The role of environmental policies in promoting venture capital investments in cleantech companies

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Abstract

This paper provides insights on the role of environmental policies in promoting venture capital (VC) investments in companies involved in the development of clean technologies. Based on a supervised machine learning algorithm, we develop a fully replicable methodology to identify cleantech companies among a comprehensive database of VC-backed companies. We, then, analyze the relationship between the stringency level of environmental policies and VC investments in cleantech companies operating in 21 OECD countries. Moreover, we explore whether policies have a differential effect in fostering Institutional VC (IVC) and Governmental VC (GVC) investments. Our findings indicate that IVC investments in cleantech are mainly driven by stringency of environmental taxes and market pull mechanism as feed in tariff and R&D subsidies, whereas GVC investment decisions are positively influenced by the stringency level of emission trading system. Moreover, our results suggest that GVC funds are developed as an alternative to incentive mechanisms: when direct incentives developed by governmental agencies are less developed, the relevance of GVC investments increases, this suggesting a complementarity between the two forms of intervention.

Keywords: Environmental innovation, Environmental policies, Environmental technologies, Risk finance, Venture capital

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1. Introduction

In recent years, scholarly interest in financing innovation for mitigating climate change has significantly grown. In 2015, at COP 21 meeting in Paris, 95 countries signed the first ever real global legally binding climate deal. The United Nation Framework Convention on Climate Change (UNFCCC) addresses crucial areas necessary to combat climate change, identifying the climate finance as an effective instrument to support mitigation and adaptation actions through public, private and alternative sources of financing. Moreover, Paris agreement advises that "*the development and transfer of climate technologies is critical for achieving the ultimate objective of the Convention. It also urges developed country Parties to take all practicable steps to promote, facilitate and finance the transfer of, or access to, climate technologies to other Parties, particularly to developing countries*".[3] Notwithstanding the Convention, the projections issued by the International Energy Agency[4] confirm the increasing trend of primary energy demand at world level (+10% between 2016 and 2025)

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[3] United Nation Framework Convention on Climate Change - UNFCC http://bigpicture.unfccc.int/#content-the-paris-agreemen.

[4] International Energy Agency "Global Energy outlook 2017", 2017, https://www.iea.org/weo/.

and the primary role of fossil fuels as global source of energy: the share will remain well above 75% in 2025.

In the final document, Paris Agreements defines a range of environmental policies essential to meet the target: production of energy from renewable sources, development of resource efficient products/processes, circular economy, biodiversity and sustainable mobility. These areas represent the main field of research for innovative companies and entrepreneurs involved in the energy/environmental sector or, so called, "clean technologies industry" ("cleantech" henceforth). The term cleantech was created by the investment community and is widely regarded as a major investment category or even asset class (Caprotti, 2012; O'Rourke, 2009; Pernick & Wilder, 2007, Midgent et al. 2017). The cleantech industry includes companies focused on green and sustainable technologies with products, processes or services able to reduce the amount of greenhouse gas emissions (Midgent 2015).

One of the most relevant issue for governments refers to the strategy to foster innovation in cleantech: according to UNFFC[5] documents, mobilizing finance for investments and innovation in low-carbon energy is a key challenge for climate change mitigation.

Typically, the development of cleantech technologies is carried heavily by small and innovative companies (Hockerts & Wüstenhagen, 2010) founded by entrepreneurs, which commonly has got technical know-how, but lack the financial resources and the managerial know-how (Gans & Stern, 2003). Venture capitalists (VCs, henceforth) have developed a strong reputation for funding promising technology companies. The extant literature has shown how VCs play a key role in the screening process (Amit et al., 1998; Chan, 1983; Tyebjee and Bruno, 1984), as well as in the post-investment monitoring of the portfolio firm (Kaplan and Strömberg, 2003; Lerner, 1995; Sahlman, 1990). Moreover, VCs provide value-adding services (Sapienza et al., 1996; Sørensen, 2007), such as coaching, mentoring and access to investment bankers, which could have signaling effects (Megginson and Weiss, 1991). Furthermore, VC-backed firms benefit from the network of contacts that may be provided by reputable, well-connected VCs (Hsu, 2006; Lindsey, 2008).

Despite academic literature demonstrates the role of VC to promote the development of innovative technologies (Barry et al., 1990; Hellmann and Puri, 2002), only few studies focus on the analysis of the role of VC in fostering cleantech companies. Cleantech initiatives are affected by decreasing financing opportunities: they are typically characterized by the public good nature (Cumming 2016) and high capital intensity along many phases of product development /commercialization (Wustenhagen 2006, Burer 2009). These characteristics reduce investment opportunities and increase risk aversion of institutional investors, compared with other innovative sectors (Gosh 2010, Polzin 2017, Chassot 2014).

Given this peculiar risk profile of cleantech companies, governments can play a crucial role in designing both demand side or supply side environmental policies aiming at reducing the risk profile of these technologies and foster financial investments by VC investors. Even if the public debate regarding best strategies to tackle climate change is becoming relevant in developed and developing countries, there are scarce evidences on the role of environmental policies in fostering VC investments in cleantech technologies. At the best of our knowledge, only Criscuolo and Menon (2015) focus on the role of environmental policies, focusing on renewable ones, in fostering the VC investments in cleantech. Based on a private commercial database of cleantech backed companies they analyze the relationship between VC investments, type and number of renewable policies. They utilize a dummy variable to capture the existence of a specific renewable policy in a given country and then utilize the number of policies as proxy of government effort. They find a prominent role of regulation quantity, like renewable energy certificates or renewable energy quotas. Moreover, they utilize government R&D expenditure, as proxy of R&D energy expenditure, and they show that R&D expenditures are positively associated with the

[5] United Nation Framework Convention on Climate Change - UNFCC http://bigpicture.unfccc.int/#content-the-paris-agreemen

number of deals. Finally, they found that sales tax reduction fosters VC investments in the energy segment of cleantech.

The contribution of our study to previous literature, relates, first, to the fact that we focus not only on the presence of an environmental policy but also on the role of the stringency level of environmental policies in fostering VC investments in the cleantech sector. Previous studies utilize dummy variables or count variables to proxy policy implementation (Criscuolo and Menon 2015, Polzin et al. 2015). Both methodologies show drawbacks in measuring the implementation and stringency level of policies. Firstly, analysis of relationship between VC investments and environmental policies based on dummy variables is not able to capture the effect of stringency level of policies between countries, but only the eventual existence of a specific intervention. Moreover, with dummy variable, is not possible to analyze the evolution of such polices over time at country level. Third, the number of policies is also affected by the stability of government policies. In framework of relative low policy stability, government frequently changes environmental policies due to change in environmental targets, political and industry lobbying activities. We try to exceed these limits and add to previous literature by measuring the policy stringency utilizing the indicators based on Botta and Koźluk (2014) research and collected in the OECD database and exploring their relationship with the VC activity. During last decades, in almost all European countries, we observe an increase in the environmental requirements in almost all industries. According to the policy stringency indicator created by Botta and Koźluk (2014) the average level of policy stringency increased in all EU countries all between 1990 and 2015. The analysis shows that, not only the average level increased over time, but also the variability between countries.

Secondly, we aim at exploring the role of VC heterogeneity: government can promote the development of cleantech initiatives both through direct investments by Governmental VC funds (GVC, henceforth) and through specific environmental policy framework to foster private Independent VC investments (IVC, henceforth). We, thus, investigate whether environmental policy strategy developed by governments varies according to the VC funds ownership structure and if government coordinates direct and indirect instruments to optimize support to cleantech companies.

Third, but not less important, our contribute is empirical as we develop a robust methodology to identify cleantech companies. Previous studies based their analysis on a set of cleantech companies either already classified by private commercial databases (Cleantech Group, Bloomberg New Energy Finance) or identified through keywords selected with exogenous procedure. Both sample selection methodologies may introduce biases: in the first case, sample selection is not known, in the second case, dictionary of keywords is arbitrarily defined by the authors without any procedure of validation of such dictionary. In this work, we build a fully replicable methodology based on supervised machine learning algorithm. Starting from the full sample of VC-backed companies, the algorithm identifies cleantech and non-cleantech companies. This approach takes advantages from the transparency of the methodology applied and the fully replicability on the sample utilized. Moreover, our analysis takes advantage of data provided by a well-established dataset on VC investments in young high-tech ventures located in Europe: the VICO database, created as a part of a research project funded by the European Commission within the 7th Framework Program (see www.vicoproject.org). We complemented the VICO database with multiple quantitative indicators of government environmental policies stringency.

Our findings indicate that IVC investments in cleantech are mainly driven by stringency of environmental taxes and emission limits, feed in tariff and R&D subsides whereas GVC investment decisions are positively influenced by the stringency level of emission trading system. Moreover, results evidence the complementarity between the two forms of public intervention to foster the development of cleantech projects: when direct incentive (such as feed in tariff or R&D subsidies) are high, the number and the amount of GVC investments decreases.

The article is organized as follows. In section 2 we discuss the literature analyzing the role of VC in promoting cleantech technologies and we present the conceptual background and our research hypotheses. Section 3 describes the VICO dataset, the machine learning methodology applied to identify cleantech companies and the sample used in our study. The econometric model is described in section 4. Section 5 discusses the results of the empirical analysis and section 6 concludes.

2. Conceptual background

2.1. The role of VC in supporting cleantech technologies

In recent years the debate on strategies to reach climate target is overflowing academic and governmental boundaries and it is becoming prominent in most OECD media. In UK, during spring 2019, the adoption of recommendation set by Committee on Climate Change by Government was heavily covered by media and a vivid debate arose across the most important press services[6].

Nonetheless, 2018 Bloomberg new Energy Finance report (BENF) data shows that governments around the world are not able to increase financial sources for innovation and R&D in cleantech industry: the amount invested varies between 4.5 and5 billion of US dollars since 2009. If direct public investment remains constant, also due to government's budget constraints, the role of other forms of financing become crucial.

The investment gaps related to sustainable technologies represent a key issue for governments. After the signature of the Paris agreement, the European Commission established the EU High-Level Group on Sustainable Finance (HLEG) to advice on how to address the flow of capital towards sustainable investments and deploying these policies on a pan-European scale[7]. In the document, the HLEG defined a roadmap to shift to a sustainable finance. In the roadmap the role for government is essential, it must ensure that price signals in capital markets reflect both positive and negative externalities, with the aim of determining faster and more efficient allocation of financial sources to technologies able to ensure positive externalities. The HLEG has focused its attention on financial reforms but recognizes that these will only fulfil their full potential if they are matched with policy changes in sectors able to mitigate the effect of climate change.

Traditionally, a crucial channel of financing innovative companies is the venture capital (VC) that provide the financial sources characterized by high risk profile (Da Rin et al., 2013; Samila & Sorenson, 2010), thanks to their ability in the screening process (Amit et al., 1998; Yuk-Shee, 1983; Tyebjee and Bruno, 1984), as well as in the post-investment monitoring of the portfolio firm (Kaplan and Strömberg, 2003; Lerner, 1995; Sahlman, 1990) and the network of contacts that may be provided by reputable, well-connected VCs (Hsu, 2006; Lindsey, 2008). The academic literature demonstrates the relevance of VC in commercializing breakthrough technologies (Barry et al., 1990; Hellmann and Puri, 2002) providing value-adding services (Sapienza et al., 1996; Sørensen, 2007), such as coaching, mentoring and access to investment bankers, which could have signaling effects (Megginson and Weiss, 1991),

Despite the relevance of VC in sustaining the innovation activities by high-tech companies, the cleantech industry faces decreasing financing opportunities and increasing risk aversion to raise equity and debt funds, comparing with other innovative sectors (Gosh 2010, Polzin 2017, Chassot 2014). Academics document multiple factors that makes much more challenging for cleantech startup obtaining equity investments from VC. The first critical difference between cleantech and other types of innovative investments is the public good nature of cleantech products and services. Environmental resources generally do not have well defined property rights. The public good nature of cleantech is linked to benefits and non-excludability of products or services (clean air, clean water, carbon mitigation): any

[6] We need a carbon tax to change consumer behavior – Financial Times 14th May 2019 - https://www.ft.com/content/2c5f19d6-7245-11e9-bf5c-6eeb837566c5
[7] https://ec.europa.eu/info/publications/180131-sustainable-finance-report_en

additional user dos not deplete the product/service and moreover, it is generally difficult or impossible to exclude people from its benefits, even if they are unwilling to pay for them (Cumming 2016).

