0.256	0.367**
	(0.0410)	(0.0474)	(0.0443)	(0.0506)	(0.156)	(0.132)
Trade	5.54e-05	0.000459	0.00170	0.000908	-0.000581	-0.00125
	(0.00829)	(0.00276)	(0.00907)	(0.00304)	(0.0132)	(0.0120)
Urb	0.0411	-0.247	-0.0186	-0.304	0.319***	0.561**
	(0.134)	(0.385)	(0.165)	(0.460)	(0.0685)	(0.237)
Ei	0.609***	0.702***	1.605***	1.588***	0.143*	0.197*
	(0.0709)	(0.0954)	(0.230)	(0.182)	(0.0754)	(0.0958)
RD	0.00925	0.00563	0.0111	0.00577	0.0167	0.0259
	(0.00659)	(0.00677)	(0.00983)	(0.00777)	(0.0210)	(0.0222)
Constant	-0.0125***	-0.00931**	-0.0114***	-0.00827*	-0.0148***	-0.0190***
	(0.00100)	(0.00352)	(0.00128)	(0.00403)	(0.00161)	(0.00290)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Observations	440	440	320	320	120	120
Number of countries	44	44	32	32	12	12
R-squared	0.153	0.159	0.168	0.188	0.298	0.299

Note: Dependent variable is *CO2*, operationalized as per capita CO2 emissions in power industry sector for robustness. All variables are at first difference. Driscoll-Kraay robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

TABLE 19: Robustness test results: power industry sector CO2 emissions as *CO2* (eq. 3.1 and 3.2)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample		**OECD**		**Non-OECD**	
IPRP	-0.00464	-0.00340	0.00265	0.00748	-0.00998	-0.0127
	(0.00897)	(0.00794)	(0.0121)	(0.0103)	(0.0136)	(0.0114)
Policy	0.0145**	0.0147**	0.00353	-0.00255	0.0218***	0.0305***
	(0.00599)	(0.00556)	(0.00808)	(0.00679)	(0.00545)	(0.00511)
IPRP x Policy	-0.00746	-0.00830*	-0.0107	-0.0143**	-0.00167	-0.00629
	(0.00429)	(0.00436)	(0.00753)	(0.00551)	(0.00606)	(0.00651)
DiffCCMTcap	0.0202	0.0177	0.0137	0.0192	0.0254	0.0281
	(0.0304)	(0.0321)	(0.0266)	(0.0373)	(0.0559)	(0.0554)
GDPcap	-0.0423	-0.0434	-0.0260	-0.0276	0.265	0.410**
	(0.0429)	(0.0520)	(0.0452)	(0.0529)	(0.145)	(0.136)
Trade	-0.00178	-0.00168	7.48e-05	-0.000729	-0.00601	-0.00654
	(0.00951)	(0.00419)	(0.00990)	(0.00542)	(0.0144)	(0.0111)
Urb	0.0325	-0.214	-0.0335	-0.329	0.277***	0.334
	(0.119)	(0.372)	(0.145)	(0.435)	(0.0767)	(0.504)
Ei	0.641***	0.730***	1.564***	1.540***	0.223**	0.300***
	(0.0751)	(0.0830)	(0.225)	(0.195)	(0.0894)	(0.0746)
RD	0.0100*	0.00831	0.0105	0.00660	0.0250	0.0308
	(0.00543)	(0.00628)	(0.00875)	(0.00766)	(0.0304)	(0.0290)
Constant	-0.0121***	-0.00964**	-0.0103***	-0.00745*	-0.0137***	-0.0152*
	(0.00122)	(0.00326)	(0.00121)	(0.00374)	(0.00139)	(0.00674)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Observations	470	470	340	340	130	130
Number of countries	47	47	34	34	13	13
R-squared	0.153	0.157	0.172	0.194	0.257	0.260

Note: Dependent variable is *CO2*, operationalized as per capita CO2 emissions in power industry sector for robustness. All variables are at first difference. Driscoll-Kraay robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

