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An Analysis of the Determinants of Green Innovation Dynamics in Europe and Climate Neutrality-related Policy Options

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Summary:

Climate change continues to challenge the global economy; particularly in industrialized countries, governments are increasingly coming under pressure to develop and implement adequate climate protection and innovation policies, as well as to co-operate in aligning them. At the same time, firms are also becoming more active in “greening”, by innovating in terms of greener products and processes in order to contribute to climate protection, stay at the technological frontier, and benefit from the increased environmental and sustainability awareness on the part of households, competitors and suppliers. Key areas of mutual concern to both policymakers and firms, therefore, include the determinants of green innovations – product or process – and how government can promote such innovation dynamics. Part of green innovations are covered by the European Union’s Community Innovation Survey (CIS), while the Organisation for Economic Co-operation and Development (OECD) also has data on green patenting dynamics. Using panel data on 35 European countries and covering the period of 2007-2018, including multiple waves of the CIS in a novel approach, we present an analysis on green innovation. The empirical analysis presented shows how key determinants of green innovation from the literature affect selected measures of green innovation. We find that the inward FDI stock intensity positively affects green process innovations (including manufacturing), while the ICT R&D Investment-GDP ratio has a negative impact on green innovativeness. As regards firms with both green process and green product innovations, GDP per capita is found to be a positive driver of innovativeness (excluding manufacturing) and is also a positive driver of green process innovations in firms with only green process innovations – but, paradoxically, is a negative driver of green product innovations in firms with only green product innovations. Regarding the rule of law, there is a positive impact on green innovations. The median age of the labor force has a negative impact on process innovations (excluding manufacturing), while the sign is positive for green process *and* product innovating firms (both including and excluding manufacturing). A green RCA variable is positively significant for green product innovating firms and green process and product innovators (including and excluding manufacturing). Our findings allow to suggest areas in which national and supranational policymakers should become more active to promote and foster green innovation in Europe.

Zusammenfassung:

Der Klimawandel ist weiterhin eine Herausforderung für die Weltwirtschaft. Insbesondere in den Industrieländern geraten die Regierungen zunehmend unter Druck, eine angemessene Klimaschutz- und Innovationspolitik zu entwickeln und umzusetzen sowie bei deren Abstimmung zusammenzuarbeiten. Gleichzeitig werden auch die Unternehmen immer aktiver, indem sie umweltfreundlichere Produkte und Verfahren entwickeln, um zum Klimaschutz beizutragen, an der technologischen Spitze zu bleiben und vom gestiegenen Umwelt- und Nachhaltigkeitsbewusstsein der Haushalte, Wettbewerber und Lieferanten zu profitieren. Zu den Schlüsselbereichen, die sowohl für politische Entscheidungsträger als auch für Unternehmen von Interesse sind, gehören daher die Determinanten grüner Innovationen – Produkte oder Prozesse – und die Frage, wie der Staat diese Innovationsdynamik fördern kann. Ein Teil der grünen Innovationen wird von der Community Innovation Survey (CIS) der Europäischen Union erfasst, während die Organisation für wirtschaftliche Zusammenarbeit und Entwicklung (OECD) auch über Daten zur Dynamik der grünen Patentierung verfügt. Unter Verwendung von Paneldaten zu 35 europäischen Ländern, die den Zeitraum 2007-2018 abdecken und mehrere Wellen der CIS in einem neuartigen Ansatz einschließen, präsentieren wir eine Analyse zu grünen Innovationen. Die vorgestellte empirische Analyse zeigt, wie sich die wichtigsten Determinanten grüner Innovation aus der Literatur auf ausgewählte Maße grüner Innovation auswirken. Wir stellen fest, dass sich die Intensität der ausländischen Direktinvestitionen positiv auf grüne Prozessinnovationen (einschließlich des verarbeitenden Gewerbes) auswirkt, während das Verhältnis von IKT-F&E-Investitionen zum BIP einen negativen Einfluss auf die grüne Innovationskraft hat. Bei Unternehmen, die sowohl grüne Prozess- als auch grüne Produktinnovationen aufweisen, erweist sich das Pro-Kopf-BIP als positive Triebkraft für die Innovationsfähigkeit (ohne das verarbeitende Gewerbe) und als positive Triebkraft für grüne Prozessinnovationen bei Unternehmen, die nur grüne Prozessinnovationen aufweisen – paradoxerweise ist es jedoch eine negative Triebkraft für grüne Produktinnovationen bei Unternehmen, die nur grüne Produktinnovationen aufweisen. Was die Rechtsstaatlichkeit betrifft, so hat sie einen positiven Einfluss auf grüne Innovationen. Das Durchschnittsalter der Erwerbsbevölkerung wirkt sich negativ auf Prozessinnovationen (ohne verarbeitendes Gewerbe) aus, während das Vorzeichen für grüne Prozess- und Produktinnovationen betreibende Unternehmen (sowohl mit als auch ohne verarbeitendes Gewerbe) positiv ist. Eine grüne RCA-Variable ist positiv signifikant für grüne Produktinnovationen vornehmende Unternehmen und grüne Prozess- und Produktinnovationen vornehmende Unternehmen (einschließlich und ohne verarbeitendes Gewerbe). Unsere Ergebnisse erlauben es, Bereiche vorzuschlagen, in denen nationale und supranationale politische Entscheidungsträger aktiver werden sollten, um grüne Innovationen in Europa zu fördern und zu unterstützen.

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1. Introduction

Since around the beginning of the 21st century, with the Kyoto Protocol (which was signed in 1997 and which entered into force in 2005) the challenge of combatting global warming has become a major issue for policymakers, large firms and households in both industrialized and developing economies. The pressing need for more climate protection policies has been further evidenced more recently with the signing of the United Nations Paris Agreement (a climate accord adopted by 193 parties at the COP21 in Paris in 2015 (UNFCCC, 2022). As regards the European Union, the United Kingdom, United States, Japan, Republic of Korea and China, i.e., a broad group of industrialized countries representing the largest economies globally – and rather similar to the G20 grouping in terms of country composition – has become quite active particularly since 2018/19 in order to realize more progress towards achieving climate neutrality.

However, over the subsequent years, the 2021 reports of the UN's Intergovernmental Panel on Climate Change (IPCC, 2021) and the UN's Emissions Gap Report of 2021 (UNEP, 2021) have shown that the situation at a global level has improved little, despite the Corona pandemic-related recession years of 2020 and 2021 which have clearly reduced growth in terms of global production output and thus also harmful greenhouse gas emissions. One key method of maintaining or increasing output and economic growth in a sustainable, environmentally-friendly and climate protecting way, is to engage in Schumpeterian innovation – particularly green innovations in terms of green product innovations and green process innovations both of which can contribute to minimizing the environmental and climate impact of production and consumption in all sectors and not just the "green" sector (for an overview of innovation in selected sectors of green innovativeness in the 35 European countries over the period from 2008-2016, see Annex 2. One can note that the ICT sector is particularly innovative). With the climate as a public good and continuing globalization, including the diffusion and extension of value chains for example, it is more important than ever for countries to cooperate in terms of climate protection policies but also in terms of their innovation environment. As argued by Angel Gurria, Secretary General of the OECD (Gurria, 2016):

"We need to ensure that we are talking about making all innovation green! To do that requires widespread adoption of the right support frameworks combined with clear and credible government commitments so that green considerations are incorporated into innovation policy settings from the outset. The direction of innovation policies matters as much as the pace of innovation itself. Strong climate policies, for example, can pull innovation in the right direction, but other instruments and policies are also important, and a lack of alignment can hamper progress."