Secondly, cleantech suffers typical risk of all innovative technologies: the technology risk. In cleantech the level of technology risk is even higher compared to other industries. Moreover, the technology risk of cleantech arises in two phases of the development: the first during the creation of the prototype, a risk shared with all other technological innovation; the second during the industrialization/commercialization phase: even if the technology works in the lab, it is not clear if it will work at scale. This situation, also known as the "technology valley of death" phenomenon, is particularly relevant for cleantech companies (Wustenhagen 2006, Burer 2009). The high-risk profile, also in the commercialization phase, implies that VC-backed cleantech companies need financial support not only in the early stages of the firm's life, but also during the subsequent stage of the technology development. VC investors can play a critical role in bridging the "valley of death", when an emerging technology developed is too advanced to receive public basic research support but not yet technically or commercially mature.

Third, another relevant barrier for VC investments is the specific regulatory risk for many cleantech companies related to its unpredictability. In fact, any change in regulation by government is largely unpredictable for private investors and, moreover, it seems hard to manage or even moving outside their area of influence. In cleantech industry, the regulatory risk is relevant, and the potential impact is huge. Environmental markets present the textbook case of market failure and need for government intervention. Markets does not adequately price environmental effects, and this failure can lead to economically viable but socially undesirable economic activity. Sir Nicholas Stern (2008), author of the Stern Review on the Economics of Climate Change, defined climate change as the result of "the biggest market failure the world has ever seen". Investors tend to underestimate, or even not price, negative externalities without policy intervention and industry regulation.

2.2. Research hypotheses

Even if the public debate about the most effective instruments to foster the development of clean technologies is becoming relevant in almost all developed and developing countries, still the analyses in this particular segment are scarce. A preliminary issue refers to the absence of an official definition of clean technologies industry. Previous studies mainly utilized classification developed by private companies (i.e Cleantech group, Bloomberg New energy Finance) in the absence of a more standard framing methodology (e.g. SIC or NACE classification).

Only few studies in recent years focus their attention on VC investments in the cleantech industry, providing interesting, albeit not conclusive, evidence. Cumming (2016) explores the relevance of country/market characteristics in influencing VC investments in cleantech: he finds that not only oil prices have a curvilinear effect on cleantech VC investing, but also media and formal institutions are important to cleantech VC activity. Gaddy et al. (2017) show that holding period of green companies is longer than average VC investments. Moreover, they evidence differences in VC response within cleantech segment: investments in cleantech fundamental hardware materials chemicals and processes tend to lose money and VC tend to reduce capital allocation to these asset classes, shifting investments to cleantech software that able to remunerate capital to early investors. On the other side, Mrkajic et al. (2017) find entrepreneurs who run a green business and position their venture in a green sector are more likely to get VC funding.

More in details, there are scarce evidences regarding the impact of policies implementation on investment decisions in cleantech companies by VC funds. At the best of our knowledge, only Criscuolo and Menon (2015) analyzes the relationship between the existence of governmental policies and cleantech VC investments, focusing on renewable energy policies. The study finds a prominent role of regulation policies affecting the quantity of renewable energy produced. Moreover, market-pull mechanisms, like feed-in tariff, with long term prospective and able to reduce the volatility of revenues, are effective instruments for favoring VC investments, whereas relative short-term fiscal policies are not. However, it is important to highlight that this previous study focuses its analysis only on the presence of environmental policies for VC, but not the level of policy stringency.

Polzin et al. (2015) focus their analysis only on electricity segment, studying the impact of public policy measures on renewable energy investments in electricity-generating capacity made by institutional investors. They utilize the number of active instances of policies affecting the renewable sector as proxy of policy stringency level. They find that feed-in tariff mechanism proved particularly successful in some countries (Germany and Italy) but not in some other ones (i.e. Spain). Their results show that grants and subsidies prove to be effective as short-term measures to alleviate finance constraints. This holds true for the solar and biomass sectors. Grants and subsidies temporally reduce the cost of finance for a project, and directly depend on a public budget.

Both methodologies evidence limits in measuring the implementation and stringency level of policies: they are not constructed upon an explicitly stated methodological framework. According to Nardo et al (2008) "*A sound theoretical framework is the starting point in constructing (...) indicators. The framework should clearly define the phenomenon to be measured and its sub-components, selecting individual indicators and weights that reflect their relative importance and the dimensions of the overall composite. This process should ideally be based on what is desirable to measure and not on which indicators are available.*" A robust index might be based on a theoretical description of the phenomenon, with a subsequent identification of relevant sub-components. Good selection criteria of subcomponents allow to clearly identify input, process and output measures of the phenomenon. According to Nardo et al (2008) this is a task which is neglected too often.

In absence of robust measures of environmental policy stringency level, previous studies utilized dummy/count variables based on qualitative information on existence of policies in a given country. Both methodologies evidence drawbacks. Dummy variables are not able to capture the effect of stringency level of policies between countries, but only the eventual existence of a specific intervention. Moreover, with dummies, it is not possible to analyze the evolution of such polices over time. On the other hand, utilizing the number of policies in a country, as a proxy of stringency, may bias the analysis. Policies' effectiveness is not only related to number of legislative interventions, but also to stability of government policies. Previous studies on political economy demonstrate negative correlation between policy volatility and economic growth (i.e., Brunetti, 1998). In a situation of relatively low environmental policy stability, government interventions may not be credible enough to modify investment behavior and foster cleantech investment.

The relevance of the stringency level of policy as driver of investment is demonstrated by several studies. Leiter et al. (2010) demonstrate that environmental variables are positively correlated with manufacturing investments, moreover their quadratic terms exhibit significantly negative parameter estimates. This, in turn, indicates a nonlinear relationship between variables that is not possible to capture with policies measured with dummy variables. Also Albrizio et al. (2016) focus their analysis on impact of stringency level of policies on productivity. They find that a tightening of environmental policy is associated with a short-term increase in industry-level productivity growth in the most technologically- advanced countries. This effect diminishes with the distance to the global productivity frontier, eventually becoming insignificant. Also this study evidences that a simple analysis of existence of a specific policy might bias the analysis: the relationship between policies and economic activity is not linear, and dummy variable appears inadequate as proxy of policy level.

We try to exceed these limits, adding to previous literature by measuring the policy stringency utilizing the indicators based on Botta and Koźluk (2014) research and collected in the OECD database. During last 20 years all European countries implemented specific environmental policies as consequence of European directive. The instruments applied and the stringency level, in terms of limits or subsides/incentives, substantially vary over countries (Botta and Koźluk 2014). In this framework become relevant understanding not only if the existence or number of policies can foster VC investments in this segment, but also how the stringency of policies is able to accelerate these investments. According to the view proposed by the Michael Porter's (Porter 1990; 1991; Porter and van der Linde 1995) environmental policies can drive innovation. International competiveness among companies is based on increasing productivity through constant innovation. In this framework, more stringent regulation fosters companies and investors to focus on technologies able to create more efficient and environmentally friendly product/production processes. Environmental policy can stimulate innovation which may compensate for the cost to comply with more stringent regulation or may even bring to an absolute advantage over foreign firms not exposed to the same level of policy stringency. Thus, properly designed environmental regulation can enhance competitiveness through an incentive to innovate more.

Based on the above analysis, this paper puts forward the first research question:

H1: Does more stringent environmental policies are able to foster the VC investments in cleantech companies?

Moreover, none of the previous studies analyze the role of government in promoting cleantech investments by considering the VC heterogeneity, i.e. disentangling between the effect of policies in fostering the investments by IVC and GVC investors.

The rationale behind the government intervention in cleantech segment is primarily directed to correct for supply-side failures in VC markets. Mazzucato (2011) and Auerswald and Branscomb (2003) show that IVCs often not invest in risky high-tech entrepreneurial firms (i.e., the financial returns are not high enough to justify the investment risk), and they prefer companies that are already quite developed. In this context, governments can reduce the specific risks of cleantech investments identifying the best policies able to drive institutional investors' investments to companies and technologies able to reduce GreenHouse Gases (GHG) emissions. As a consequence, environmental polices able to reduce volatility of revenues such as feed in tariffs, or policies that increase costs in non-cleantech companies as environmental taxes and emission trading schemes may incentivize IVC investments in this segment.

On the other side, government may play a role through a direct intervention: previous studies evidence differences in investment strategy according to the type of VC. Colombo et al (2016) show that, in contrast with a lack of success in some countries, there have been successful GVC initiatives, such as the Australian Innovation Investment Fund. Rationales of direct government intervention rather than policies to promote them derive from the needs to alleviate the equity gap of young innovative firms and to stimulate the development of a private VC industry, as well as from expectations of positive externalities and spillover effects on the (local) economy. GVCs can play an important role: Colombo et al (2016) state that "due to the information asymmetries surrounding young innovative firms, it is likely that adverse selection, moral hazard, and agency problems may lead to a market failure for entrepreneurial finance". Then GVC plays an important role in underdeveloped seed and early-stage market. The signaling effect of early-stage companies selected and invested by GVC may reduce the risk aversion of IVC funds, characterized by huge asymmetry of information and lack of specific industry knowledge. Grilli and Murtinu (2014) demonstrate that GVCs might show less risk-averse attitudes in their investment choices to the extent that they also value the social benefits that are brought in by the selected targets. If GVC are able to overcome market failures, we may infer a negative relationship between presence of GVCs and environmental policies that drive public expenditure, as feed in tariff and R&D subsidies. Rational governments may avoid any overlap of policies/ market instrument with common target: in the presence of financial institution able to reduce market failures (GVCs), government may develop policies able to reduce the emission of (GHG) with no impact on public expenditure. At the same time, we may infer that the same supply side policies may boost investments by IVCs. Incentive policies, like feed in tariff are able to stabilize revenues, then reduce investment risk profile and increase project return, two relevant investment drivers for IVCs.

Based on the above analysis, this paper aims to specifically explore the impact of environmental policies on both IVC and GVC investments and puts forward these two research questions:

H2: Which environmental policies are more effective in promoting investment by IVC funds?

H3: Which environmental policies are more effective in promoting investment by GVC funds?

3. Data

3.1. The Identification of cleantech companies

The identification of backed cleantech companies moves from a comprehensive dataset of VC investments in European ventures: the VICO database. The VICO database represents the final output of a research project funded by the 7th Framework Program of the European Commission. (http://www.vicoproject.org/). This database combines information from country-specific proprietary databases and other secondary sources, in addition to commercial databases (i.e., Thomson One, VC-pro, and Zephyr). VICO database includes data on invested companies, at deals level, located in 31 OECD countries, observed from 1994 to 2014. Where possible, data on deals were cross-checked with information publicly available from the ventures' websites, press releases, initial public offering (IPO) documents, and the annual reports and websites of VC firms. A central unit coordinated the data collection process and assured the consistency of data across countries.
For each round of investment, made by a VC, VICO includes information on backed company and on VC: deal date, NACE industry classification of backed company, geographical location of both company and VC, amount invested, round of investment, exit strategy applied (where identified by collected information). A comprehensive description of the procedures and sources used in the data collection process and on all of the company, investment, and investor-level variables in the VICO dataset, is provided in Bertoni and Martí (2011).