TABLE 20: Robustness test results: transport sector CO2 emissions as *CO2* (eq. 1.1 and 1.2)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample		**OECD**		**Non-OECD**	
IPRP	0.00472	0.00397	0.00786	0.00753	-0.000404	-0.000721
	(0.00586)	(0.00581)	(0.00685)	(0.00710)	(0.00268)	(0.00272)
Policy	-0.00217	-0.00466*	-0.00711**	-0.00967***	-0.000430	-0.000525
	(0.00227)	(0.00228)	(0.00249)	(0.00285)	(0.000827)	(0.00103)
DiffCCMTcap	-0.0521**	-0.0548*	-0.0734*	-0.0781*	-0.00670	-0.00405
	(0.0212)	(0.0280)	(0.0346)	(0.0409)	(0.0172)	(0.0119)
GDPcap	0.119***	0.113***	0.127***	0.119***	0.0457	0.0612**
	(0.0200)	(0.0186)	(0.0225)	(0.0194)	(0.0280)	(0.0241)
Trade	0.00217	0.00155	0.00258	0.00174	0.00369	0.00335
	(0.00235)	(0.00221)	(0.00296)	(0.00268)	(0.00289)	(0.00305)
Urb	-0.0306	0.113***	-0.0634	0.148***	0.0416	0.136
	(0.0202)	(0.0336)	(0.0515)	(0.0414)	(0.0709)	(0.312)
Ei	0.161***	0.173***	0.418***	0.401***	0.0210	0.0691***
	(0.0346)	(0.0312)	(0.0480)	(0.0518)	(0.0548)	(0.0209)
RD	0.00573	0.00147	0.00840	0.00287	0.00422	0.00383
	(0.00581)	(0.00600)	(0.00638)	(0.00638)	(0.0128)	(0.0110)
Constant	-0.00299***	-0.00411***	-0.00306***	-0.00452***	-0.00175*	-0.00320
	(0.000665)	(0.000444)	(0.000806)	(0.000494)	(0.000867)	(0.00418)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Observations	470	470	340	340	130	130
Number of countries	47	47	34	34	13	13
R-squared	0.183	0.210	0.220	0.253	0.115	0.110

Note: Dependent variable is *CO2*, operationalized as per capita CO2 emissions in transport sector for robustness. All variables are at first difference. Driscoll-Kraay robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

TABLE 21: Robustness test results: transport sector CO2 emissions as *CO2* (eq. 2.1 and 2.2)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample		**OECD**		**Non-OECD**	
IPRP	0.00481	0.00364	0.0109*	0.00984	9.27e-05	8.89e-05
	(0.00554)	(0.00549)	(0.00545)	(0.00585)	(0.00223)	(0.00197)
Policy	-0.00217	-0.00468*	-0.00917**	-0.0111**	-0.000826	-0.00122
	(0.00231)	(0.00216)	(0.00389)	(0.00408)	(0.00142)	(0.00185)
IPRP x Policy	-0.000227	0.000881	-0.00427	-0.00320	0.00137	0.00203
	(0.00129)	(0.00130)	(0.00310)	(0.00264)	(0.00201)	(0.00237)
DiffCCMTcap	-0.0521**	-0.0548*	-0.0736*	-0.0781*	-0.00674	-0.00396
	(0.0212)	(0.0280)	(0.0347)	(0.0407)	(0.0167)	(0.0121)
GDPcap	0.119***	0.113***	0.127***	0.119***	0.0471	0.0635**
	(0.0198)	(0.0185)	(0.0237)	(0.0195)	(0.0285)	(0.0250)
Trade	0.00217	0.00151	0.00278	0.00198	0.00357	0.00314
	(0.00233)	(0.00221)	(0.00282)	(0.00253)	(0.00266)	(0.00254)
Urb	-0.0304	0.113***	-0.0613	0.149***	0.0418	0.156
	(0.0198)	(0.0341)	(0.0513)	(0.0420)	(0.0709)	(0.338)
Ei	0.161***	0.173***	0.411***	0.396***	0.0180	0.0660**
	(0.0346)	(0.0318)	(0.0477)	(0.0536)	(0.0567)	(0.0270)
RD	0.00574	0.00140	0.00858	0.00304	0.00427	0.00371
	(0.00577)	(0.00610)	(0.00615)	(0.00611)	(0.0130)	(0.0111)
Constant	-0.00299***	-0.00410***	-0.00301***	-0.00449***	-0.00176*	-0.00347
	(0.000661)	(0.000440)	(0.000795)	(0.000506)	(0.000871)	(0.00450)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Observations	470	470	340	340	130	130
Number of countries	47	47	34	34	13	13
R-squared	0.183	0.210	0.222	0.254	0.117	0.260

Note: Dependent variable is *CO2*, operationalized as per capita CO2 emissions in transport sector for robustness. All variables are at first difference. Driscoll-Kraay standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