Some progress has been made in this regard particularly amongst the OECD and EU countries (see, e.g., OECD, 2015). With the European Commission announcing the European Green Deal in 2019 (European Commission, 2019) and the 2030 Climate Target Plan (European Commission, 2020) the goal of transforming the EU as a bloc into a modern, resource-efficient and competitive economy has been set, with the targets of, firstly, achieving climate neutrality (i.e., net zero emissions) by 2050; secondly, realizing economic growth which has been decoupled from resource use; and thirdly, doing so in a fair, sustainable and equitable manner for citizens, countries and regions across the Union. Climate risks are therefore relevant for firms and financial service providers in the form of either transition risks towards climate neutrality or high physical risk for economic actors in a period of global warming (ECB, 2021). Thus, in Europe there have been policies at a supra-national and national level which have been aimed at promoting green innovation and encouraging firms to develop environment-friendly products and to carry out their economic activities in a sustainable way (see, e.g., Cecere et al., 2020 ; Xie et al., 2019). Furthermore, green innovation has been associated with positive employment effects (see, e.g., Kunapatarawong and Martinez-Ros, 2016; Triguero, Cuerva and Alvarez-Aledo, 2017), as well as being positively associated with firms' international competitiveness measured in terms of export participation (Melitz, 2003; Meneto and Siedschlag, 2020).

Therefore, gaining an understanding of what factors positively or negatively impact green innovations is crucial for policymakers seeking to promote a more climate-friendly economy which can progress towards the goals set out for the coming decades. Previous contributions to the literature have indeed examined the push and pull factors which effect green innovation activities in particular countries or sectors, including in Europe. However, cross-country or time series analyses are relatively rare. It has been argued that the potential of longitudinal studies to evaluate differences in terms of the innovation activities and characteristics using panel data has not been fully exploited (Makrevska Disoska et al., 2021; Peiró-Signes et al., 2022).

From this perspective, it is indeed crucial to identify the macroeconomic and institutional factors which either promote or hinder green innovation. Therefore, in this paper, we seek to examine the effect of key economic and institutional variables as determinants of green innovation. Thus, the paper was motivated by the following research questions:

1. What does our data tell us about the key determinants of green innovation?
2. What role is played by selected variables of interest, namely investment in Research and Development (R&D) in Information and Communication Technologies (ICT), inward and outward FDI, plus the rule of law?

Thus, this paper contributes to closing a research gap in the literature by investigating the key determinants of green innovation in Europe by employing a panel data analysis which covers 35 European countries (namely, the EU27 plus 8 neighboring states – see Annex 1 for the complete list of countries covered) and covering the period of 2007-2018. To do so, we make use of multiple waves of the EU's Community Innovation Survey in a novel way, by construction a panel data set.

Amongst other results, we find that inward FDI stock intensity should be high – to raise green innovativeness - which requires to raise the attractiveness of the host country. The rule of law should be strengthened, which implies for inventors and investors a long-term investment horizon relevant for green innovations; there is also a need for a reduction in transaction costs and risk – solid institutions and a credible consistent legal framework are crucial in this context. We also find that the outward FDI stock intensity could weaken green innovations in the respective source country which could be reflecting techno-globalization (as more R&D takes place in foreign subsidiaries, the need to reinforce green R&D activities in the headquarter country is reduced – international technology diffusion should be encouraged and or barriers to technology diffusion should be reduced). A high green revealed comparative advantage stands for an ecosystem which is supportive of green innovations more broadly; more government (national or EU level) emphasis on green products and services could be useful. Finally, a critical minimum of ICT R&D investment relative to gross domestic product is needed in some countries, whereby government R&D promotion should be reinforced. By examining the determinants of green innovation in Europe, we derive policy recommendations for national governments across Europe as well as for the European Union as a bloc.

The rest of the paper is structured as follows: Section 2 presents the conceptual background of the determinants of green innovations and the development of hypotheses. In Section 3 we discuss the data, methodology and model. The results of the empirical analysis are presented and discussed in Section 4, while Section 5 concludes with recommendations for policymakers and avenues for future research.

2. Conceptual Background and the Development of Hypotheses

There have been many contributions to the literature on the determinants of green or eco-innovation (to mention a few, Rennings, 2000; Horbach, 2008; Horbach, Oltra and Belin, 2013; del Rio, Penasco and Romero-Jordan, 2015; Doran, 2016; Leitner, 2018; Peiró-Signes et al., 2022). Selected findings which motivate the selection of the variables in our model are presented subsequently. Three key channels which serve to motivate green innovation, namely 'market pull', 'technology push' and 'regulation', have been identified in the literature (see **Table 1**; see also Horbach, 2019) which consist of both endogenous and exogenous factors as well as firm-specific dynamics and more general, business environment conditions. For the purposes of our analysis we will focus on the macro factors, in particular on crucial factors which affect both the demand-side and supply-side, namely ICTs and inward as well as outward FDI. Following the theoretical approach of Abernathy and Utterback (1975; 1978), we present empirical evidence that the ratio of product to process innovations in EU countries can partly be explained by sectoral (ICT) R&D outlays (supply-side), the influence of multinational investment in the form of inward and outward FDI stocks (supply-side), the telecommunication density which could reflect network effects (demand- and supply-side) and the rule of law (regulation).

Table 1: Channels of Motivation to Engage in Green Innovation

Channel	***Examples***
Demand-side (market pull)	• Market demand or expectations of future demand • Environmental awareness and preferences for green products and processes amongst public • Customer benefits • Market characteristics • Firm performance
Supply-side (technology push)	• Firms' R&D capabilities • Knowledge capital endowment • Search for cost and energy efficient processes • Firms' organization and management
Institutional and political (regulatory) framework	• Environmental standards • Legal protections for innovations • Creation of lead markets

Source: *Own representation on the basis of Horbach, Oltra and Belin (2013; Table 1, p. 526) and Ghisetti, Marzucchi and Montresor (2015).*

Demand-Side Channel

One channel through which impulses to engage in green innovation reach firms is from the market itself, or the demand-side. Consumer preferences and public opinion can lead firms to engage in innovation in a broad perspective (von Hippel, 1986). In a period in which climate-change and the effects of phenomena such as global warming and extreme weather events are high on the policy agenda as well as prominent in the public consciousness, this should hold for green innovation in particular. Demand-side factors thus include consumer preferences in terms of products and services (Borghesi et al., 2015) and also with regard to the associated environmental impact and the perceived environmental impact of firms.

A green product could improve firms' market share, improve brand name recognition, increase competitiveness and attract new consumers (Calza, Parmentola and Tulore, 2017). Important factors influencing the demand-side are the disposable income of households (and willingness to pay for green products and processes) as well as pro-environmental attitudes and behaviors. While the demand-side (consumer driven) is likely to induce green product innovations, whereas impulses for green process innovations are likely to originate instead within the firms themselves (Lin et al., 2014).

The expansion of the ICT sector, particularly the Internet, digital networks and communication subsectors, has contributed to raising environmental awareness (including disseminating more knowledge with respect to, and incubating a stronger orientation in favor of, fighting global warming); empirical evidence has brought interesting results here for both the OECD countries and developing countries, for example that a higher digital communication intensity reinforces the interest in sustainability in industrialized countries (Udalov and Welfens, 2021). The Internet could thus play a significant role in inducing consumer demand for 'green' products and, in turn, green product innovation in particular.