VICO dataset include deals of multiple types of VCs: institutional, corporate, governmental, banking, business angel. Firstly, we delimited our analysis focusing on independent professional investors, i.e. Institutional VCs (IVC) and Governmental VCs (GVC).

We then complemented the VICO database with multiple quantitative indicators of government environmental policies stringency, based on Botta and Koźluk (2014) research and OECD database. The policy database developed by OECD cover 1998-2015 period, but does not include all countries represented in VICO, we then exclude 10 countries[8] out of 31, that account for 6.55% of total companies in the VICO database.

Secondly, in order to define cleantech companies we employed a machine-learning algorithm based on the extensive business description of a company. To this purpose, VICO dataset was thus enhanced by adding the extended textual business description of each VC-backed company. This information was collected from two sources: BVD Orbis and S&P Capital IQ datasets, to maximize the number of companies with an explicit business description. The extended business description is a standardized description of the company activity, wrote in the same language (English) for all companies. Out of the total VICO dataset that includes, between 1998 and 2014, in the 10 countries identified, 46966 deals related to GVC and IVC and 19415 VC-backed companies, we found an extended business description for 11769 companies (60.06% of companies). The subsample of companies with business description show significant differences with the original VICO sample, as confirmed by Chi-squared tests ($\chi2[21]=479.94$, $\chi2[19]=200.17$ and $\chi2[2]=217.51$ for country, industry and foundation period, respectively). Countries with largest number of observations in VICO evidence even higher frequency when we move to the subsample with business description. Moreover, companies with business description are, on average, older than the whole sample: 56.93% of companies in VICO sample were founded within 2007, whereas this percentage increases at 63.59% in our subsample. Tables with the

[8] Bulgaria, Croatia, Cyprus, Estonia, Israel, Latvia, Lithuania, Luxembourg, Malta, Romania

distribution of the two subsamples are reported in the Appendix (Appendix A, Appendix B, Appendix C).

Even if broad definitions of clean technologies are utilized both at governmental and academic level, more difficult is the punctual identification and classification of cleantech innovative companies. As for many emerging/innovative sectors, also for cleantech, standard industry classification as NACE Rev2, typically, is not able to capture the sustainable characteristics of particular business or activity (Criscuolo and Menon 2015, Cumming 2016, Christensen 2017, Mazzucato 2017). The definition issue arises also at EU level. The final report on sustainable finance published in 2018 by the high-Level Expert Group on Sustainable Finance - Secretariat provided by the European Commission[9] identifies a common taxonomy on sustainability at the EU level as one of the key recommendations to guarantee a common framework to financial institutions. The subsequent technical report on Taxonomy published in June 2019 is focused on climate change risks taxonomy. It defines relevant climate change risks for private companies (climate change adaptation and climate change mitigation of underling activities) and identifies a first subset of sub-industries characterized by high level of these two specific risks. This report represents, not only, the first comprehensive taxonomy on sustainability, but also underlines the importance of taxonomy as first step to provide a common ground to investors and financial institutions who are approaching the topic.

Then the first step of our analysis is devoted to the definition and identification of cleantech companies. Based on common definitions (Midgent 2015), cleantech are products, services and technologies able to improve the productive and responsible use of natural resources, to reduce or eliminate negative environmental impacts, and to provide superior performance at a lower cost compared to existing solutions. According to UNFCC[10] cleantech sector consists of energy efficiency, renewable energy, waste beneficiation, water efficiency, green buildings, transport, advanced materials and chemicals.

All definitions are extremely general and are not able to support in identifying cleantech projects among the entire sample of VC backed companies. Therefore, any analysis of cleantech must be forego by a specific punctual industry reclassification of the sample or database utilized in the analysis. Several previous studies (Malen et al. (2017), Criscuolo and Menon (2015) Polzin et al. (2015)) analyzed VC cleantech investments already collected and classified by third party information provider (Cleantech Group, Bloomberg New Energy Finance). Some other authors (Shapira 2014, Petkova (2014), Gaddy 2017, Cumming (2016) Cumming (2017), Mazzuccato (2017)) applied a punctual reclassification of start-up to identify cleantech ones through an exogenous dictionary of cleantech relevant words. As highlighted by Butticè (2018), the exogenous selection of keywords may introduce a relevant bias: dictionary of keywords is arbitrarily defined by the authors without any procedure of validation of such dictionary.

In this paper, we build a fully replicable methodology that, starting from the full sample of VC-backed companies for which we collected the extensive business description, identifies cleantech and non-cleantech companies. We employ a machine-learning algorithm to create a content-specific classifier of cleantech companies based on their extensive business description. We developed and applied a supervised machine learning algorithm that, rather than relying on a predetermined list of keywords, automatically built a dictionary of words, to identify cleantech companies. This approach has several advantages. Firstly, it addresses the need for transparent analysis based on publicly available data. The methodology applied is fully replicable on the sample utilized thank to the identification process transparent and based on specific algorithm.

Moreover, this approach has the main advantage of reducing biases that typically affect the creation of exogenous dictionary, considering that it is much easier for an analyst to characterize a concept extensionally, i.e., to select instances of it, rather than intentionally, i.e., to describe the concept in words (Sebastiani, 2002). Text classification firstly analyses a set pre-classified business description (training

[9] https://ec.europa.eu/info/publications/180131-sustainable-finance-report_en

[10] United Nation Framework Convention on Climate Change - UNFCC http://bigpicture.unfccc.int/#content-the-paris-agreemen

set), derives a decision function, and then applies it to predict the category of description whose class is unknown. A widely approach consists in the bag-of-words model (Sebastiani, 2002), where each business description (or document) is treated as a set of terms and converted in a numeric vector containing the frequency of occurrence of each term in the document.

We apply this technique, analyzing the extended business description of each company in our dataset to identify cleantech companies. First step of the procedure consists of randomly splitting the dataset by identifying a subset of description to create the training set. The training set consists of 380 companies descriptions that was manually tagged as "cleantech" or "non-cleantech" according to the definition of cleantech set by Midgent (2015) where cleantech includes companies focused on green and sustainable technologies with products, processes or services able to reduce the amount of greenhouse gas emissions. Manual tagging has been made by two research assistants separately. When differences in the tagging arose (< 5% of the cases), one of the authors classified the document and then discussed the tagging with the research assistants until agreement was reached. Each labeled text was then analyzed using natural language processing (NLP) filters and was converted into a numeric vector. A machine learning algorithm was finally implemented to identify the optimal classification function, which was used to predict the classification of the remaining companies in the sample. Different machine learning algorithms have been utilized to classify texts; among these, the Random Forest algorithm (Breiman, 2001) was selected thanks to its accuracy, efficiency and robustness. Random forest has shown great potential in several domains, ranging from risk assessment in social lending (Malekipirbazari and Aksakalli, 2015) to bank failure forecasts (Barboza et al., 2017).

In addition to the forecast properties, however, two other characteristics put forward its implementation use in the present research. First, unlike other machine-learning algorithms, it requires limited number of iterations for tuning its parameters, Second, it generates internal estimates of the importance of the variables, such as the mean decrease in accuracy (MDA), which measures the relevance of the predictors both in individual and in multivariate interactions. This property has been utilized to identify the words that, among others, contributed most to the accurate discrimination between cleantech and non-cleantech companies. Not surprisingly, terms such as "energy", "water", "waste" and "solar" emerged as the most influential according to the best classification model. The list of the 30 most relevant words generated by the learning process is provided in Figure 1.

[Insert Figure 1 here]

Cleantech companies, identified by RF algorithm, represents 9.21% of the entire sample of companies: our sample is finally composed by 1207 cleantech companies and 11902 non cleantech companies.

3.1. VC investments in cleantech initiatives

Based on the classification applied it is possible to analyze the characteristics of VC-backed cleantech and cleantech companies and the role of IVCs and GVCs in cleantech investments.
Figure 2 shows the evolution of VC initiatives between 1998 and 2014. The graph evidences the percentage of cleantech VC-backed companies over the total number of VC backed over time. Along the period analyzed the relative importance of this segment increased over time: between 1998 and 2003, on average it represents the 6.42% of the entire sample, whereas in subsequent period (2004-2011) it accounts for 11.06%. In the last three years the weight of deals on cleantech companies slightly decreases to 8.29%. The 2010 peak and subsequent drop in cleantech investments is coherent with finding in other works: Polzin (2017) show that renewable investments, at world level, reached the peak in 2011 and then drop in subsequent years.

[Insert Figure 2 here]

The geographical distribution of cleantech and non-cleantech VC-backed companies is reported in Table 1. Results indicate a higher percentage of cleantech companies in countries where VC market is already well-developed (i.e. UK, France, Germany). As for non-cleantech companies, also for cleantech ones we observe concentration in small number of countries: the first ten countries (United Kingdom, France, Germany Finland, Spain, Netherland, Italy, Sweden, Belgium and Denmark) account for 94.7% of total cleantech companies.

[Insert Table 1 here]

Table 2 shows the sectoral distribution of cleantech/non cleantech companies. We can observe that cleantech companies are distributed along many sectors: 44.1% are classified within the very general manufacturing sector and, surprisingly, only 8.8% of cleantech companies are included in electricity & gas sector, one of the most relevant targets for clean technologies. Comparing industry classification of cleantech with non-cleantech companies we can observe that cleantech ones are more dispersed along industries: 81.2% of cleantech companies belongs to the first 5 industries (not including "not classified" cluster), while for non-cleantech ones the first 5 sectors account for 86.8%. The last column shows the relative weight of cleantech companies within each sector. Not surprisingly in sectors characterized by high energy/natural resources usage intensity (electricity and gas, water, mining, and construction) we observe high proportion of cleantech initiatives backed by VCs. Conversely, even if IT industry is the second sector in terms of number of cleantech initiatives backed (131), the relative weight of backed cleantech companies within the sector is limited (3.20%).

[Insert Table 2 here]

The distribution of VC-backed companies reported in Table 3 evidences differences between cleantech and non-cleantech companies by year of foundation. Results indicate a significant difference in their distributions: 41.37% of VC-backed cleantech companies were founded in the period 2001-2007 whereas in the same period were founded 36.98% of non-cleantech companies. Moreover, in this period, VCs overweight cleantech investments comparing to previous and following foundation period: 10.03% comparing to 8.98% and 8.12%.

[Insert Table 3 here]

Table 4 summarizes the characteristics of cleantech and non-cleantech deals in terms of numbers of investments received, amount invested per deal and age of companies at the first investment. In terms of deals, cleantech segment represent 8.44% of the entire sample: 2615 cleantech deals over 31012 associated to companies with business description. According to Cumming (2016), cleantech initiatives tend to be very capital intensive and face greater technology risk than typical VC investments. Accordingly, data in Table 4 show that, the average amount invested in each deal is greater than the mean on the whole sample, confirming the capital intensity of this segment. Moreover, on average, cleantech are financed at a later stage of the company lifecycle: 0.64 years later than the overall sample of VC deals. This evidence seems to confirm the higher risk profile of cleantech companies that force VCs to invest in cleantech companies with higher maturity in order to reduce the risk.