TABLE 22: Robustness test results: transport sector CO2 emissions as *CO2* (eq. 3.1 and 3.2)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample		**OECD**		**Non-OECD**	
De jure	0.0121*	0.00741**	0.0173	0.0145*	0.000290	-0.00140
	(0.00638)	(0.00326)	(0.0122)	(0.00773)	(0.00634)	(0.00618)
De facto	0.00203	0.00302	0.00160	0.00360	0.00184	0.00112
	(0.00292)	(0.00218)	(0.00441)	(0.00359)	(0.00260)	(0.00292)
Policy	-0.00132	-0.00407*	-0.00914**	-0.0134**	-0.000418	-0.000469
	(0.00149)	(0.00221)	(0.00379)	(0.00563)	(0.00122)	(0.000781)
DiffCCMTcap	-0.0624**	-0.0654**	-0.0852*	-0.0922**	-0.0178	-0.0126
	(0.0261)	(0.0278)	(0.0418)	(0.0405)	(0.0169)	(0.0135)
GDPcap	0.119***	0.114***	0.131***	0.124***	0.0516**	0.0642**
	(0.0210)	(0.0183)	(0.0268)	(0.0222)	(0.0219)	(0.0234)
Trade	0.00184	0.000958	0.00266	0.00162	0.00255	0.00226
	(0.00270)	(0.00217)	(0.00348)	(0.00295)	(0.00209)	(0.00245)
Urb	-0.0269	0.0995*	-0.0540	0.128**	0.0508	0.0778
	(0.0204)	(0.0453)	(0.0412)	(0.0550)	(0.0663)	(0.326)
Ei	0.160***	0.171***	0.436***	0.434***	0.0120	0.0590**
	(0.0302)	(0.0363)	(0.0685)	(0.0641)	(0.0495)	(0.0207)
RD	0.00541	2.37e-05	0.00829	0.000840	0.00232	0.00290
	(0.00551)	(0.00567)	(0.00566)	(0.00528)	(0.0131)	(0.0120)
Constant	-0.00209***	-0.00314***	-0.00173***	-0.00282***	-0.00192**	-0.00247
	(0.000416)	(0.000725)	(0.000277)	(0.000763)	(0.000736)	(0.00454)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Observations	440	440	320	320	120	120
Number of countries	44	44	32	32	12	12
R-squared	0.186	0.211	0.222	0.258	0.125	0.111

Note: Dependent variable is *CO2*, operationalized as per capita CO2 emissions in transport sector for robustness. All variables are at first difference. Driscoll-Kraay standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

TABLE 23: Robustness test results: processes sector CO2 emissions as *CO2* (eq. 1.1 and 1.2)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample		**OECD**		**Non-OECD**	
IPRP	-0.00377	-0.00595**	-0.00670	-0.00887**	0.00321	0.00158
	(0.00404)	(0.00233)	(0.00530)	(0.00365)	(0.00685)	(0.00653)
Policy	-0.0104**	-0.0142**	-0.0115**	-0.0158**	-0.00728	-0.0104**
	(0.00422)	(0.00455)	(0.00380)	(0.00554)	(0.00532)	(0.00427)
DiffCCMTcap	0.0578	0.0465	0.00547	-0.00399	0.173***	0.182***
	(0.0379)	(0.0324)	(0.0571)	(0.0378)	(0.0391)	(0.0478)
GDPcap	0.0137	0.00250	0.00904	0.00348	0.123	0.0156
	(0.0307)	(0.0316)	(0.0204)	(0.0299)	(0.103)	(0.123)
Trade	-0.00771	-0.00651	-0.0114	-0.0109	0.00229	0.00620
	(0.00601)	(0.00663)	(0.00791)	(0.00936)	(0.00575)	(0.00860)
Urb	-0.0462	-0.0282	-0.0485	0.0294	-0.110	0.0388
	(0.0372)	(0.120)	(0.0810)	(0.128)	(0.118)	(0.389)
Ei	0.213***	0.150***	0.0399	0.0164	0.204**	0.213***
	(0.0437)	(0.0445)	(0.0724)	(0.0586)	(0.0720)	(0.0521)
RD	-0.00820	-0.00818	-0.00700	-0.0102	0.00901	0.0151
	(0.00652)	(0.00823)	(0.00904)	(0.0114)	(0.0133)	(0.0152)
Constant	-0.00728***	-0.00712***	-0.00306***	-0.00452***	-0.00607***	-0.00780
	(0.000415)	(0.00103)	(0.000806)	(0.000494)	(0.00103)	(0.00527)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Observations	470	470	340	340	130	130
Number of countries	47	47	34	34	13	13
R-squared	0.142	0.141	0.137	0.148	0.330	0.310