Supply-Side Channel

The supply-side, or technology push, channel relates to impulses from the firms' themselves and the markets in which they operate. Firms may choose to implement green process innovations in the production process to reduce costs, increase energy, material or resource efficiency, and optimize production times (Calza, Parmentola and Tulore, 2017). Here, firms' own research and development (R&D) capabilities as well as firms' access to external innovations play key roles (Stucki and Woerter, 2012). Government innovation policy is crucial in this respect. The ICT sector has been recognized as a particularly innovative sector since the 1980s and the digital expansion of the economy in the OECD countries has continued over more than four decades where ICT equipment, software, digital services/the Internet are key pillars of innovativeness. Amongst all ICTs, the Internet has had a particularly broad influence across developed and developing economies and it can be argued (OECD, 2013) that many ICTs indeed possess the characteristics of a General Purpose Technology (GPT). If one follows the characterization of a GPT by Bresnahan and Trajtenberg (1995; p. 83) then ICT should exhibit "innovational complementarities" – i.e., ability of improvements in a GPT to support product and process innovations in downstream sectors, including in terms of green product and process innovations. Amongst the effects of ICT are allowing for an optimization in production and processes such as the use of smart metering and smart grids to monitor and improve energy-efficiency or emissions, dematerialization by reducing the need for raw materials (e.g. replacing traditional physical goods with digital alternatives such as e-books rather than tradition paper books, e-ticketing, streaming of content rather than videos or DVDs etc.) resulting in cost savings for firms. Since ICT stands for a rather high R&D intensity in OECD countries, there is the problem of an optimum innovation policy with regard to investment in ICT R&D in the EU and the OECD countries, respectively. Many contributions to the literature have shown that ICTs and the diffusion of ICT can have a significant and positive impact on reducing CO2 emissions (see, e.g., Zhang and Liu, 2015; Asongu et al., 2018; Amri, 2018; Park et al., 2018; Danish et al., 2018, Charfeddine and Kahia, 2021). For instance, the positive impact on environmental via channels such as telecommuting and telenetworking reducing commuting and international business travel, smart transport systems, e-commerce and (Danish et al., 2018; Shabani and Shahnazi, 2019). However, the ICT-climate literature also provides evidence that the direct effect, where ICT is positively related to the level of CO_2 emissions, cannot be ruled out and must be taken into consideration (Danish et al., 2018).

The results of Cheng et al. (2021), for example, indicate that technological innovation directly reduces CO_2 emissions in particular via R&D investment. While innovation policies alone are unlikely to stabilize the global CO_2 concentration and temperature rises, combining climate and innovation policies could result in significant efficiency gains (Bosetti et al. 2011). Spiezia (2011) finds that ICTs act as an enabler of innovation, particularly for product and marketing innovation, in both the manufacturing and services sectors but does not find any evidence that ICT use increases firms' "inventive" capabilities by increasing firms' capability to co-operate, develop innovations in-house or to introduce products new to the market. Shirazi and Hajli (2021) find that variables, such as ICT access and ICT broadband network, positively influence sustainable innovation in conjunction with socio-economic and political parameters. Despite the other differences between the 127 economies the authors consider over the period from 2008 to 2017 - in terms of ICTs, socio-economic development, and educational attainment - ICTs are the significant drivers of sustainable innovation.

GeSI (2015) estimated that the ICT sector's own global footprint of 1.25Gt CO_2e in 2030 compared favorably with the 12Gt CO_2e of emissions avoided through the use of ICT solutions demonstrating that ICT delivers a benefit 9.7 times higher. In other words, for each ton of CO_2e used to power ICT, users in 2030 could on average realize almost 10 tons of CO_2e savings in 2030. Therefore, continuing R&D in the ICT sector to provide innovative ICT-based solutions to industry and homes is key to making more progress towards reducing emissions including by fostering the diffusion of information between firms and enabling co-operation. Meanwhile, firms also require information about market developments and the activities of competitors and firms both upstream or downstream in the production chain – firms that choose not to innovate themselves, or to adopt the innovations of others, and continue with inefficient technologies, processes or products, may become uncompetitive and lose market share (Porter and van der Linde, 1995). Firms may also seek to collaborate and cooperate in the field of R&D and innovation – whereby particularly ICTs may play an important role in facilitation such activities, communication and transmission of knowledge. Thus, R&D in the ICT sector and Internet diffusion could be important determinants of innovation more broadly, and green innovation in particular.

> ***Hypothesis 1: R&D investment in ICT will have a positive effect on green innovation in Europe.***

Under the Ownership-Location-Internalization (OLI) Paradigm of Dunning (1973, 1979), which seeks to explain why firms invest abroad in the form of FDI, the advantages conferred by ownership include i.a. access to technological know-how, skills, better products and more efficient processes. It has been shown that innovation cooperation (e.g., in R&D) is more effective for green innovations than for non-environmental innovations (De Marchi, 2012). In the context of techno-globalization, new research (Guellec and von Pottelsberghe de la Potterie (2001) who have a focus on international patenting; Jungmittag (2020) who has a broader R&D internationalization focus) puts an emphasis on firms from country i and firms from country j joining forces in international R&D - read: joint international research projects or firms from country i conduct R&D in subsidiaries abroad (i.e., in country j) or firms from country j conduct R&D in subsidiaries in country i – so that the respective multinational company's R&D activities could be split across countries; if R&D activities in country j is enhanced, the R&D activities in country i indeed might be reduced in the context of an optimal international R&D approach and, at the same time, the international diffusion of new technologies is slowed down in both overall innovations and green innovations. An alternative view could be a reduction of country i research activities as a consequence because higher R&D activities in country j is taking place with a focus on green innovations while green R&D activities in country i indeed are slowing down. De Marchi (2012) finds a substitution effect between co-operation activities with others and internal R&D efforts – which may indicate that innovations may be developed with co-operating partners – including abroad - rather than 'in house'.

Thus, FDI is a key channel of disembodied technology transfer including in the field of green innovations through a spillover effect. FDI is important for technology transfer and environmental technology transfer, as multinationals are often the first to bring new environmental technologies to a country (Popp, 2009; Dasgupta et al. 2002). This is referred as the 'pollution halo hypothesis' - inward FDI brings with it new processes, skills and technologies which are 'greener' than what exists in the host country with many studies showing a positive effect of inward FDI with regard to, for example, a reduction in the emissions of greenhouse gases (see, e.g., Tamazian and Rao, 2010; Kirkulak et al., 2011; Song et al., 2013; Zhang and Zhou, 2016; Mert and Caglar, 2020). FDI destination economies can also benefit indirectly from externalities in the form of productivity spillovers (Blomström, Kokko and Zejan., 2000) via imitation or adoption of processes or products, an improvement in the human capital available, or the effects of increased competition in the FDI host country.

Wang et al. (2020) have shown for China, that high-quality FDI is more beneficial for green technology uptake in the host country than the quantity of FDI. Xu et al. (2021) find a negative effect of inward FDI on green innovations in Chinese regions, with a greater negative effect in high-tech manufacturing sectors compared to low-tech manufacturing sectors. Jiangfeng et al. (2018) also differentiate between labor-intensive FDI and capital-intensive FDI, finding that capital-intensive FDI plays a stronger role in encouraging green innovation in countries with strong environmental regulations. Luo, Salman and Lu (2021) examining the role of FDI on green innovation across Chinese regions find support for the 'pollution halo effect', i.e. a positive effect on green innovations while outward FDI from China to developed countries also results in positive reverse green technology dynamics.

On the other hand, the 'pollution haven hypothesis' would suggest that firms may outsource pollution-intensive production, for example, rather to jurisdictions with lower environmental standards rather than incur the costs of making domestic processes greener through green innovations. A higher outward foreign direct investment stock relative to the source country capital stock should have an effect on innovativeness in general and possibly also on green innovativeness in particular. Shahbaz et al. (2018) have shown that the pollution haven hypothesis holds more for low- and middle-income countries, whereas the pollution halo hypothesis holds for more for high-income countries, possibly a reflection of the distinction between labor-intensive and capital-intensive FDI, with labor-intensive FDI primarily going to low- and middle-income countries where labor costs are relatively low.

Considering outward FDI, this could produce a reverse spillover effect, by also transferring technologies and know-how back to the source country. Luo, Salman and Lu (2021) find outward FDI from China results in positive reverse green technology dynamics from developed countries, similar results are found by Bai et al. (2020). Dai et al. (2021) consider Chinese regions and examine outward FDI and green innovations. The authors find that the effect a negative but not significant effect of outward FDI but this varies by region. They also find that the effect of outward FDI is related to environmental regulations in the source region; where environmental regulation is less stringent, outward FDI negatively affects green innovation. In regions where the environmental regulation is moderately stringent, does the estimated coefficient of outward FDI turns positive, but remains not significant. Only in regions in which environmental regulation stringency is high intensity, can outward FDI significantly promote green innovation. The role of outward FDI in fostering green innovations is also related to institutional characteristics such as intellectual property rights (IPR) and the rule of law which is discussed subsequently. Studying Chinese provinces, Han (2021) finds that as the level of intellectual property protection continues crosses a threshold value, the effect direction of outward foreign direct investment on environmental technology innovation undergoes a sudden change from inhibition to promotion. However, when intellectual property protection is too high, the promotion effect is relatively limited.