[Insert Table 4 here]

Table 5 reports the characteristics of VC investments by category of investors. The data evidence that GVCs invest more frequently than IVC in cleantech technologies: relative number of cleantech deals with respect to non-cleantech ones is equal to 9.80% for GVC, while for IVC they represent 8.24% of deals. At the same time, when IVCs decide to invest in cleantech technologies, they invest on average more, both comparing to the amount invested in other segments, both comparing to investments by GVC. However, t-test shows that, for IVC, average amount invested in cleantech initiatives is not statistically different from the amount invested in other sectors, meaning that the variability around the

average value is high. This suggests that investment decision made by IVC are largely related to specific characteristics of cleantech initiatives.
Descriptive statistics on company's age at first investment are peculiar: if IVC, compared to GVCs, invest in more mature companies in non-cleantech sector, for cleantech we can observe opposite behavior. Cleantech companies invested by IVC, at the first round of investment are 7.2 months older than non-cleantech and this value increases to 15.2 months for GVCs investments. These descriptives provide a picture that may be interpreted as follows: Colombo et al. (2016) highlighted that, if we look at risk-return paradigm, IVCs have superior selection know-how comparing to GVC. On the other hand, GVCs may have different investment objectives, seeking not only pure financial return but also positive externalities and spillover effects on the (local) economy. This different approach may influence the characteristics of cleantech companies backed: when IVCs select cleantech companies they invest only in most promising ones and, moreover, they invest a lot to sustain the development, whereas GVCs may support more mature cleantech companies not able to overcome the "valley of death" phase.

[Insert Table 5 here]

3.2. Environmental policy stringency measures

To evaluate policy stringency effect, we utilized indicators developed by Botta and Koźluk (2014). They identify, at yearly and country basis, the stringency level of 5 environmental policies indicators: three market based and two non-market based. Market based indicators are trading scheme of environmental certificates (ETS), environmental taxes (Taxes) and feed-in tariff (FIT) mechanisms. Non-market-based policies are emission limits and R&D subsidies. For each indicator, authors analyzed multiple information and quantitative measures and then score and aggregate them into the five policy indicators reported and described in Table 6..

[Insert Table 6 here]

Authors also developed a comprehensive synthetic indicator: OECD PSI Index. Even if, as stated by Criscuolo and Menon (2015), this indicator is not able to capture the heterogeneity of policies applied by each government, its graphical representation may help to identify the trend of environmental policies in Europe between 1998 and 2014. Figure 3 shows the evolution of OECD PSI index in first 5 countries in terms of number of cleantech companies financed by VCs. A positive long-term trend of environmental policy stringency characterized all countries, but yearly variations evidence that specific governmental interventions determine a peculiar short-term behavior in each country. The graph demonstrates that resorting to dummy variables as proxy of policy context may bias the analysis as in presence of trends, investors behavior can be also influenced by the policy intensity.

[Insert Figure 3 here]

Analysis of synthetic PSI index can provide only a general framework of environmental policies evolution at country level, but it is not able to disentangle the impact of each category of environmental policy on VC investments. We then focus our analysis on policy indicators identified by Botta and Koźluk (2014).

Figure 4 - Figure 8 show the minimum, the maximum and the average value of each policy stringency indicator. Minimum and maximum, do not frequently represent first and last observation of indicator in a given country[11]; the stringency level of a single instrument evolves during the horizon analyzed, also based on the general environmental country policy: therefore, for several countries/policies we can

[11] i.e. for taxes minimum and maximum represent first and last observation only in 12 out of 42

observe initial increase and subsequent decrease, with, eventually, last value lower than the first one. For this reason, we opt for a minimum-maximum representation of each stringency indicator (Table - Appendix D presents the detail data of each stringency indicator at country level). Figure 4 - Figure 8 show that the heterogeneity among countries is high: countries rank, based on average value, is different across indicators, proof of different global environmental strategy applied in each country. Not only average level, but also volatility around this value, varies at country and instrument level. Volatility of stringency level is also influenced by specific government law or regulation, that, on yearly basis, can modify incentives to developed clean technologies and penalties to pollute.

[Insert Figure 4-8 here]

Table 7 shows preliminary evidence on the relationship between environmental policies and number of cleantech VC investments in the most representative five countries (78.9% of total VC investment sample). The correlation between number of VC deals in a country and emission limits, ETS and R&D subsidies is positive and for many countries statistically significant. Other instruments as taxes or FIT show volatility, both in terms of significance and sign of correlation: taxes and FIT seems to foster investments in some countries while hinder in others.

[Insert Table 7 here]

When we disentangle according to types of VC (Table 8), we observe that, both for GVCs and IVCs, we can observe statistically significant relationship between number of deals and policy indicators, independently from the type of VC investors: emission limits, ETS and FIT evidence positive correlation with high significance. This preliminary evidence seems not to suggest a differential role of environmental policies in influencing different types of VC investments. In the following section (Section 4) we describe the model we resort for our multivariate analysis aiming to test our research hypotheses.

[Insert Table 8 here]

4. Model specification

The aim of our study is to look at the policy determinants of VC investments in cleantech initiatives across countries. We investigate the relationship between cleantech VC investments and environmental policies aggregating the available deal-level information into year-country data. Compared to previous work by Criscuolo and Menon (2015) , the identification of cleantech companies among a large dataset of VC-backed companies guarantees the existence of a robust control group composed by all non-cleantech initiatives. At yearly and country level is then possible identify the number of cleantech and non-cleantech deals made by VCs. The impact of environmental policies on VC investments is analyzed by considering two different dimensions of investments: the number of deals and the amount invested by VCs.

In the first equation (Eq. 1) the dependent variable is total number of VC deals in cleantech companies at year y, in country c:

$$
\begin{aligned}
N°cleantech\,VC\,deals_{y,c} \\
&= \alpha + Taxes_{y-1,c} + {Taxes_{y-1,c}}^2 + ETS_{y-1,c} + {ETS_{y-1,c}}^2 + FIT_{y-1,c} \\
&+ Emission\_limit_{y-1,c} + {Emission\_limit_{y-1,c}}^2 + R\&D\_subsidies_{y-1,c} \\
&+ EPI_{y-1,c} + N°\_deals_{y,c} + Oil\_price_{y-1} + D_y + D_c
\end{aligned}
$$

Where Taxes, ETS, FIT, Emission limit and R&D subsidies are the policy stringency indicators described in Section 3.2. According to Krass et al (2013), the firm's response to taxation may be non-monotone: higher levels of taxes may induce dirtier rather than cleaner technology. Based on these findings we assume a non-monotone behavior of the three taxation mechanisms in our model: environmental taxes, ETS and emission limits by including their squared terms. These three instruments determine increase in costs for pollutants: directly through taxes or ETS certificates that companies must acquire/obtain, or indirectly through the emission limits imposed to companies. As to control variables, we first include the $EPI_{y-1,c}$, the Environmental Performance Index in each country that, as highlighted by Buttice (2018), reflects the aggregate result from the implementation of measures on multiple environmental aspects at social, technological and economic level. As such, it represents a highly desirable proxy to control for the environmental sustainability orientation of a country's in the year before. $N°\_deals_{y,c}$ is the number of VC investments in country c and year y and represent the control for the development of VC market, $D_y + D_c$ are year and country dummy variables, whereas Oil_price_{y-1} is the price of oil in each given year and represent a proxy of market momentum for cleantech initiatives. According to Cumming (2016), price of energy commodities, proxied by oil price, affects the level of cleantech investments. Environmental policies, market momentum variable and environmental sustainability orientation are lagged, avoiding any possible endogeneity issue and assuming that investor response to change in policy stringency or in the price of energy commodities is not immediate, due to typical investment decision process of VC funds last several months.

As in Criscuolo and Menon (2015), the relationship between number of deals and policies (Eq. 1) is estimated via a Negative Binomial model, to deal with count dependent variable, with non-negative integer values characterized by overdispersion with respect to theoretical Poisson distribution. The number of cleantech deals include a significant share of zeros, which rules out the possibility of a logarithmic transformation and determine overdispersion. Since in the Negative Binomial model the estimated coefficients correspond to semi-elasticities, coefficient estimates can be directly converted into marginal effects. For a continuous regressor x, the marginal effect is $\partial E\,[y|x])/\partial xj = \exp(x\beta)\beta j$. The table reports marginal effects calculated at the mean.

In the second equation (Eq. 2), the dependent variable is the total amount of equity invested by VCs in cleantech companies in logarithm at year y, in country c:

$$\begin{aligned} Amount\_invested\_cleantech_{y,c} \\ = \alpha + Env\_taxes_{y-1,c} + ETS_{y-1,c} + FIT_{y-1,c} + Emission\_limit_{y-1,c} \\ + R\&D\_subsidies_{y-1,c} + Equity\_invested_{y,c} + Oil\_price_{y-1} + D_y + D_c \end{aligned}$$

Explanatory variables are the same as in the first equation, whereas the model is estimated through a generalized linear model (GLM). According with Papke and Wooldridge, J (1996) we do not opt for Tobit regression, a censored model that is not applicable where values beyond the censoring point are infeasible.

5. Results

We estimate Eq. 1 and Eq. 2, as described in the previous section, for all VC investments and separately for IVC and GVC investments in order to test our research hypotheses. Starting from the VC investments database at deal level we aggregate transactions to build the dependent variable identifying number and value of investments made by IVC and GVC. The aggregation process must consider one peculiar aspect

of VCs investments: the syndication.[12] Syndication can be formed by solely IVC, GVC or combination of them. To analyze the effect of environmental policies on the two subset of investors we then classify each investment round, defined as the investment made by more than one investor in one company in a given year, as IVC-only, GVC-only and Co-invested round. We then build four dependent variables for each equation. For Eq.1, we count the numbers of IVC-only, GVC-only and Co-invested deals in each country for a given year. For Eq.2, we calculate the total amount invested for IVC-only, GVC-only and Co-invested deals. IVC-only and GVC-only include both deals in a round syndicated only by one type of investors or round where a VC invests alone in the funded company.
Table 9 shows the results of the Negative Binomial model of Eq. (1), while Table 10 reports the results of the GLM estimation of Eq. (2). For each Model, we estimate four different models: Column I refers to estimates on the whole sample, column II refers to IVC-only investments, while column III reports the analysis restricted to the sample of GVC-only investments, the last column refers to co-investment round where at least one GVC and one IVC founded the company. All estimates also include unreported controls: country and year dummies and Number of deals/amount invested by VCs at country/yearly level. Regression coefficients of Negative Binomial model are expressed as marginal effects.

[Insert Table 9 here]

Results in the first column of Table 9 suggest that environmental polices affect investment strategy of VCs: in fact, results of the entire sample show that, as predicted by Krass et al. (2013), environmental taxes evidence a U shape behavior, with initial positive effect of this instruments in fostering VC investment in cleantech and subsequent negative effect in the presence of extremely high taxation level, corresponding to the highest 5% of the observations. Also, for emission limits we find a significant nonlinear relationship between emission limit and the number of VC deals. More in details, the U-shaped relationship is opposite comparing with taxes: initially, emission limit determines reduction in investments, but at a level of stringency between 25% and 50% percentile of the distribution of emission limit data in our sample, the effect become positive. This behavior may be related to well-known carbon leakage effect. In the first years of EU regulation, emission limits range set by different countries were broad, in this context carbon leakage effect arise. Companies decision on location were driven also by environmental limits and determined delocalization of high pollutant companies to countries with less stringent emission limits. In this context, there wasn't any incentive in investment in cleantech technologies if it was possible to maintain more pollutant technology without any penalty. In the last years when, at EU level, we can observe harmonization of emission limits rules, the effect has been a reduction, within EU countries, of carbon leakage effect and a positive impact of more stringent emission limits on VC investment in cleantech technologies.
EPI and price of oil are not significant, nonetheless the signs of coefficient are in line with Cumming (2016) and Butticè (2018) findings.
We then explore whether responses to policies are different between IVC and GVC investments: results, reported in columns II and III of Table 8, show that policies play important role as driver of investments for IVCs and GVCs, but the driver of investments are different between different class of investors. IVC investors are mainly driven by monetary incentives and penalties. According to what found for the entire sample, for IVCs the level of taxation represents a strong driver in investing in cleantech companies following a U-shaped relationship: an initial positive effect and a subsequent disincentive effect. Moreover IVCs investment are driven by market push mechanisms: R&D subsidies and FIT are able to increase the activity of IVCs in cleantech segment. This result confirms that these supply side

[12] Contrary to other institutional investors, very frequently, VCs are actively involved in providing managerial and operational know-how as well as support in terms of strategic goal setting (Cumming and Johan, 2007, Gompers and Lerner, 2002;). In this context, given the aim of portfolio diversification, VCs utilize syndication to expand their portfolios towards multiple companies and different sectors, where they may not have specific know-how or competencies. Though the syndication process VCs can identify a lead investor, typically the player with specific knowledge of the company/industry, able to directly advise funded firm. The syndication can also exploit levering capabilities and competencies provided to funded firms, if more than one investor is able to provide specific know-how.

mechanisms, able to increase the return of the investments through revenue increases (FIT) or cost reductions (R&D subsidies), foster VC investment in cleantech companies by institutional investors. As predicted by Cumming (2016), IVC investors may be influenced by the market momentum: oil price has a positive and significant impact on the number of IVC deals.

