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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 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 firms among a comprehensive database of invested companies by venture capital funds. We then analyse the relationship between the stringency level of environmental policies and venture capital investments in cleantech companies operating in 21 OECD countries. We explore whether policies have a differential effect in fostering institutional venture capital (IVC) and governmental venture capital (GVC) investments. Our findings indicate that IVC investments in cleantech are mainly driven by the level of environmental taxes and market pull mechanisms as feed-in tariffs and R&D subsidies, whereas GVC investment decisions are driven by a country's commitment to reach environmental targets. Moreover, our results suggest that GVC funds are developed as an alternative incentive mechanism: when direct incentives applied by governments are less developed, the relevance of GVC investments increases, which suggests a substitution effect between the two forms of intervention.

Keywords: Cleantech, environmental policies, venture capital, machine learning, environmental finance

JEL Codes: G24, G30, H23

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1 Introduction

In recent years, scholarly interest in financing innovation for mitigating climate change has significantly grown. In 2015, at the COP 21 meeting in Paris, 95 countries signed the first ever real, global, legally binding climate deal. The United Nations Framework Convention on Climate Change[1] addresses crucial areas necessary to combat climate change, identifying climate finance as an effective instrument to support mitigation and adaptation actions through public, private and alternative sources of financing.[2]

The final version of the Paris Agreement 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 the 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 (Pernick and Wilder, 2007; O'Rourke, 2009; Caprotti, 2012; Migendt *et al.*, 2017).

One of the most relevant issues for governments refers to the strategy to foster innovation in cleantech. However, this is not an easy task. Typically, the development of cleantech technologies is borne heavily by small and innovative companies (Hockerts and Wüstenhagen, 2010) founded by entrepreneurs, which commonly have technical know-how but lack the financial resources and managerial know-how (Veugelers and Cassiman, 1999; Bhide, 2000).

Venture capitalists (VCs, henceforth) have developed a strong reputation for funding promising technology companies. Despite academic literature demonstrating that the role of VC promotes the development of innovative technologies (Barry *et al.*, 1990; Hellmann and Puri, 2002), only a 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 characterised by the public's good nature (Cumming *et al.*, 2016) and high-capital intensity along many phases of product development/commercialisation (Wustenhagen and Teppo, 2006; Bürer and Wüstenhagen, 2009). These characteristics reduce investment opportunities and increase risk aversion of institutional investors, compared with other innovative sectors (Ghosh and Nanda, 2010; Chassot *et al.*, 2014; Polzin, 2017).

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[1] http://bigpicture.unfccc.int/#content-the-paris-agreemen.

[2] Notwithstanding the Convention, the projections issued by the International Energy Agency ("Global Energy outlook 2017", 2017, https://www.iea.org/weo/) confirm the increasing trend of primary energy demand at world level (+10% between 2016 and 2025) and the primary role of fossil fuels as a global source of energy: the share will remain well above 75% in 2025.

Given this peculiar risk profile of cleantech companies, governments can play a crucial role in designing environmental policies for both demand or supply aimed at reducing the risk profile of these technologies and fostering 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 is scarce evidence on the role of environmental policies in fostering VC investments in cleantech technologies. In this paper, we aim to fill this gap, adding to previous literature through several dimensions.

Firstly, we explore the role of the stringency of regulation in favouring VC investments in cleantech companies. In fact, according to the Porter Hypothesis (PoH, henceforth) (Porter, 1991; Porter and Linde, 1995), the stringency of regulation is a crucial element: more stringent environmental policies incentivise innovation, efficiency improvements and company-reorganization, leading to higher productivity. Johnstone *et al.* (2010) have studied the features that can positively affect the effectiveness of regulation policies: the stringency of regulation can produce incentives to innovate and the stability of general norms and standards can reduce the uncertainty of investment projects. Large parts of previous studies (Criscuolo and Menon, 2015; Polzin *et al.*, 2015; Cumming *et al.*, 2016) did not analyse the stringency level and the evolution over time but only the presence of a certain category of environmental policies in favouring VC investments.

Secondly, we aim to explore the role of VC heterogeneity in promoting cleantech investments. VCs funds can be classified according to their ownership structure: independent and private Venture Capital funds (IVC, henceforth) owned by private investors coexist with Governmental VC funds (GVC, henceforth), mainly owned by public entities. Previous literature evidences the different roles of IVC and GVC: the former has superior selection know-how and obtains higher returns on backed companies (Grilli and Murtinu, 2014), whereas GVCs may overcome market failure alleviating the equity gap and stimulating the development of a private VC industry (Colombo *et al.*, 2014). Moreover, GVCs' investments have a signalling effect: entrepreneurial companies backed by GVCs increase the probability of being invested in by IVCs (Guerini and Quas, 2016). In this context, responses of GVCs and IVCs to environmental policies may differ: if PoH is verified, environmental policies can promote sustainable innovation and drive IVCs' investments to the cleantech sector. On the other hand, governments can support cleantech through indirect support to investments (i.e., environmental policies), or can directly invest though GVC funds with a substitution effect.