Alternatively, with respect to outward FDI stocks, outward FDI could have a negative effect on green innovation since MNCs could split R&D in a way that more R&D takes place abroad along with higher R&D activities of subsidiaries while R&D in the headquarter country is reduced – in line with R&D globalization concepts. Finally, there is another alternative view in which the firms' size play a role: one may assume that outward FDI stocks are a proxy for the firm's respective size: with higher outward FDI, the respective MNC becomes larger and will have an even more significant lobbying influence in the headquarter country – with more influence on weaker green regulation and then also lower green R&D in that country.

In respect of developed economies, however, in examining the nexus between environmental regulation, FDI and green technology innovation in OECD countries, Behera and Sethi (2022), have shown that FDI can have a negative effect of green innovation. They find that a 1% increase in the flow of FDI to the host country results in a 0.03% decrease in the GTI promotion (in terms of patents of green technology) which undermines the existence of the pollution halo hypothesis for developed countries. To the best of the authors' knowledge, a distinction has not been made in the literature on the FDI-green innovation relationship between green product and/or green process innovations.

> ***Hypothesis 2a: A higher foreign capital participation will have a positive effect on green innovation in Europe.***

> ***Hypothesis 2b: A higher participation in the global capital market will have a positive effect on green innovation in Europe.***

Institutional and Political (Regulatory) Aspects

Following the Porter hypothesis (Porter and van den Linde, 1995) according to which green innovation could result in a 'win-win' scenario by which firms could improve competitiveness while also realizing environmental benefits Rennings (2000) analyzed innovation arguing that there is a need to not only consider demand-driven and supply-driven innovation dynamics in the field of environmental technological progress with its potential double dividend but that there is additionally a need to analyze potential benefits in terms of higher innovation dynamics stemming from climate-friendly regulations and policies (see also Bernauer et al., 2007; Veugelers, 2012; Peiró-Signes et al., 2022), whereby careful consideration should be paid to the policy mix as this may be more important than individual policy instruments (Rogge and Schleich, 2018). Such regulations should partly be adopted at the supranational level since otherwise major policy inconsistencies are to be expected. Following the findings in the field of passive energy houses as a field of innovations in Austria (Dachs and Budde, 2020), there is a clear need for the European Commission to help avoid the scenario in which the globally-leading position of Austrian firms is undermined by national – and also by regional – regulations in, for example, the German construction and real estate sector: novel housing concepts which have become a climate-friendly success story in Austria cannot be applied in neighboring Bavaria/Germany, since the protectionist lobbying of German firms effectively prevents the cross-border diffusion of new knowledge in the field of passive house construction; this is all the more strange as some of the relevant R&D support for firms in Austria has come from EU funding.

Green public procurement could also play a particular role in the coming years as a driver of green innovation. With regard to the removal of barriers which hinder the diffusion of technologies and innovations, Dechezleprêtre, Glachant and Ménìere (2013) study a panel of 96 countries over the period from 1995 to 2007 and offer interesting insights. The authors find strong evidence that lax Intellectual Property regimes have a strong and negative impact on the international diffusion of patented knowledge in the area of climate-change mitigation technologies, while restrictions on international trade and foreign direct investment also hinder the diffusion of climate-friendly technologies. The authors find that if intellectual property rights (IPR) are weakened, innovators rather rely on secrecy to protect their inventions than, for example, patenting, negatively impacts the international diffusion of knowledge because secret inventions diffuse less extensively. For a review of the literature on regulations and green innovation, see Borsato and Bazani (2021). Thus, we form the following hypothesis:

> ***Hypothesis 3: The governance quality is positively associated with green innovation in Europe.***

3. Methodology and Data

Use of the Community Innovation Survey in Green Innovation Research

The Community Innovation Survey (CIS) was introduced by participating member states of the European Union in 1992 and intended to collect data on, and facilitate an overview of, innovation activities (from research and development, to innovation expenditure, financing and innovation-related turnover to challenges and barriers to innovation) in enterprises in member states. Originally intended to be implemented every four years, from 2004 on the CIS has been conducted biennially becoming the largest such survey in the world in terms of countries covered, including selected non-EU countries, and respondent enterprises, itself becoming an innovation which has become a benchmark for similar innovation surveys in Australia, Canada, China, Japan, and Russia amongst others while research interest in the findings of the CIS has increased over time (Eurostat, 2022; Arundel and Smith, 2013). Analyzing CIS findings in the context of a panel dataset, is however, not straightforward (Mairesse and Mohnen, 2010), leading many contributors to perform econometric analyses on particular waves of the CIS as a cross-section, or individual countries separately, even in comparative studies.

The early literature made use of the CIS in investigating innovation and, in particular, eco-innovations (see, e.g., Horbach, Rammer, and Rennings, 2012). Despite noting the difficulties in developing consistent time series for analysis in the early years of the CIS, Aghion, Veugelers and Serre (2009) note that by CIS2006 business sector respondents did not appear to be particularly motivated by green innovations arguing that environmental benefits were a side-effect of firms' general innovation activities (p. 3). Numerous early papers considered determinants of eco-innovations for individual countries covered by the CIS or for a particular wave of the CIS given its cross-sectional nature (e.g. on Germany, see Horbach, 2008; Mazzanti and Zoboli (2006) and De Marchi and Grandinetti (2013) on Italy, Madaleno et al. (2017) on Portugal, Lewandowska, Gołębiowski and Rószkiewicz (2022) using CIS2014 or Ghisetti, Marzucchi and Montresor (2015) using CIS2008).

Multi-country analyses which allow the identification of "international" determinants are more recent (see, e.g., Horbach, Oltra and Belin (2013). The authors find that the determinants of eco-innovation in the two countries exhibit remarkable similarities with a central role played by regulation and cost savings (supply-side) in motivating eco-innovations. External sources of knowledge and information play a more crucial role when it comes to eco-innovation than innovation in general suggesting that ICT could indeed be crucial for innovating firms. Using a binary probit model to analyze the determinants of eco-innovations in 19 EU member countries using the CIS, Horbach (2016) shows that regulation activities and environmentally-related subsidies seem to be more important for the Eastern European EU member countries than for the relatively wealthier Western European EU member states. The author also finds that Eastern European countries rely more on competitors and external R&D as sources of information, indicating a possible role of technology transfer from Western EU to Eastern EU member countries.

Biscione, Caruso and de Felice (2020) examine the determinants of environmental innovation of manufacturing firms in eight European transition countries (Bulgaria, Croatia, Estonia, Hungary, Latvia, Lithuania, Romania and Slovakia) by using cross-sectional data from the Community Innovation Survey – CIS2014 and employing a multivariate probit model.

Similarly, Biscione et al. (2021) use the same data and methodology to examine firms in the Baltic countries alone.

An early contribution to use the CDM structural model of Crepon et al. (1998) is that Lööf et al. (2001) using separate datasets for each country under consideration, namely Norway, Finland and Sweden, but applying the same econometric model to each. Also employing the two-stage structural econometric model (CDM), Makrevska Disoska et al. (2021) conduct a detailed longitudinal analysis on the innovation performance in nine European countries (Bulgaria, Czech Republic, Germany, Hungary, Norway, Portugal, Romania, Slovakia and Spain) by conducting a separate CDM estimation for each country using data from three waves of the Community Innovation Survey, namely CIS2010, CIS2012 and CIS2014.

Biagi, Pesole and Stancik (2016) analyze innovative activities undertaken by ICT-producing firms and provide evidence on innovative activity in the ICT sector in comparison to all sectors (i.e., the general economy including the ICT sector). The authors create an original panel dataset which matched the information collected in different waves of the Community Innovation Survey (CIS) from 2004 to 2012 in twenty EU member states. Data availability and consistency issues means that the authors were restricted to only those variables that were available for the period under consideration and for the largest number of countries were included. They find that on average, firms in the ICT sector tend to innovate more relative to the economy as a whole: shares of both innovators and technological innovators are consistently higher within the ICT sector than they are in the economy as a whole.