As for GVC investments, results confirm that venture capital investments by the government are implemented as indirect driver of development of cleantech investments: investments by GVCs are negatively correlated with direct supply side mechanisms as R&D subsidies. Moreover, similarly to what we find for the entire sample, GVC investments are driven by emission limits trough an inverted U-shaped relationship: an initial negative relationship due to carbon leakage effect and a subsequent positive effect.

The presence of both IVCs and GVCs as co-investor determines more complex relationship with policy indicators. Since VICO database does not identify the lead investor, co-investment is a mix of round where IVC or GVC lead the syndication of investors. In this context, emerges that ETS has a direct impact: higher ETS price and higher obligation in terms of percentage of renewable energy are able to foster investments in syndication by IVC and GVC funds.

It is interesting to explore the results when the amount invested is considered as dependent variable (Eq. 2). Table 10 reports the marginal effects of these same policies on the total amount of VC funding across country-year, conditional on the value being positive.

[Insert Table 10 here]

Results in the first column of Table 10 suggest that analyzing the whole sample environmental policies seem not affect amount invested. Dividing the whole sample in IVC and GVC deals, reported respectively in Column II and III, emerges that for both the types of investors, market momentum appears relevant and positive. Amount invested by IVCs is also driven by market push policies: both R&D subsides and FIT are positive, but only R&D regressor is also significant. IVC confirm the U shape behavior of environmental taxes on amount invested, with initial positive impact and subsequent negative effect. The analysis of the amount invested confirms that governmental VC funds are developed in countries where market push instrument and incentives are less developed, and, moreover, that IVCs and GVCs have opposite responses to ETS mechanisms: they represent a disincentive for IVC investments while act as an incentive for GVC ones.

6. Discussion and conclusion

In recent years the debate on strategies to reach climate target is overflowing academic and governmental boundaries and it is becoming prominent in most OECD countries. Nonetheless, 2018 Bloomberg new Energy Finance report (BENF) data shows that governments around the world are not able to increase financial sources for innovation and R&D in cleantech industry: the amount invested varies between 4.5 and-5 billion of US dollars since 2009. If direct public investment remains constant, also due to government's budget constraints, the role of other forms of financing become crucial.

The investment gaps related to sustainable technologies represent a key issue for governments. After the signature of the Paris agreement, the European Commission established the EU High-Level Group on Sustainable Finance (HLEG) to advice on how to address the flow of capital towards sustainable investments and deploying these policies on a pan-European scale. In the document, the HLEG defined a roadmap to shift to a sustainable finance. In the roadmap the role for government is essential, it must ensure that price signals in capital markets reflect both positive and negative externalities, with the aim of determining faster and more efficient allocation of financial sources to technologies able to ensure positive externalities. The HLEG has focused its attention on financial reforms but recognizes that these will only fulfil their full potential if they are matched with policy changes in sectors able to mitigate the effect of climate change. Policy makers can thus play an important role in promoting the development of cleantech sector through equity financing. This study represents a first attempt to evaluate the linkages between the stringency level of both market-based policies and non-market policies and VC investments in companies involved in the development of clean technologies.

First of all, it is important to highlight that we provided, for the first time, a fully replicable methodology that, starting from a full sample of VC deals, identifies cleantech and non-cleantech companies through a supervised machine-learning algorithm. Cleantech companies represents 9% of backed companies of VICO dataset and they are characterized by higher average equity investment, with respect to non-cleantech backed companies, and higher average age at first investments. These findings confirm the higher capital intensity of cleantech initiatives and the higher risk aversion of VC funds: on average, they invest more and in more mature cleantech companies comparing with all other VC investments.

Results of our analysis show that, as predicted by Krass et al. (2013), environmental taxes evidence a U shape relationship with the number of VC investments in the cleantech sector, with initial positive effect of this instruments in fostering VC investment in cleantech and subsequent negative effect in the presence of extremely high taxation level, corresponding to the highest 5% of the observations. As to emission limits, we find a significant inverted U-shaped relationship between the stringency level of emission limit and the number of VC deals: initially, emission limit determines reduction in investments, but at a level of stringency between 25% and 50% percentile of the distribution of emission limit data in our sample, the effect become positive.

Moreover, our study evidences that the relationship between the stringency level of environmental policies and VC investments must be analyzed considering the ownership structure of the investor. When we compare IVC and GVC investments in cleantech companies, we observe that, when IVCs select cleantech companies they seem to invest only in most promising ones and, moreover, they invest a lot to sustain their development, whereas GVCs may support more mature cleantech companies not able to overcome the "valley of death" phase.,. Moreover, IVC and GVC investment strategies react to different policies impulses: while IVC investments are mainly driven by market push mechanisms and environmental taxes, GVC investments are developed as alternative with respect to direct monetary incentives. showing a negative relationship with R&D subsides and FIT. Moreover, GVCs increase in amount and number where ETS policies are more stringent.

The study demonstrates that policy makers can play an important role at different points in the market development process to foster innovation activity and entrepreneurship in the cleantech sector. Government might define the appropriate set of policies and the stringency level of each policy based on the specific VC ownership structure. Policies are able to foster investment if set at adequate level, but over taxation can disincentive VC in providing financial resources to the sector.

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Figures

Figure 1 - Mean decrease in accuracy

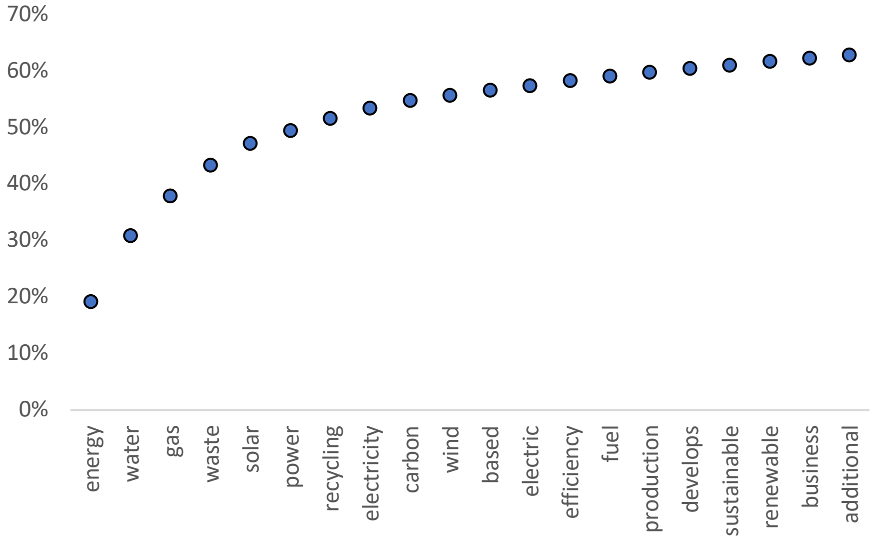


Figure 2 – % of cleantech companies invested per year

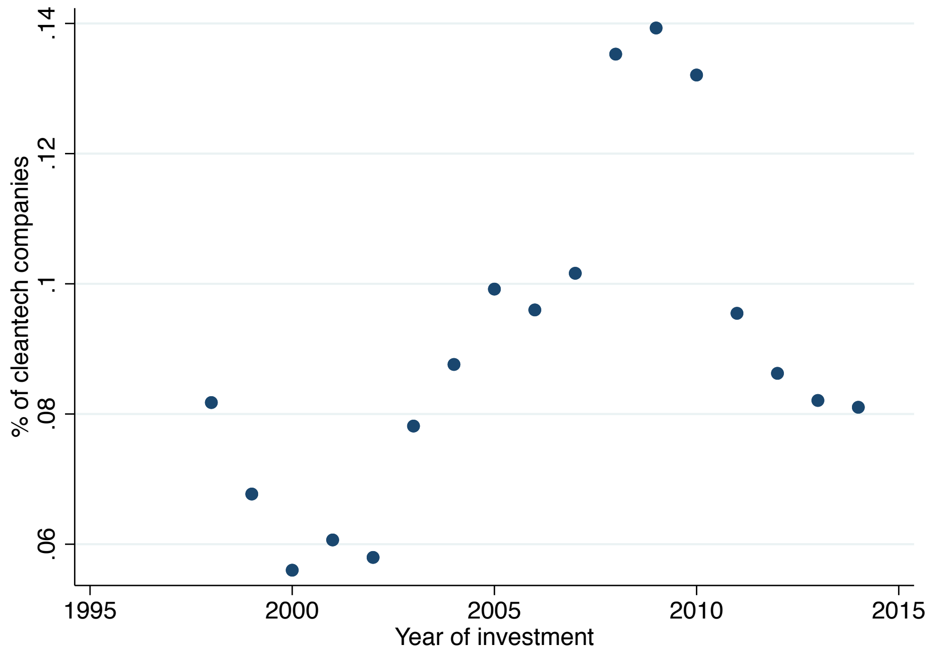


Figure 3 – OECD PSI index in five European countries

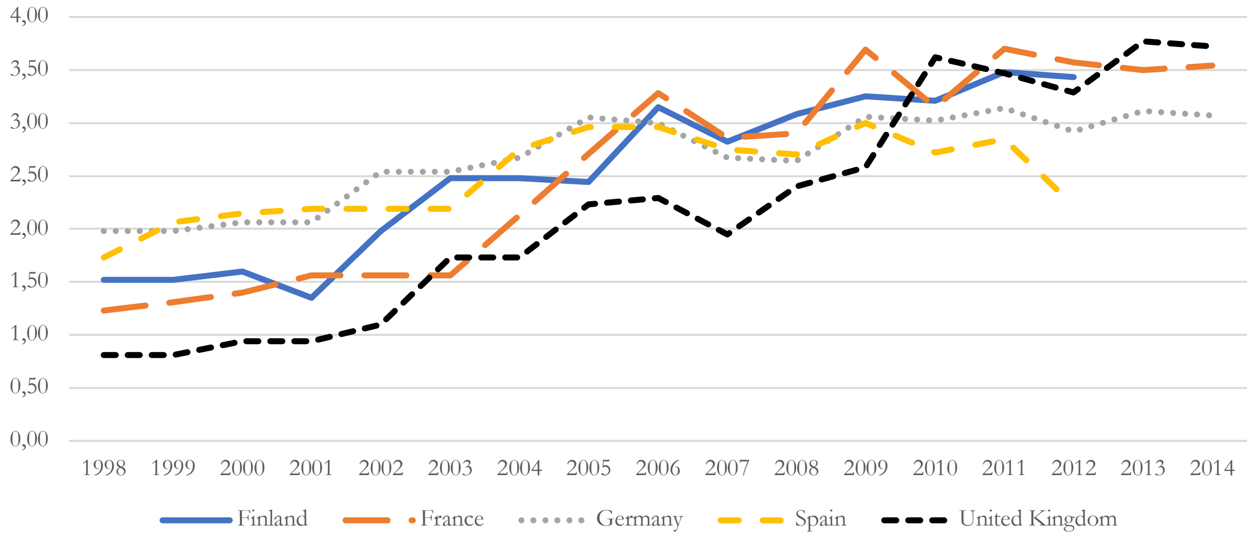


Figure 4 – Maximum, minimum and average value of environmental stringency of taxes in the period 1994-2014