Note: Dependent variable is *CO2*, operationalized as per capita CO2 emissions in processes sector for robustness. All variables are at first difference. Driscoll-Kraay standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

TABLE 24: Robustness test results: processes sector CO2 emissions as *CO2* (eq. 2.1 and 2.2)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample		**OECD**		**Non-OECD**	
De jure	0.00513	-0.000861	0.00107	-0.00866	-0.00181	0.00119
	(0.00465)	(0.00354)	(0.00739)	(0.00806)	(0.00885)	(0.00649)
De facto	-0.000214	-0.00128	-0.000209	-0.00120	-0.00746	-0.00644
	(0.00424)	(0.00474)	(0.00591)	(0.00509)	(0.00531)	(0.00547)
Policy	-0.0175*	-0.0212**	-0.0434*	-0.0493**	-0.00922	-0.0107**
	(0.00846)	(0.00826)	(0.0195)	(0.0207)	(0.00524)	(0.00472)
DiffCCMTcap	0.0761**	0.0652**	0.0205	0.0135	0.200***	0.196***
	(0.0254)	(0.0284)	(0.0389)	(0.0285)	(0.0484)	(0.0583)
GDPcap	0.0170	0.00839	0.0173	0.0135	0.0973	0.0176
	(0.0366)	(0.0353)	(0.0277)	(0.0319)	(0.104)	(0.139)
Trade	-0.00251	-0.00105	-0.00426	-0.00330	0.00464	0.00716
	(0.00361)	(0.00415)	(0.00547)	(0.00643)	(0.00690)	(0.00997)
Urb	-0.0424	-0.0485	-0.0421	0.0127	-0.139	0.00446
	(0.0413)	(0.130)	(0.0637)	(0.116)	(0.117)	(0.450)
Ei	0.200***	0.159***	0.0824	0.0628	0.224**	0.238***
	(0.0416)	(0.0463)	(0.0717)	(0.0517)	(0.0754)	(0.0537)
RD	-0.00102	0.000802	0.00143	-0.000447	0.0158	0.0194
	(0.00473)	(0.00694)	(0.00768)	(0.0104)	(0.0161)	(0.0166)
Constant	-0.00765***	-0.00762***	-0.00173***	-0.00901***	-0.00427**	-0.00624
	(0.000383)	(0.00117)	(0.000277)	(0.00105)	(0.00160)	(0.00698)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Observations	440	440	320	320	120	120
Number of countries	44	44	32	32	12	12
R-squared	0.160	0.161	0.179	0.193	0.339	0.306

Note: Dependent variable is *CO2*, operationalized as per capita CO2 emissions in processes sector for robustness. All variables are at first difference. Driscoll-Kraay standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