Furthermore, the authors find that the ICT sector has a higher share of innovative firms which perform R&D. Results of the empirical study indicate that R&D investment plays an important role in the innovative ICT sector, that a large share of ICT innovative firms report that intellectual property rights are not used to increase or maintain their levels of competitiveness, that firms cooperate widely with clients and suppliers, but their cooperation with universities and government varies considerably across the EU member states under consideration and that a lack of finance and qualified personnel are perceived to be the most frequent barriers to innovation.

Based on the three hypotheses, our primary variables of interest in this analysis are (i) Research and Development (R&D) expenditures in the Information and Communication Technology sector and Internet diffusion (ii) stock of inward and outward FDI and (iii) the Rule of Law as a proxy for the institutional framework within which firms operate in a particular country.

Estimation method and variable selection

We create a panel covering the years 2007 to 2018 by including data from the biennial Community Innovation Surveys and using interpolation techniques to include data from the intervening years in a novel approach. The empirical analysis presented herein considers as alternative independent variables the following set: product innovations, process innovations as well as firms reporting both product and process innovations; in addition, we look at the ratio of product to process innovations and the ratio of green patents in total patents. The sectoral definition of the green sector – considering the CIS framework – used here is listed in **Table 2**.

Table 2: The Sectoral Definition of the Green Sector

No.	*Sector*	*Green Sector*
1	Agriculture, forestry and fishing	
2	Mining and quarrying	
3	Manufacturing	Yes
4	Electricity, gas, steam and air-conditioning supply	Yes
5	Water supply, sewerage, waste management and remediation activities	Yes
6	Construction	
7	Wholesale and retail trade, repair of motor vehicles and motorcycles	
8	Transportation and storage	Yes
9	Accommodation and food service activities	
10	Information and communication	Yes
11	Financial and insurance activities	Yes
12	Real estate activities	
13	Professional, scientific and technical activities	Yes
14	Administrative and support service activities	

Source: *Eurostat, authors' own interpretation.*

As regards the empirical approach, a two-way fixed effects panel data analysis is useful here. Several models are considered subsequently where the analytical focus is both on product innovations and process innovations in green sectors in the EU27 countries plus other European countries covered by the Community Innovation Survey.

$$Green\ Innovation_{it} = \alpha_1 + \beta_1(ICT\ Investment\ R\&D)_{it} + \beta_2(GDP\ per\ capita)_{it} + \beta_3(Internet\ Density)_{it} + \beta_4(Inward\ FDI\ Stock)_{it} + \beta_5(Median\ Age\ of\ the\ Labor\ Force)_{it} + \beta_6(Green\ Revealed\ Comparative\ Advantage)_{it} + \mu_i + \delta_t + \epsilon_{it}$$

whereby *i* refers to the selected European countries[1] (i=1,…35) and t denotes to time (t=2007,… 2018). μ_i is the unobservable, time-invariant individual specific effects, δ_t control for the year-specific effects, and ϵ_{it} are the disturbances.

As regards economic control variables and on the basis of the literature, we consider the following variables:

- The ICT R&D-GDP ratio: the higher that ratio is, the higher could be green innovativeness in general – assuming that the ICT sectors' technological dynamics are of particular relevance for green innovativeness.
- GDP per capita (in PPP figures) generally may be assumed to raise the demand for high quality products which are also green products or climate-friendly products.

[1] The 35 countries included in the empirical analysis are Austria, Belgium, Bulgaria, Switzerland, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Croatia, Hungary, Ireland, Iceland, Italy, Lithuania, Luxembourg, Latvia, North Macedonia, Malta, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovak Republic, Slovenia, Sweden and Turkey.

- As a proxy for the regulatory system of European countries, we use the Rule of Law. Our choice of Rule of Law is motivated by the following considerations. Firstly, that a stronger rule of law will lead to higher levels of innovations as recorded by the CIS as inventors and firms will be more likely to report innovations if they are confident in the ability to legally safeguard their findings via patenting, licensing etc. Secondly, a strong rule of law is likely to increase the confidence of investors to engage in inward FDI, and to finance original R&D or share innovations from the headquarter country. Thirdly, firms and other economic actors will have more confidence in the respective legal system to pursue restitution through the relevant courts for any breaches or misuse of innovations. One may also note, that in recent years in the rule of law has been weakened in a number of EU and European countries which may undermine efforts to promote green innovation and climate-protection policies.

- The Internet density might be an important variable for innovation or – more likely on theoretical considerations – for green diffusion.

- The inward FDI capital stock should raise process innovativeness as international technology transfer is both associated with international mergers & acquisitions and greenfield investment.

- The median age of the workforce should have a negative effect on the innovativeness – at first sight. However, given the fact that IMF analysis (Aiyar, Ebeke and Shao, 2019) shows the labor productivity of only two professions is a positive function of age, namely physicians and professors, it cannot be excluded that the knowledge and experience accumulation effects of these two professions could have a positive effect on innovativeness.

- Green RCA as defined by the GSI (Global Sustainability Indicator) of the EIIW could be a significant variable if one assumes that a positive RCA in green products reflects a relatively strong ability of green product firms to refinance R&D expenditures in international markets.

A description of all variables, source information on the data and the time period covered in the empirical analysis is presented in **Table 3**.

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Table 3: A Description of the Variables Used in the Regression Analyses

Variables	*Acronym*	*Description*	*Source*
Proc_Inn	pcinn	Number of process innovative enterprises in green sector	Eurostat
Prod_Inn	pdinn	Number of product innovative enterprises in green sector	Eurostat
Proc&Proc_Inn	ppinn	Number of process and product innovative enterprises in green sector	Eurostat
Prod/Proc_Inn	pd_pc_inn	The ratio of product to process innovative enterprises in green sector	Eurostat
Green patents	patent_env_p	Environmentally-related technologies as a % of all technologies (patents)	OECD
ICT Inv. R&D, %GDP	ict_inv_rd	R&D in ICT sector, ICT investment in Research and Development as % of GDP	OECD
GDP per capita	gdppc	GDP per capita based on purchasing power parity (PPP) constant 2017 international $	Word Bank
Rule of law	rle	Rule of law	OECD
Internet Density	fixbs_per100	Fixed broadband subscriptions (per 100 people)	Word Bank
Inward FDI Stock Intensity	ifdi_stock_gdp	Inward FDI Stock as % of GDP	UNCTAD
Outward FDI Stock Intensity	ofdi_stock_gdp	Outward FDI Stock as % of GDP	UNCTAD
Median Age of the Labor Force	medage	Median age of the labour force, ILO modelled estimates, Nov. 2020	ILO
Green RCA	rca_green	Green Revealed comparative advantage indicator	EIIW

Source: *Own representation.*

The summary statistics and correlation matrix for the variables are presented in **Table 4**.