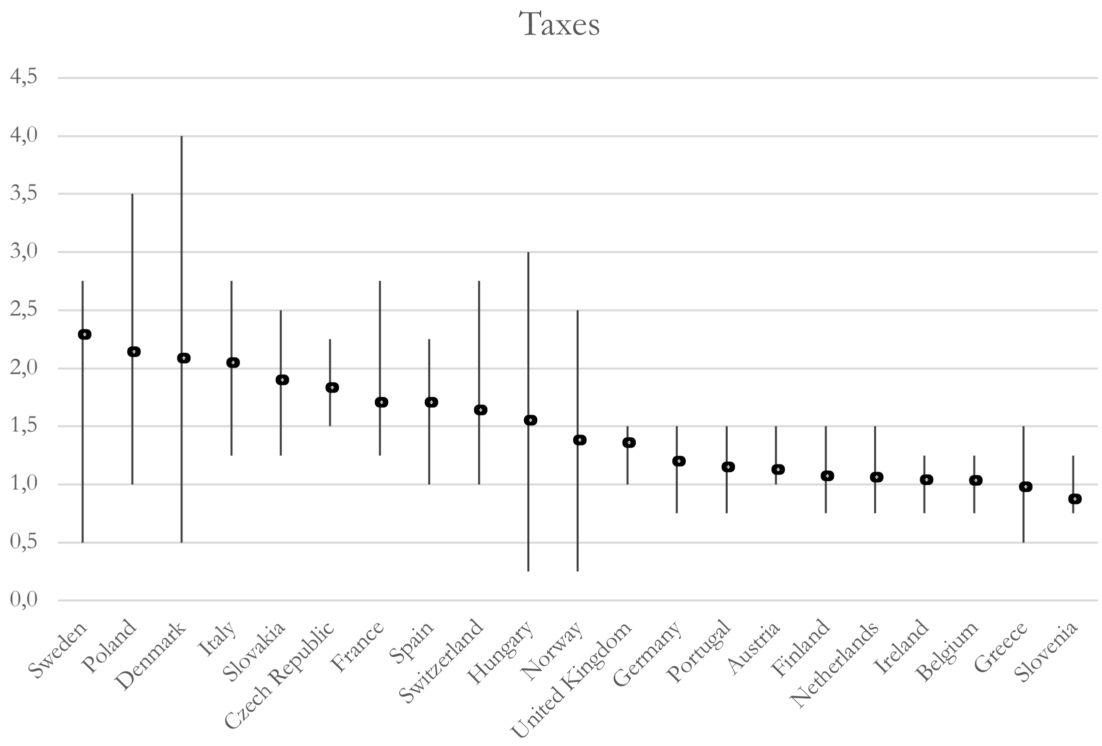


Figure 5 – Maximum, minimum and average value of environmental stringency of emission limits in the period 1994-2014

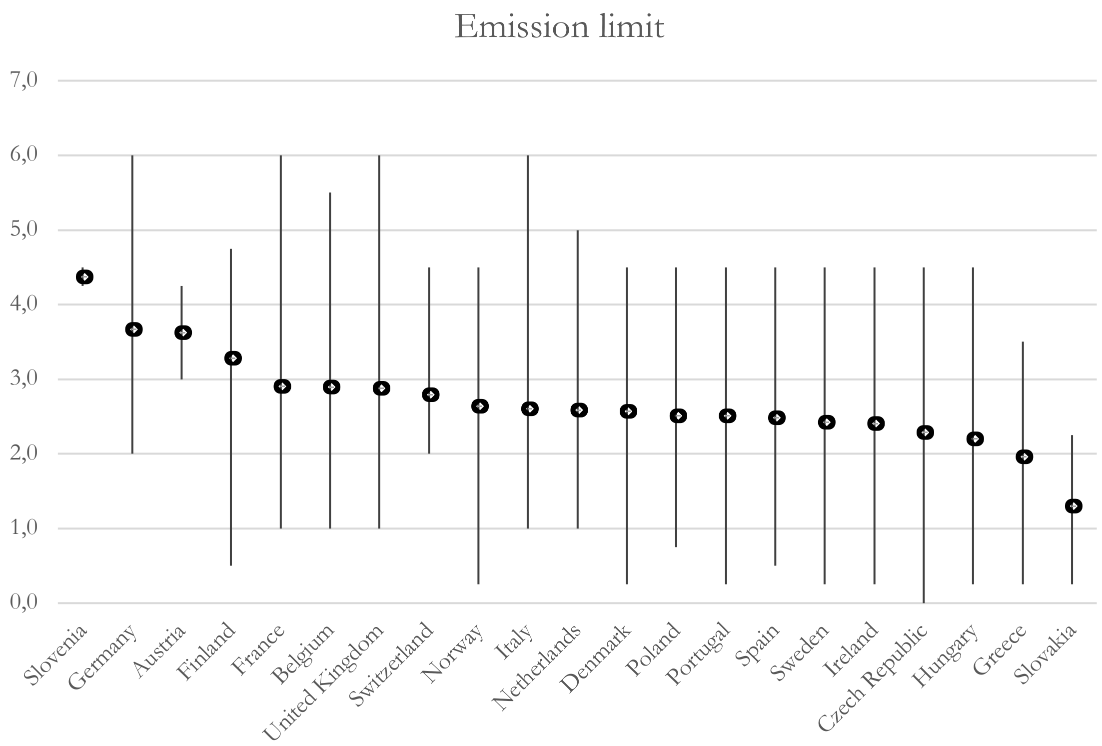


Figure 6 – Maximum, minimum and average value of environmental stringency of ETS in the period 1994-2014

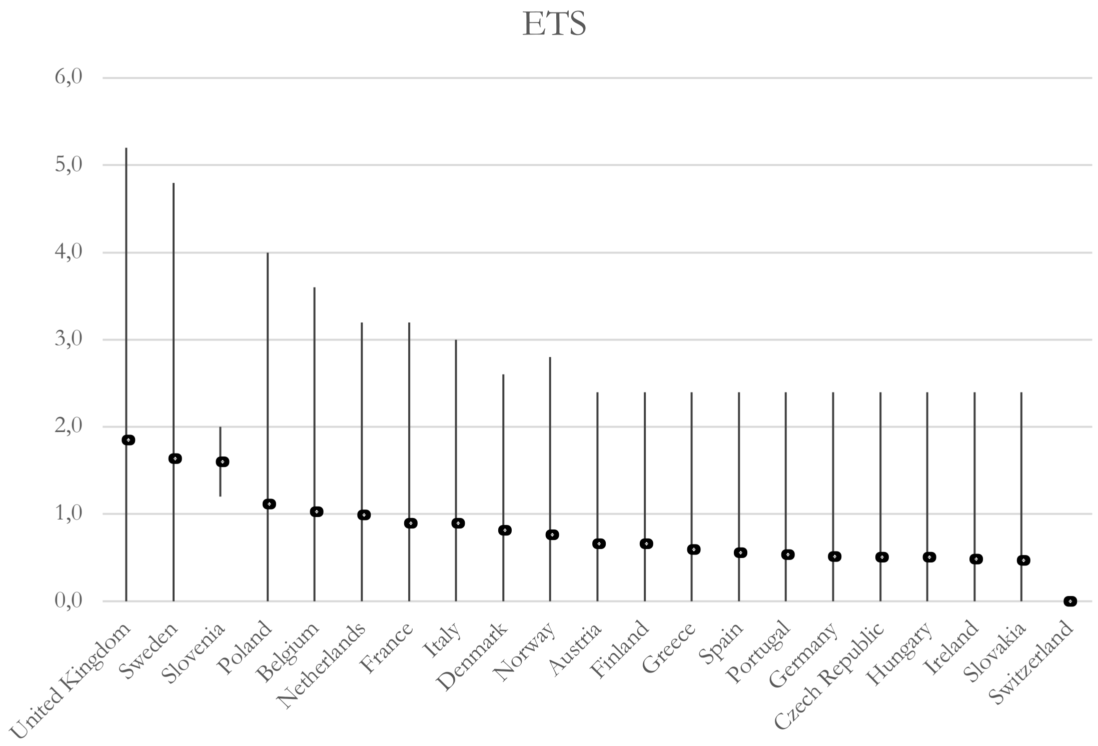


Figure 7– Maximum, minimum and average value of environmental stringency of FIT in the period 1994-2014

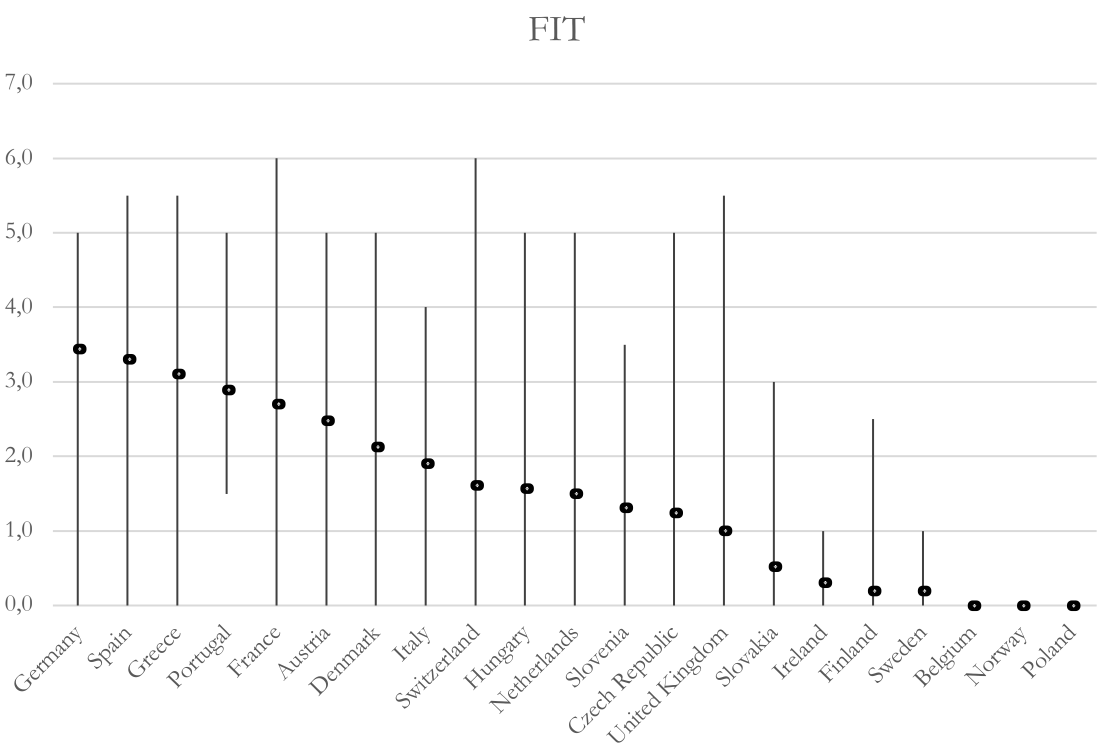
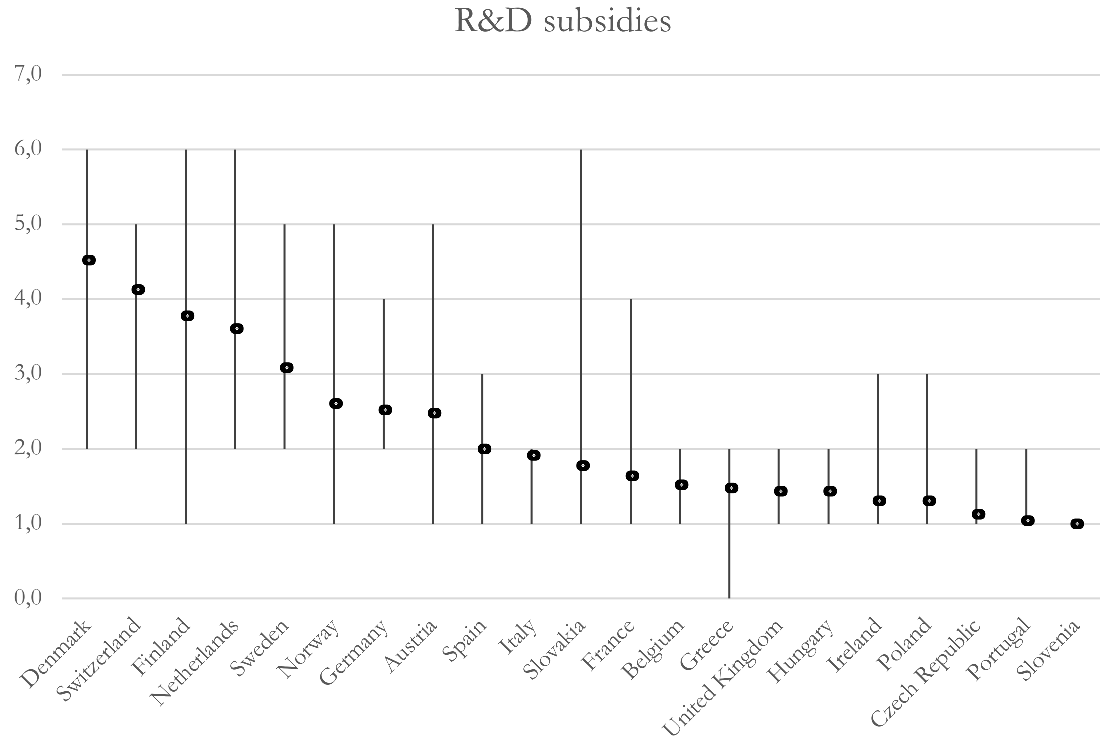