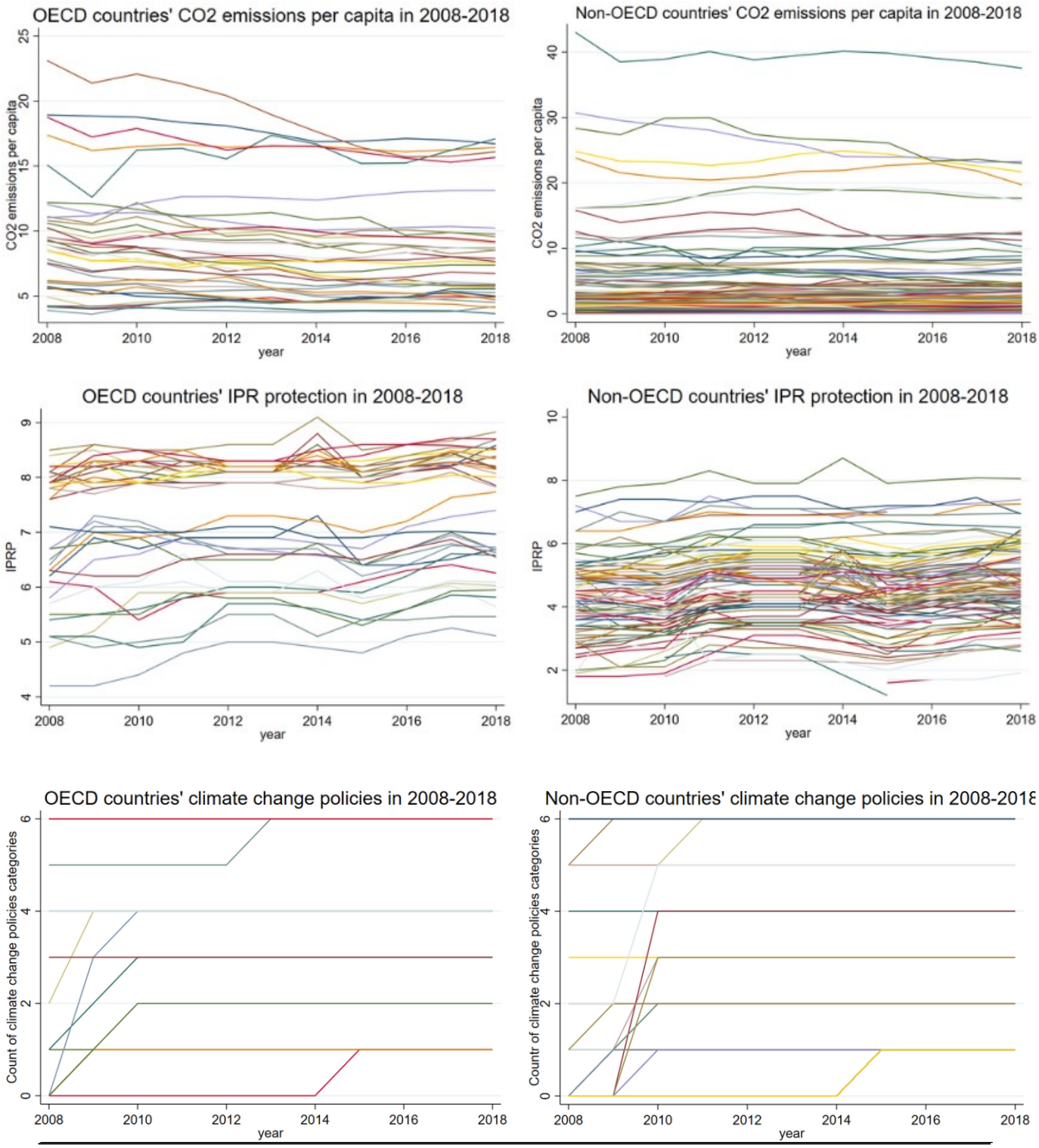
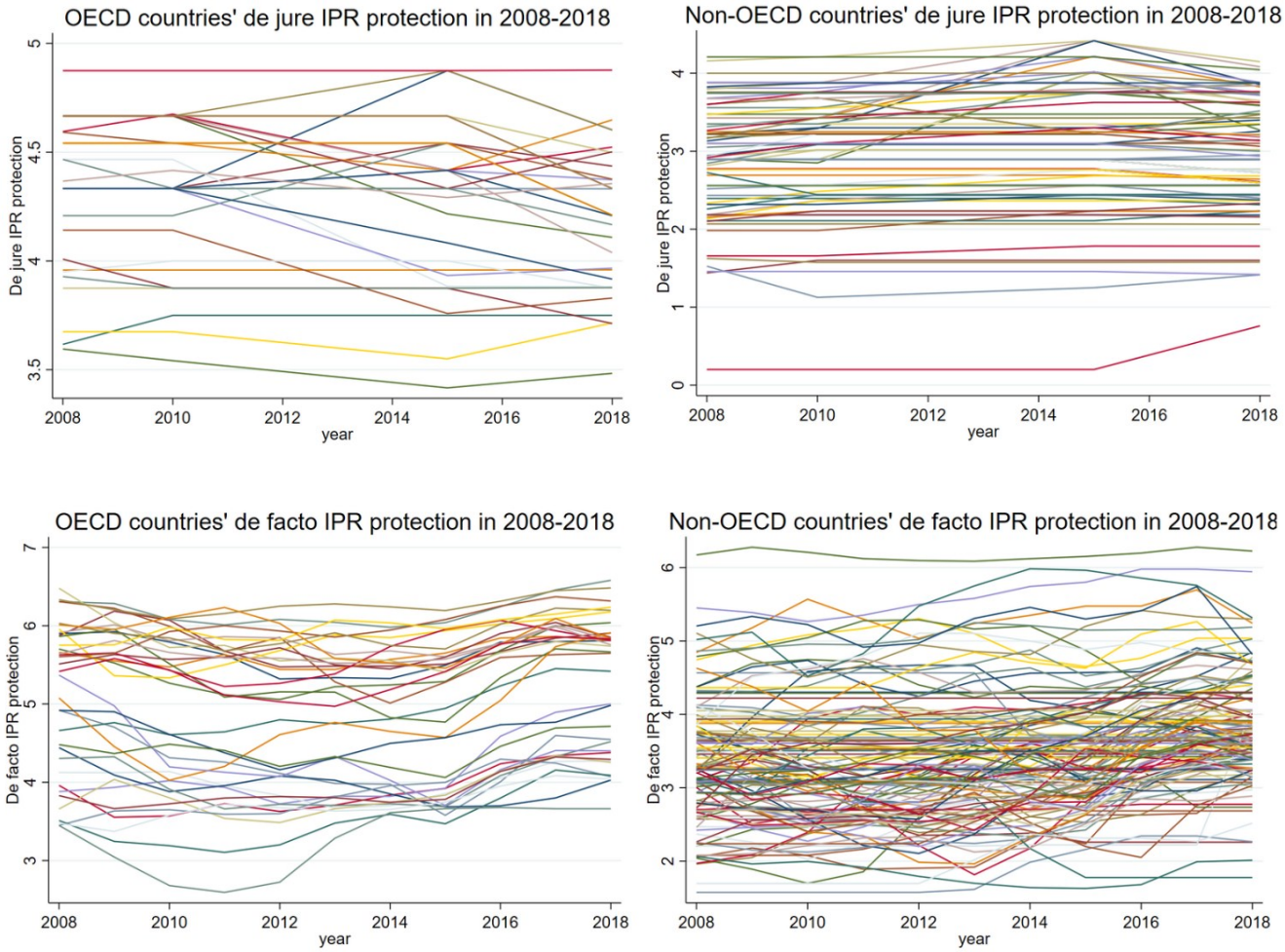
TABLE 25: Robustness test results: processes sector CO2 emissions as *CO2* (eq. 3.1 and 3.2)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample		**OECD**		**Non-OECD**	
IPRP	-0.00369	-0.00613	-0.00997	-0.0139	0.00416	0.00244
	(0.00548)	(0.00348)	(0.0169)	(0.0159)	(0.00734)	(0.00658)
Policy	-0.0104**	-0.0142**	-0.00920	-0.0127	-0.00804	-0.0112*
	(0.00432)	(0.00445)	(0.0106)	(0.0116)	(0.00587)	(0.00500)
IPRP x Policy	-0.000211	0.000482	0.00466	0.00698	0.00263	0.00214
	(0.00513)	(0.00425)	(0.0172)	(0.0171)	(0.00433)	(0.00400)
DiffCCMTcap	0.0578	0.0465	0.00568	-0.00392	0.173***	0.182***
	(0.0380)	(0.0327)	(0.0568)	(0.0377)	(0.0398)	(0.0479)
GDPcap	0.0137	0.00234	0.00826	0.00235	0.126	0.0180
	(0.0319)	(0.0324)	(0.0217)	(0.0315)	(0.105)	(0.124)
Trade	-0.00770	-0.00653	-0.0117	-0.0115	0.00206	0.00598
	(0.00603)	(0.00670)	(0.00817)	(0.00995)	(0.00550)	(0.00832)
Urb	-0.0461	-0.0282	-0.0508	0.0272	-0.110	0.0590
	(0.0375)	(0.120)	(0.0777)	(0.129)	(0.118)	(0.380)
Ei	0.213***	0.150***	0.0477	0.0286	0.199**	0.209***
	(0.0438)	(0.0455)	(0.0930)	(0.0732)	(0.0735)	(0.0534)
RD	-0.00819	-0.00821	-0.00719	-0.0106	0.00910	0.0150
	(0.00637)	(0.00819)	(0.00881)	(0.0111)	(0.0133)	(0.0150)
Constant	-0.00728***	-0.00712***	-0.00813***	-0.00835***	-0.00607***	-0.00809
	(0.000404)	(0.00104)	(0.00114)	(0.00138)	(0.00105)	(0.00508)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Observations	470	470	340	340	130	130
Number of countries	47	47	34	34	13	13
R-squared	0.142	0.141	0.138	0.150	0.331	0.310

Note: Dependent variable is *CO2*, operationalized as per capita CO2 emissions in processes sector for robustness. All variables are at first difference. Driscoll-Kraay standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

8.2 List of figures

GRAPH 2: Panel visualization of variables in 2008-2018 by OECD membership



GRAPH 2 (continued): Panel visualization of variables in 2008-2018 by OECD membership