Table 4: Summary statistics and the correlation matrix

	Variable	Obs	Mean	Std. Dev.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1)	ln(pcinn)	380	6.76	1.40	1.00												
(2)	ln(pdinn)	380	6.55	1.59	0.88*	1.00											
(3)	ln(ppinn)	380	7.34	1.37	0.92*	0.84*	1.00										
(4)	pd_pc_inn	380	104.27	92.14	-0.13*	0.24*	0.04	1.00									
(5)	patent_env_p	405	12.44	4.94	0.02	0.04	-0.04	-0.03	1.00								
(6)	ict_inv_rd	245	1.87	1.73	0.08	0.12	0.10	0.04	-0.14*	1.00							
(7)	ln(gdppc)	420	10.48	0.45	0.07	0.14*	0.07	0.13*	-0.12*	0.35*	1.00						
(8)	rle	408	1.08	0.72	0.01	0.11*	-0.01	0.17*	-0.03	0.42*	0.87*	1.00					
(9)	fixbs_per100	420	26.68	9.22	0.05	0.13*	0.00	0.14*	-0.01	0.26*	0.73*	0.74*	1.00				
(10)	ln(ifdi_stock_gdp)	405	4.11	1.04	-0.54*	-0.55*	-0.51*	-0.08	-0.07	0.21*	0.20*	0.16*	0.20*	1.00			
(11)	ln(ofdi_stock_gdp)	401	3.29	1.71	-0.18*	-0.18*	-0.14*	0.03	-0.13*	0.46*	0.72*	0.68*	0.62*	0.65*	1.00		
(12)	medage	336	41.1	1.55	0.45*	0.45*	0.39*	0.05	0.12*	-0.03	0.00	-0.01	0.34*	-0.52*	-0.31*	1.00	
(13)	rca_green	384	0.03	0.17	0.42*	0.45*	0.44*	0.13*	0.08	0.05	0.11*	0.09	0.12*	-0.22*	0.02	0.39*	1.00

*Notes: * shows significance at the .05 level*

4. Results

The subsequent table presents the initial regression results (**Table 5** and **Table 6**), we consider our set of variables when both including and excluding the manufacturing industry which implicitly suggests that the Old Economy is not so relevant for identifying the position of countries' respective green innovation position. Manufacturing is included in models (1) to (4) and excluded in the subsequent models (5) to (9). In a second step, we also consider other potentially relevant variables on the right-hand side. The subsequent regressions include country-fixed effects as well as time fixed effects.

The results show that the ICT Investment in R&D-GDP ratio has a negative impact on green innovativeness, thus we do not find support for Hypothesis 1.This suggests that it is not just ICT Investment in R&D expenditures which are crucial for green innovativeness**.** The empirical analysis has shown that the inward FDI stock intensity positively affects process innovations (with the manufacturing (denoted as MFG) industry excluded) providing some evidence in support of Hypothesis 2a. As regards firms with both process and product innovations, GDP per capita is found to be a positive driver of innovativeness (with innovativeness disregarding manufacturing) and also a positive driver of process innovations – but, paradoxically, it is a negative driver of product innovations. The median labor force age has a negative impact on process innovations (excluding manufacturing) while the sign is positive for process and product innovating firms (when including and excluding manufacturing). Green RCA is positively significant for product innovation firms and process & product innovators (including and excluding manufacturing). We thus have interesting empirical evidence which has considerable policy implications. The internet variable was not significant, while model (9) for the Green patents does not offer a useful explanation – further research is needed here. Clearly, not all product innovations can be easily patented; a caveat which is most important in the services sector where, however, trademarks and other intellectual property rights play a rather prominent role.

Table 5: Regression Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Incl.MFG				Excl.MFG				GreenPatents
VARIABLES	Proc_Inn	Prod_Inn	Proc&Prod_Inn	Prod/Proc_Inn	Proc_Inn	Prod_Inn	Proc&Prod_Inn	Prod/Proc_Inn	
ICT inv. R&D, %GDP	-0.023*	-0.013	-0.047*	0.077	-0.025**	0.003	-0.035	3.163	-0.138
	(0.012)	(0.014)	(0.026)	(3.090)	(0.011)	(0.013)	(0.029)	(3.269)	(0.142)
GDP per capita	0.566	-0.635	1.468*	-33.488	0.675*	-1.018**	1.039	-95.359	0.419
	(0.375)	(0.511)	(0.764)	(80.178)	(0.391)	(0.474)	(0.869)	(93.175)	(5.986)
Internet density	-0.0004	0.005	-0.016	-0.311	-0.008	0.021	-0.030	3.538	-0.175
	(0.011)	(0.013)	(0.020)	(1.810)	(0.012)	(0.020)	(0.023)	(3.000)	(0.114)
Inward FDI stock intensity	0.129	0.214	-0.019	-13.595	0.306**	0.189	-0.021	-40.131	0.592
	(0.139)	(0.149)	(0.231)	(39.210)	(0.138)	(0.153)	(0.275)	(42.582)	(1.113)
Median age of the labor force	-0.087*	-0.046	0.267**	10.137	-0.092	-0.031	0.279**	7.607	-0.353
	(0.052)	(0.056)	(0.107)	(8.566)	(0.060)	(0.071)	(0.132)	(12.446)	(0.526)
Green RCA	1.258	1.685*	2.578**	114.285	2.285	1.758*	2.585*	-160.409	6.064
	(0.985)	(0.884)	(1.151)	(190.935)	(1.402)	(1.060)	(1.558)	(209.181)	(8.069)
Constant	4.607	14.831***	-18.461*	35.535	2.347	16.877***	-14.947	784.135	26.216
	(4.519)	(5.620)	(10.708)	(955.776)	(4.925)	(5.828)	(12.315)	(1,106.780)	(74.997)
Observations	229	229	229	229	227	229	229	227	234
R-squared	0.955	0.963	0.914	0.410	0.954	0.956	0.882	0.505	0.555
Country-FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors are reported in parentheses, significance level: *** p<0.01, ** p<0.05, * p<0.1

In the following regression results presented in **Table 6**, both inward FDI stock intensity and outward FDI stock intensity are considered here as explanatory variables. Here, we find that inward FDI has a positive and significant relationship with product innovations, while outward FDI has a negative and significant effect, providing mixed evidence for Hypothesis 2b and possible support for the findings of Beheri and Sethi (2022) for OECD countries; there is positive evidence for the alternative hypothesis on outward FDI stocks as stated above and this could be interpreted as support for the phenomenon of techno-globalization, indeed. Alternatively, one may assume that outward FDI stocks are a proxy for the firm's respective size: with higher outward FDI, the respective MNC becomes larger and will have an even more significant lobbying influence in the headquarter country where the MNC pushes via the political system for weaker environmental regulation and thus can reduce its R&D efforts in the headquarter country. Indirectly this is line with FDI gravity modelling which shows positive evidence for the pollution haven hypothesis in a reverse and possible parallel pattern for the host country and the source country (see Bahlmann and Welfens, 2021) As regards robustness checks, we have tested for a regression using only the actual bi-annual data from the CIS – see Annex 3 (annual data used here are based on linear interpolation of the bi-annual original CIS data).

Moreover, per capita income is replaced with the institutional variable Rule of Law, whereby Rule of Law in turn is obviously a good proxy for higher per capita income (the political demand for a stricter interpretation of the rule of law should be a positive function of real per capita income in purchasing power parity). We find that the rule of law is indeed significant and positive in relation to process innovations when both including and excluding manufacturing, while results in relation to product innovations are not significant. Thus, we have mixed evidence for Hypothesis 3.

The fact that the median age of the workforce has a positive effect on firms – including manufacturing - which have combined product and process innovations suggests that the experience of the labor force could be of particular relevance for such firms' innovation success. One may indeed assume that firms which come up with both types of innovations are Schumpeterian leaders in their respective sector. The robustness check shows weaker results for the rule of law variable and also for the green RCA effects.