Figure 8– Maximum, minimum and average value of environmental stringency of R&D subisidies in the period 1994-2014



Tables

Table 1 – Distribution of cleantech/non-cleantech VC-backed companies by country

	Cleantech		Non-Cleantech	
	num.	%	num.	%
United Kingdom	357	*33.5%*	3118	*29.1%*
France	200	*18.8%*	2010	*18.8%*
Germany	170	*15.9%*	1831	*17.1%*
Finland	66	*6.2%*	633	*5.9%*
Spain	48	*4.5%*	675	*6.3%*
Netherlands	47	*4.4%*	448	*4.2%*
Sweden	40	*3.8%*	490	*4.6%*
Italy	35	*3.3%*	284	*2.7%*
Belgium	25	*2.3%*	307	*2.9%*
Denmark	22	*2.1%*	222	*2.1%*
Ireland	17	*1.6%*	261	*2.4%*
Poland	12	*1.1%*	141	*1.3%*
Norway	10	*0.9%*	37	*0.3%*
Czech Republic	6	*0.6%*	30	*0.3%*
Austria	5	*0.5%*	105	*1.0%*
Slovakia	4	*0.4%*	10	*0.1%*
Portugal	1	*0.1%*	67	*0.6%*
Slovenia	1	*0.1%*	3	*0.0%*
Greece	0	*0.0%*	14	*0.1%*
Hungary	0	*0.0%*	16	*0.1%*
Switzerland	0	*0.0%*	1	*0.0%*
Total	1066		10703	
Pearson chi2(20) = 50.5683 Pr = 0.000				

Table 2 – Distribution of cleantech/non-cleantech VC-backed companies by industry

	Cleantech		Non Cleantech		% of cleantech investments
Industry	num.	%	num.	%	
Manufacturing	470	*44.09%*	2556	*23.88%*	*15.53%*
Information and communication	131	*12.29%*	3957	*36.97%*	*3.20%*
Electricity, gas, steam and air cond.	94	*8.82%*	1243	*11.61%*	*7.03%*
Professional, scientific and tech.	93	*8.72%*	31	*0.29%*	*75.00%*
Water supply; sewerage, waste man.	78	*7.32%*	916	*8.56%*	*7.85%*
Wholesale and retail trade	48	*4.50%*	15	*0.14%*	*76.19%*
Construction	41	*3.85%*	622	*5.81%*	*6.18%*
Mining and quarrying	35	*3.28%*	85	*0.79%*	*29.17%*
Financial and insurance activities	29	*2.72%*	53	*0.50%*	*35.37%*
Administrative and support service	17	*1.59%*	378	*3.53%*	*4.30%*
Agriculture, forestry and fishing	12	*1.13%*	282	*2.63%*	*4.08%*
Transportation and storage	5	*0.47%*	30	*0.28%*	*14.29%*
Human health and social work act.	4	*0.38%*	95	*0.89%*	*4.04%*
Accommodation and food service act.	2	*0.19%*	83	*0.78%*	*2.35%*
Other service activities	2	*0.19%*	161	*1.50%*	*1.23%*
Arts, entertainment and recreation	2	*0.19%*	27	*0.25%*	*6.90%*
Education	1	*0.09%*	5	*0.05%*	*16.67%*
Public administration and defence	1	*0.09%*	54	*0.50%*	*1.82%*
Real estate activities	1	*0.09%*	64	*0.60%*	*1.54%*
Not classified	0	*0.00%*	46	*0.43%*	*0.00%*
Total	1066		10703		
Pearson chi2(19) = 30.128 Pr = 0.000					

Table 3 - Distribution of cleantech/non-cleantech companies by year of foundation

	Cleantech		Non Cleantech		% of cleantech investments
Period of establishment	num.	%	num.	%	
Before 2000	277	*25.98%*	2808	*26.24%*	*8.98%*
Between 2001 and 2007	441	*41.37%*	3958	*36.98%*	*10.03%*
After 2007	348	*32.65%*	3937	*36.78%*	*8.12%*
Total	1066		10703		
Pearson chi2(2) = 9.581 Pr = 0.008					

Table 4 – Characteristics of cleantech/non cleantech deals

	Cleantech	Non-cleantech	Overall
Number of deals	2 615	28 397	31 012
Perc. of total	*8.43%*	*91.57%*	
Amount invested per round (mean)	4 881.79	3 320.31	3 461.85
Age at first investment received (mean)	4.24***	3.53	3.60

*t-test H0: diifference from overall value - sig: *** = 99%, ** = 95%, * = 90%*

Table 5 - Characteristics of cleantech/non cleantech deals by type of investor

	IVC			GVC		
	Cleantech	Non-Cleantech	Overall	Cleantech	Non-Cleantech	Overall
Number of deals	2 234	24 892	27 126	381	3 505	3 886
Perc. of total	*8.24%*	*91.76%*		*9.80%*	*90.20%*	
Equity invested per round (mean)	5 478.44	3 603.22	3 769.60	2 113.36	1 718.76	1 760.58
Age at first investment received (mean)	4.17***	3.56	3.62	4.61*	3.34	3.47

*t-test H0: diifference from overall value - sig: *** = 99%, ** = 95%, * = 90%*

Table 6 – Description of policy stringency variables

Policy category	Policy indicator	Policy Instrument	Information considered for scoring
Market-based policy	ETS	Emission Trading Scheme(CO2)	Price of one CO2 allowance
Market-based policy	ETS	Renewable Energy Certificates Trading Scheme	% of renewable electricity that has to be procured annually
Market-based policy	ETS	Energy Certificate Emission trading Scheme	% of electricity saving that has to be delivered annually
Market-based policy	ETS	Emission trading Scheme for SO2	Price of one SO2 allowance
Market-based policy	Taxes	CO2 tax	Tax rate in EUR/ tonne
Market-based policy	Taxes	NOx Tax	Tax rate in EUR/ tonne
Market-based policy	Taxes	SOx Tax	Tax rate in EUR/ tonne
Market-based policy	FIT	Feed In Tariff for wind	EUR/kWh
Market-based policy	FIT	Feed In Premium for wind	EUR/kWh
Market-based policy	FIT	Feed In Tariff for solar	EUR/kWh
Market-based policy	FIT	Feed In Premium for solar	EUR/kWh
Non-market policy	Emission limit	Particulate Matter Emission Limit Value for newly built coal-fired plant	Value of Emission Limit in mg/m3
Non-market policy	Emission limit	SOx Emission Limit Value for newly built coal-fired plant	Value of Emission Limit in mg/m3
Non-market policy	Emission limit	NOx Emission Limit Value for newly built coal-fired plant	Value of Emission Limit in mg/m3
Non-market policy	R&D Subsidies	Government R&D expenditures for renewable energy technologies	Expressed as % of GDP

Table 7 – Correlation between numbers of cleantech VC deals and policy indicators at country level

	UK	Germany	France	Finalnd	Spain	Overall
Taxes	-0.53	-0.82***	0.66***	-0.56***	-0.11	-0.14**
Emission limits	0.69***	0.79***	0.73***	0.34	0.29	0.29***
ETS	0.72***	0.68***	0.55***	0.49*	0.02	0.34***
FIT	0.31	-0.40	0.20	-0.07	-0.15	0.20***
R&D subsidies	0.56**	0.62***	0.67***	0.35	0.00	-0.02
*sig: *** = 99%, ** = 95%, * = 90%*						

Table 8 - Correlation between numbers of cleantech deals and policy indicators by type of investor

	Overall	**IVC**	**GVC**
Taxes	-0.14**	-0.12*	-0.20***
Emission limits	0.29***	0.26***	0.36***
ETS	0.34***	0.34***	0.23***
FIT	0.20***	0.18***	0.24***
R&D subsidies	-0.02	-0.05	0.16**
*sig: *** = 99%, ** = 95%, * = 90%*			

Table 9 - Number of VC deals

	All sample	IVC-only	GVC-only	Co-invest
ETS	-0.162	-1.842*	-0.122	3.796***
	(1.58)	*(0.98)*	*(0.30)*	*(1.38)*
ETS^2	0.034	0.094	0.102**	-0.132
	(0.21)	*(0.14)*	*(0.04)*	*(0.16)*
Taxes	13.289**	16.556***	-1.573**	2.088
	(5.51)	*(4.26)*	*(0.76)*	*(3.05)*
$Taxes^2$	-2.283**	-3.134***	0.326**	-0.326
	(1.12)	*(0.97)*	*(0.15)*	*(0.62)*
Emission limit	-6.456**	-0.976	-1.150***	-2.510
	(2.86)	*(1.93)*	*(0.38)*	*(2.48)*
Emission $limit^2$	0.848**	0.039	0.145***	0.304
	(0.40)	*(0.27)*	*(0.05)*	*(0.31)*
FIT	0.360	0.606***	0.024	-0.519**
	(0.35)	*(0.23)*	*(0.07)*	*(0.22)*
R&D subsidies	0.405	0.965**	-0.206***	-0.295
	(0.58)	*(0.40)*	*(0.08)*	*(0.44)*
Oil price	0.064	0.089*	-0.005	0.015
	(0.08)	*(0.05)*	*(0.01)*	*(0.04)*
EPI	-0.041	0.198	-0.038	-0.156
	(0.37)	*(0.24)*	*(0.06)*	*(0.23)*
N. obs	213	213	213	213

Note: Estimates reported in the table are average marginal effects. The unit of observation is country-year data (country with at least 1 cleantech backed initiative in a given year). All regressions include control for country, year effect and for number of total backed companies in a given country/year. Robust standard errors clustered at country–year level in parentheses.