Table 6: Regression Results – Extended Analysis

VARIABLES	(1) Incl.MFG Proc_Inn	(2) Incl.MFG Prod_Inn	(3) Incl.MFG Proc&Prod_Inn	(4) Incl.MFG Prod/Proc_Inn	(5) Excl.MFG Proc_Inn	(6) Excl.MFG Prod_Inn	(7) Excl.MFG Proc&Prod_Inn	(8) Excl.MFG Prod/Proc_Inn	(9) GreenPatents
ICT inv. R&D, %GDP	-0.005	-0.015	-0.022	-0.858	-0.000	-0.008	-0.019	0.032	-0.067
	(0.010)	(0.010)	(0.020)	(2.708)	(0.009)	(0.012)	(0.024)	(2.782)	(0.091)
Rule of Law	0.528***	0.178	0.166	-33.958	0.843***	-0.148	-0.110	-101.376**	1.215
	(0.188)	(0.233)	(0.318)	(44.194)	(0.204)	(0.212)	(0.362)	(49.707)	(2.945)
Internet density	0.005	-0.000	-0.008	-0.758	-0.000	0.011	-0.027	2.489	-0.161
	(0.011)	(0.014)	(0.019)	(1.988)	(0.013)	(0.019)	(0.023)	(3.183)	(0.120)
Inward FDI stock intensity	0.153	0.600***	-0.172	-7.610	0.415**	0.637***	-0.090	-44.806	1.984
	(0.206)	(0.182)	(0.323)	(65.408)	(0.181)	(0.180)	(0.364)	(64.740)	(1.485)
Outward FDI stock intensity	-0.127	-0.523***	0.079	-3.296	-0.284**	-0.556***	0.009	23.085	-2.553**
	(0.139)	(0.169)	(0.235)	(43.971)	(0.121)	(0.141)	(0.261)	(45.637)	(1.282)
Median age of the labor force	-0.063	-0.025	0.275***	8.988	-0.052	-0.021	0.280**	3.067	-0.217
	(0.051)	(0.057)	(0.101)	(8.338)	(0.058)	(0.068)	(0.124)	(12.213)	(0.560)
Green RCA	1.251	1.687**	2.807**	119.378	2.255*	1.797*	2.823*	-155.858	5.605
	(0.960)	(0.798)	(1.193)	(189.125)	(1.330)	(0.942)	(1.581)	(204.357)	(7.600)
Constant	9.026***	7.454***	-3.084	-214.739	6.943***	6.433**	-3.300	80.098	27.274
	(1.893)	(2.233)	(3.797)	(328.881)	(2.214)	(2.773)	(4.730)	(533.166)	(24.858)
Observations	229	229	229	229	227	229	229	227	234
R-squared	0.956	0.966	0.913	0.411	0.957	0.960	0.881	0.508	0.565
Country-FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors are reported in parentheses, significance level: *** p<0.01, ** p<0.05, * p<0.1

5. Policy Conclusions and Further Research

Green innovativeness will be key going forward in terms of meeting national and supranational climate targets in Europe. Furthermore, promotion of green innovation could serve to improve firms' international competitiveness and have a positive impact on employment in Europe. From an economic policy perspective, one may emphasize that higher green innovativeness or higher green innovation dynamics requires several adjustments from the side of the policymakers in the country considered:

- There is a critical minimum of ICT R&D investment relative to gross domestic product needed in some countries: government R&D promotion should be reinforced.
- The inward FDI stock intensity should be high – to raise green innovativeness - which requires to raise the attractiveness of the host country (e.g., adequate regulation and rather modest taxation would be required here).
- The rule of law should be strengthened: a long-term investment horizon relevant for green innovations; there is a need for the reduction of transaction costs and risk – solid institutions and a credible consistent legal framework are crucial in this context.
- The outward FDI stock intensity could weaken green innovations in the respective source country which could be reflecting techno-globalization (as more R&D takes place in foreign subsidiaries, the need to reinforce green R&D activities in the headquarter country is reduced – international technology diffusion should be encouraged and or barriers to technology diffusion should be reduced; here, there could be a potential problem: competition issues emerge as high outward FDI intensity could raise market power problems and mark-up problems which translates into lower green innovativeness.
- High green revealed comparative advantage stands for an ecosystem which is supportive of green international innovations; government emphasis on more green products/services exported could be useful.

Stimulating inward FDI intensity should be a natural task of policy makers in the EU27+ countries. Here, national policymakers would seem to be quite important, and obviously there are considerable FDI differences across EU27+ countries (see, e.g., UNCTAD, 2020; 2021; Roeger and Welfens, 2021). In the EU, the supranational policy layer is an only modestly active actor – but the Corona pandemic induced €750 billion in terms of extra EU budget funding of 2021 gives a somewhat larger role to Brussels as an implicit coordinator of high EU funding opportunities. The findings with regard to the median age are not really clear and further research is needed here. The Green RCA variable normally reflects primarily the institutional quality of a country and the strength of the tradables sector; not just the export sector, since intelligent imports of intermediate imports are crucial for gaining a positive revealed comparative advantage in certain fields. Both higher R&D funding from the EU as well as a more co-operative R&D funding of EU countries could be useful, namely to the extent that there are international spillover effects in the European Union.

To justify the high risks associated with investing in start-up projects particularly, venture capitalists tend to invest in high-technology businesses with significant growth potential, particularly in the fields of ICT and biotechnology (Harroch, 2018). Thus, venture capitalists play a particularly important role with regard to innovation dynamics in the ICT sector and this role should be reflected in government policy especially as Europe has, in recent years, lagged behind competitors such as the United States or Japan when it comes to venture capital investments and investment in R&D more broadly. This disparity resulted in the EU establishing what it called the "Innovation Union" in 2020 which was aimed at creating jobs and economic growth by support access to and improving the conditions associated with financing R&D. In 2021, the European Innovation Council was established with a budget of approximately €10 billion intended to support "game-changing" innovations throughout their lifecycle from early stage research, to proof of concept, technology transfer, and the financing and scale up of start-ups and SMEs.

Climate-friendly government procurement policies in EU countries could also play a stronger role in the future; not just in the field of ICT products but in nearly all sectors relevant for government procurement. The role of sector-specific risk premia as an impediment for more climate-friendly innovations should be carefully considered by policymakers; prudential supervision rules of the European Central Bank (ECB) referring to both transition risks and physical risks associated with global warming should be framed in a way that competition among companies quoted on the stock market will be enhanced and that indeed firms with strong green innovation dynamics could expect a rise of their own stock market price relative to the overall stock market index. De Haas and Popov (2019) show that equity markets play an important role as regards greening the economy, since they encourage a shift in investments from more polluting to less polluting sectors, and encourage carbon-intensive sectors to engage in green innovation. Moreover, their study indicates that more developed stock markets produce more green patents (De Haas and Popov 2018).

The EU-US Trade and Technology Council (TTC) could become relevant in the future for green innovativeness as this new transatlantic initiative is a crucial impulse to industrial policy of the Western world and stands for more cooperation in high technology – including digital and green fields – in the future (Welfens and Hanrahan, 2022). One should hope that the TTC initiative, which could in part make up for the failed TTIP initiative will not lead to a strong new tendency to bypass the World Trade Organization (there seems to be some US pressure in this direction in 2022). Since global warming indeed concerns a global public good and since it is not only Western countries which can contribute to enhanced green technological progress it is quite important that a global, multilateral organization can maintain a leading role in terms of the global allocation of resources and the encouragement of more green Schumpeterian dynamics.

The fundamental idea here is that green innovations has a strong overlap with climate-friendly innovations. This broad view of green innovativeness omits the problem of rebound effects which could only be analyzed in a study which makes a clear distinction between the short- and medium-term on the one hand; here, one might be less optimistic with respect to digital goods and services although they could stand themselves for a reduced form of material- and energy-intensive good. The more interesting aspect here is that of capital goods whose productivity seems to be increasing in the digital age in the long run. Again, digital capital goods whose share in total equipment will increase as the relative price of capital goods is falling over time could contribute to a kind of negative endogenous rebound effect as the new (innovative) capital goods are less energy- and material-intensive than traditional capital goods (Welfens, 2022). On the other hand, the long-term equilibrium approach which would largely reflect a green growth modeling perspective - with endogenous growth (see, e.g., Bretschger, 2017); hence innovation dynamics, including green innovation dynamics, could be part of a general equilibrium solution.

There are also, however, other critical aspects, namely that we do not know much about the links between process innovation and product innovations; e.g., one may argue that new products can indeed only be produced with new capital goods/innovative capital goods - in the Internet age, increasingly in the form of immaterial assets whose growing share in overall capital formation represents a broad new analytical challenge itself (Haskel and Westlake, 2018). The service sector's share in overall output is continuously rising in OECD countries and thus could bring about a fall of trade intensity - over time, international innovativeness could face a slow down since trade intensity is typically a driver of more innovativeness; the problem is that there would be less opportunities for Melitz-type innovative firms which need international exports to expand successfully. However, it is unclear whether trade cannot partly be replaced outward FDI (and the respective technology transfer benefits of foreign direct investment) here. There is an additional aspect of the modern economy for innovation dynamics: The increasing use of ICT facilitates means that value-added is increasingly internationalized - with a larger space covered for producing the final goods or services; indeed, FDI should therefore play a stronger role in the long run and again international technology transfers will increase which implies a stronger role for international R&D cooperation. To the extent that subsidiaries of MNCs' exert adequate, pro-R&D support lobbying pressure on host country governments, the problem of internalizing positive international innovation effects could be less complicated than one might first think. Empirical analysis on the lobbying activities of headquarter companies and their respective subsidiaries are necessary here. Furthermore, oligopolistic international interdependency might be critical in some sectors.