Table 10 - Amount invested

	All sample	IVC-only	GVC-only	Co-invest
	b/se	b/se	b/se	b/se
ETS	-0.280	-0.805*	3.494***	0.024
	(0.40)	*(0.46)*	*(0.68)*	*(0.75)*
ETS^2	0.038	0.105	-0.122	0.195**
	(0.06)	*(0.07)*	*(0.12)*	*(0.10)*
Taxes	1.339	5.361**	-2.046*	-4.856***
	(0.87)	*(2.41)*	*(1.07)*	*(1.87)*
Taxes^2	-0.321	-1.536**	0.911***	2.106***
	(0.20)	*(0.75)*	*(0.24)*	*(0.56)*
Emission limit	0.125	-0.063	8.654***	0.348**
	(0.10)	*(0.10)*	*(2.40)*	*(0.15)*
Emission limit^2	0.099	0.039	-0.060	-0.317***
	(0.08)	*(0.09)*	*(0.13)*	*(0.11)*
FIT	-0.222	0.914	-90.430***	-2.847*
	(0.79)	*(0.86)*	*(25.12)*	*(1.48)*
R&D subsidies	0.134	0.535**	-0.635***	-0.358
	(0.18)	*(0.22)*	*(0.22)*	*(0.25)*
Oil price	-0.014	0.031**	1.169***	0.001
	(0.02)	*(0.02)*	*(0.34)*	*(0.02)*
EPI	-0.042	-0.214*	0.353	0.022
	(0.10)	*(0.12)*	*(0.44)*	*(0.15)*
Equity invested	0.774***	0.817***	-0.028	-0.159
	(0.18)	*(0.21)*	*(0.18)*	*(0.27)*
N. obs	103	96	40	55

Appendix

Table - Appendix A

	VICO		VICO companies with business description	
	n	%	n	%
United Kingdom	5185	26.71%	3475	29.53%
France	3426	17.65%	2210	18.78%
Germany	2804	14.44%	2001	17.00%
Sweden	1182	6.09%	530	4.50%
Spain	1247	6.42%	723	6.14%
Netherlands	882	4.54%	495	4.21%
Denmark	576	2.97%	244	2.07%
Ireland	570	2.94%	278	2.36%
Finland	988	5.09%	699	5.94%
Italy	582	3.00%	319	2.71%
Portugal	306	1.58%	68	0.58%
Poland	381	1.96%	153	1.30%
Hungary	209	1.08%	16	0.14%
Austria	300	1.55%	110	0.93%
Belgium	469	2.42%	332	2.82%
Norway	101	0.52%	47	0.40%
Czech Republic	85	0.44%	36	0.31%
Greece	60	0.31%	14	0.12%
Slovakia	40	0.21%	14	0.12%
Slovenia	19	0.10%	4	0.03%
Switzerland	3	0.02%	1	0.01%
Total	***19415***		***11769***	
Pearson chi2(21)=479.94, Pr=0.000				

Table - Appendix B

	VICO		VICO companies with business description	
	n	%	n	%
Information and communication	6678	34.40%	4088	34.74%
Manufacturing	4460	22.97%	3026	25.71%
Professional, scientific and tech.	1528	7.87%	994	8.45%
Wholesale and retail trade	1031	5.31%	663	5.63%
Financial and insurance activities	663	3.41%	395	3.36%
Administrative and support service	479	2.47%	294	2.50%
Human health and social work act.	250	1.29%	163	1.38%
Electricity, gas, steam and air cond.	189	0.97%	124	1.05%
Construction	162	0.83%	120	1.02%
Transportation and storage	149	0.77%	99	0.84%
Accommodation and food service act.	145	0.75%	85	0.72%
Mining and quarrying	130	0.67%	82	0.70%
Education	103	0.53%	55	0.47%
Arts, entertainment and recreation	102	0.53%	65	0.55%
Water supply; sewerage, waste man.	94	0.48%	63	0.54%
Real estate activities	70	0.36%	46	0.39%
Other service activities	65	0.33%	29	0.25%
Agriculture, forestry and fishing	57	0.29%	35	0.30%
Public administration and defence	18	0.09%	6	0.05%
Not classified	3042	15.67%	1337	11.36%
Total	***19415***		***11769***	
Pearson chi2(19)=200.17, Pr=0.000				

Table - Appendix C

Period of establishment	VICO		VICO companies with business description	
	n	%	n	%
Until 2000	4684	24.13%	3085	26.21%
Between 2001 and 2007	6369	32.80%	4399	37.38%
After 2007	8362	43.07%	4285	36.41%
Total	***19415***	***100%***	***11769***	***100%***
Pearson chi2(2)=217.51, Pr=0.000				

- Appendix D

Taxes					
	average	first obs.	last obs.	min obs.	max obs.
Austria	1.13	1.00	1.00	1.00	1.50
Belgium	1.03	1.00	0.75	0.75	1.25
Czech Republic	1.84	1.75	1.75	1.50	2.25
Denmark	2.09	0.50	3.75	0.50	4.00
Finland	1.08	1.25	0.75	0.75	1.50
France	1.71	1.25	2.75	1.25	2.75
Germany	1.20	1.25	1.00	0.75	1.50
Greece	0.98	0.50	0.75	0.50	1.50
Hungary	1.55	0.25	2.75	0.25	3.00
Ireland	1.04	1.25	0.75	0.75	1.25
Italy	2.05	1.25	2.25	1.25	2.75
Netherlands	1.07	1.00	0.75	0.75	1.50
Norway	1.38	0.25	2.50	0.25	2.50
Poland	2.14	1.25	2.50	1.00	3.50
Portugal	1.15	1.25	0.75	0.75	1.50
Slovakia	1.90	1.25	1.75	1.25	2.50
Slovenia	0.88	1.00	0.75	0.75	1.25
Spain	1.71	1.00	1.75	1.00	2.25
Sweden	2.29	0.50	2.25	0.50	2.75
Switzerland	1.64	1.50	2.50	1.00	2.75
United Kingdom	1.36	1.25	1.25	1.00	1.50

Emission limit					
	average	first obs.	last obs.	min obs.	max obs.
Austria	1.13	1.00	1.00	1.00	1.50
Belgium	1.03	1.00	0.75	0.75	1.25
Czech Republic	1.84	1.75	1.75	1.50	2.25
Denmark	2.09	0.50	3.75	0.50	4.00
Finland	1.08	1.25	0.75	0.75	1.50
France	1.71	1.25	2.75	1.25	2.75
Germany	1.20	1.25	1.00	0.75	1.50
Greece	0.98	0.50	0.75	0.50	1.50
Hungary	1.55	0.25	2.75	0.25	3.00
Ireland	1.04	1.25	0.75	0.75	1.25
Italy	2.05	1.25	2.25	1.25	2.75
Netherlands	1.07	1.00	0.75	0.75	1.50
Norway	1.38	0.25	2.50	0.25	2.50
Poland	2.14	1.25	2.50	1.00	3.50
Portugal	1.15	1.25	0.75	0.75	1.50
Slovakia	1.90	1.25	1.75	1.25	2.50

Slovenia	0.88	1.00	0.75	0.75	1.25
Spain	1.71	1.00	1.75	1.00	2.25
Sweden	2.29	0.50	2.25	0.50	2.75
Switzerland	1.64	1.50	2.50	1.00	2.75
United Kingdom	1.36	1.25	1.25	1.00	1.50

	ETS				
	average	first obs.	last obs.	min obs.	max obs.
Austria	1.13	1.00	1.00	1.00	1.50
Belgium	1.03	1.00	0.75	0.75	1.25
Czech Republic	1.84	1.75	1.75	1.50	2.25
Denmark	2.09	0.50	3.75	0.50	4.00
Finland	1.08	1.25	0.75	0.75	1.50
France	1.71	1.25	2.75	1.25	2.75
Germany	1.20	1.25	1.00	0.75	1.50
Greece	0.98	0.50	0.75	0.50	1.50
Hungary	1.55	0.25	2.75	0.25	3.00
Ireland	1.04	1.25	0.75	0.75	1.25
Italy	2.05	1.25	2.25	1.25	2.75
Netherlands	1.07	1.00	0.75	0.75	1.50
Norway	1.38	0.25	2.50	0.25	2.50
Poland	2.14	1.25	2.50	1.00	3.50
Portugal	1.15	1.25	0.75	0.75	1.50
Slovakia	1.90	1.25	1.75	1.25	2.50
Slovenia	0.88	1.00	0.75	0.75	1.25
Spain	1.71	1.00	1.75	1.00	2.25
Sweden	2.29	0.50	2.25	0.50	2.75
Switzerland	1.64	1.50	2.50	1.00	2.75
United Kingdom	1.36	1.25	1.25	1.00	1.50

	FIT				
	average	first obs.	last obs.	min obs.	max obs.
Austria	2.48	0.00	3.50	0.00	5.00
Belgium	0.00	0.00	0.00	0.00	0.00
Czech Republic	1.24	0.00	3.50	0.00	5.00
Denmark	2.13	0.00	2.00	0.00	5.00
Finland	0.20	0.00	2.50	0.00	2.50
France	2.70	0.00	3.00	0.00	6.00
Germany	3.44	0.00	2.00	0.00	5.00
Greece	3.11	0.00	4.50	0.00	5.50
Hungary	1.57	0.00	2.50	0.00	5.00
Ireland	0.30	0.00	1.00	0.00	1.00
Italy	1.90	0.00	4.00	0.00	4.00
Netherlands	1.50	0.00	4.00	0.00	5.00

Norway	0.00	0.00	0.00	0.00	0.00
Poland	0.00	0.00	0.00	0.00	0.00
Portugal	2.89	2.00	3.00	1.50	5.00
Slovakia	0.52	0.00	3.00	0.00	3.00
Slovenia	1.31	0.00	3.50	0.00	3.50
Spain	3.30	0.00	2.50	0.00	5.50
Sweden	0.20	0.00	0.00	0.00	1.00
Switzerland	1.61	0.00	4.50	0.00	6.00
United Kingdom	1.00	0.00	4.50	0.00	5.50

	R&D subsidies				
	average	first obs.	last obs.	min obs.	max obs.
Austria	2.48	1.00	4.00	1.00	5.00
Belgium	1.52	1.00	2.00	1.00	2.00
Czech Republic	1.13	1.00	1.00	1.00	2.00
Denmark	4.52	3.00	6.00	2.00	6.00
Finland	3.78	2.00	6.00	1.00	6.00
France	1.64	1.00	3.00	1.00	4.00
Germany	2.52	2.00	4.00	2.00	4.00
Greece	1.48	2.00	1.00	0.00	2.00
Hungary	1.43	1.00	2.00	1.00	2.00
Ireland	1.30	1.00	2.00	1.00	3.00
Italy	1.92	2.00	2.00	1.00	2.00
Netherlands	3.61	5.00	5.00	2.00	6.00
Norway	2.61	2.00	5.00	1.00	5.00
Poland	1.30	1.00	2.00	1.00	3.00
Portugal	1.04	1.00	1.00	1.00	2.00
Slovakia	1.78	1.00	6.00	1.00	6.00
Slovenia	1.00	1.00	1.00	1.00	1.00
Spain	2.00	2.00	1.00	1.00	3.00
Sweden	3.09	3.00	4.00	2.00	5.00
Switzerland	4.13	5.00	4.00	2.00	5.00
United Kingdom	1.44	2.00	2.00	1.00	2.00