Finally, there is another critical question which concerns the issue of why green tax rates (environmentally-related tax revenues as a percentage of GDP) across OECD countries differ widely: In 2019, from around 0.5% in Colombia, to circa 1.7% in Germany and to 3.2% in Denmark, 3.6% in the Netherlands and 3.8% in Greece (figures for 2020; OECD, 2022). At least with respect to a country such a Germany - compared to the Netherlands and Denmark - one would have to raise the question of why in Germany the internalization of negative effects from emissions is so much weaker than in the two smaller, neighboring EU countries. This could be an interesting point for the European Commission for the future, namely to highlight such apparent policy inefficiencies. A certain part of the EU's budget - say 3% of EU GDP - could be allocated in a progressive way in favor of countries which can offer evidence that the internalization of negative external effects is largely optimal – such countries would obtain a larger share of EU innovation funding and structural change funds, respectively. Countries with a rather inefficient internalization policy would instead would face a progressive reduction in EU co-financing of innovation projects and in EU structural change funds: The principle should be that the internalization of negative external effects - as well as the internalization of positive external effects - should be optimally designed at the national policy layer first. With such a new incentive-compatible policy approach of the EU and the EU member countries, respectively, the allocation of resources would be optimized in a broad way and less government intervention of income redistribution and compensation for inefficient domestic (and foreign) economy policy would be necessary.

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Appendix

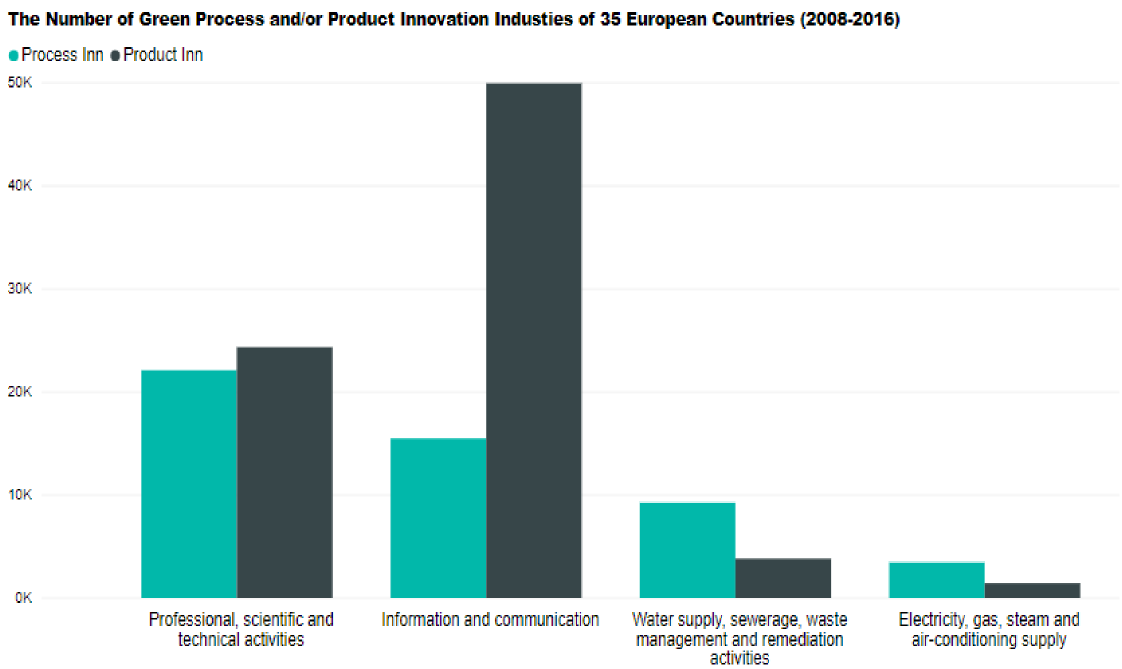
Annex 1: List of Countries and Sectors Included in the Analysis

Countries: Austria, Belgium, Bulgaria, Switzerland, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Croatia, Hungary, Ireland, Iceland, Italy, Lithuania, Luxembourg, Latvia, North Macedonia, Malta, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovak Republic, Slovenia, Sweden, Turkey

Sectors: Manufacturing (selected models, see text), Electricity, gas, steam and air-conditioning supply, Water supply, sewerage, waste management and remediation activities, Transportation and storage, Information and communication, Financial and insurance activities, Real estate activities, Professional, scientific and technical activities

Annex 2: Green Innovativeness in Selected Sectors in the EU+, 2008-2016

Figure 1: Selected Sub-sectors of Green Innovativeness in Selected Sub-sectors in the EU+; 2008-2016



Source: *CIS data and EIIW calculation.*

Annex 3: Robustness check

Considering **Table 6** and the subsequent **Table 7**, one may basically point out that the Rule of Law and Green RCA are weaker in terms of significant impact shown here.

Table 7: Robustness check - Regression with bi-annual CIS data

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Incl.MFG				Excl.MFG				patent_env_p
VARIABLES	ln(pcinn)	ln(pdinn)	ln(ppinn)	pd_pc_inn	ln(pcinn)	ln(pdinn)	ln(ppinn)	pd_pc_inn	
ict_inv_rd	0.001	-0.011	-0.001	0.725	0.015	0.016	0.018	0.974	-0.119
	(0.019)	(0.014)	(0.016)	(4.237)	(0.019)	(0.026)	(0.031)	(4.999)	(0.091)
rle	0.294	0.110	0.257	37.687	1.140**	-0.039	0.139	-189.607	3.273
	(0.596)	(0.476)	(0.530)	(109.659)	(0.500)	(0.520)	(0.610)	(116.490)	(3.403)
fixbs_per100	-0.002	-0.012	-0.009	-0.448	0.007	-0.015	-0.061	1.144	-0.073
	(0.035)	(0.026)	(0.032)	(7.892)	(0.038)	(0.042)	(0.047)	(9.221)	(0.168)
ln (ifdi_stock_gdp)	0.243	0.701**	-0.127	-75.953	0.553	0.755**	0.273	-159.136	3.034*
	(0.616)	(0.301)	(0.347)	(171.024)	(0.446)	(0.360)	(0.403)	(184.677)	(1.741)
ln (ofdi_stock_gdp)	-0.435	-0.478*	0.005	95.886	-0.718**	-0.701**	-0.487*	141.194	-1.854
	(0.481)	(0.248)	(0.286)	(133.507)	(0.323)	(0.284)	(0.278)	(143.080)	(1.543)
medage	-0.059	-0.050	0.139	2.922	-0.175	-0.110	0.034	12.491	0.232
	(0.135)	(0.114)	(0.139)	(25.023)	(0.140)	(0.214)	(0.242)	(29.305)	(0.632)
rca_green	1.282	1.396	1.448	268.582	3.019	2.600	1.727	-190.867	8.169
	(2.403)	(1.345)	(1.648)	(467.889)	(4.005)	(2.384)	(2.998)	(583.055)	(7.749)
Constant	9.580*	8.272*	2.322	-151.151	11.866**	10.022	7.575	-103.210	-4.822
	(5.129)	(4.593)	(5.414)	(929.788)	(5.394)	(8.984)	(9.843)	(1,316.974)	(28.870)
Observations	86	86	85	86	84	86	85	84	190
R-squared	0.936	0.978	0.947	0.564	0.944	0.957	0.945	0.601	0.589
Country-FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors are reported in parentheses, significance level: *** p<0.01, ** p<0.05, * p<0.1

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