Thirdly, but not less important, our contribution is empirical, as we develop a robust methodology to identify cleantech companies. In this work, we build a fully replicable methodology based on a supervised machine learning algorithm. Starting from the full sample of VC-backed companies, the algorithm identifies cleantech and non-cleantech companies. This approach benefits from the transparency of the methodology applied and the fully replicability on the sample utilised.

Our findings indicate that GVCs' and IVCs' investment in the cleantech sector are driven by different environmental policies. IVC investments react positively to mechanisms able to increase revenues and, with non-monotone behaviour, to instruments that impose a pollution cost on companies. On the contrary, GVCs and indirect support mechanisms, such as subsides and tariffs, result in substitutes and GVCs seems to support cleantech initiatives in countries where the implementation of environmental policies is more stringent. The evidence that private and governmental VCs show a differential relationship with environmental policies provides strong support to the relevance of the analysis on VC heterogeneity in evaluating the effect of policies in the financing of the cleantech sector.

The article is organised as follows: in Section 2, we discuss the literature on the role of VC in promoting cleantech technologies, we present the conceptual background and we derive our research hypotheses. Section 3 describes the dataset, the sample used in our study and the econometric model. Section 4 discusses the results of the empirical analysis and Section 5 the conclusions and the policy implications.

2 Conceptual Background

In recent years, the debate on strategies to reach climate targets is crossing over academic and governmental boundaries and is becoming prominent in most OECD media. Nonetheless, Bloomberg new Energy Finance report (BENF) data from 2018 shows that governments around the world are not able to increase financial sources for innovation and R&D in the cleantech industry: the amount invested varies between 4.5 and 5 billion US dollars since 2009. If direct public investment remains constant, also due to governmental budget constraints, the role of other forms of financing become crucial.[3]

Traditionally, a crucial channel of financing innovative companies is the venture capital (VC), which provides the financial sources characterised by a high-risk profile (Samila and Sorenson, 2007; Rin *et al.*, 2013), thanks to

[3]The investment gaps related to sustainable technologies represent a key issue for governments. In the final report (https://ec.europa.eu/info/publications/180131-sustainable-finance-report_en), the EU High-Level Group on Sustainable Finance (HLEG) defined a roadmap to shift to a sustainable financing. In the roadmap, the role for government is essential, as it must ensure that price signals in capital markets reflect both positive and negative externalities, with the aim of determining a 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 recognises that these will only fulfill their full potential if they are matched with policy changes in sectors able to mitigate the effect of climate change.

their ability in the screening process (Yuk-Shee, 1983; Tyebjee and Bruno, 1984; Amit *et al.*, 1998) as well as in the post-investment monitoring of the portfolio firm (Kaplan and Stromberg, 2003; Lerner, 1995; Sahlman, 1990). The academic literature demonstrates the relevance of VC in commercialising breakthrough technologies (Barry *et al.*, 1990; Hellmann and Puri, 2002) providing value-adding services (**bi56**; Sebastiani, 2002), such as coaching, mentoring and access to investment bankers, which could have signalling 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 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, compared with other innovative sectors (Ghosh and Nanda, 2010; Chassot *et al.*, 2014; Polzin, 2017). Academics document multiple factors that make it much more challenging for cleantech start-ups to obtain 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 additional user does 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 *et al.*, 2016).

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, in addition, it seems hard to manage or even move outside their area of influence. In the cleantech industry, the regulatory risk is relevant, and the potential impact is huge. Environmental markets present the textbook case of market failure and the need for government intervention.[4] Nonetheless, Randjelovic *et al.* (2003) identified the implementation of environmental policies as a key factor for fostering the development of new green VC funds.

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, the analyses in this particular segment are still scarce. Only few studies in recent years focus their attention on VC investments in the cleantech industry, providing interesting, albeit not conclusive,

[4]Markets does not adequately price environmental effects, and this failure can lead to economically viable but socially undesirable economic activity. Sir Stern (2008) 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.

evidence. Cumming *et al.* (2016) explores the relevance of country/market characteristics in influencing VC investments in cleantech: they find 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 the holding period of green companies is longer than average VC investments. Moreover, they provide differences in VC response within the cleantech segment: investments in cleantech fundamental hardware materials, chemicals and processes tend to lose money and VC tends to reduce capital allocation to these asset classes, shifting investments to cleantech software able to remunerate capital to early investors. On the other hand, Mrkajic *et al.* (2017) find entrepreneurs who run a green business and position their venture in a green sector are more likely to receive VC funding. Within entrepreneurial finance literature, several authors explore the role of crowdfunding in fostering investments in sustainable initiatives. Cumming *et al.* (2017) study the role of market momentum, a country's cultural characteristics and campaign characteristics to identify the differences between cleantech and non-cleantech crowdfunding campaigns. They find that cleantech campaigns are more common when oil prices are rising and in countries with low levels of individualism. Moreover, cleantech campaigns utilise more soft information to promote the initiative, consistent with the view that cleantech projects are perceived to be riskier and potential investors would have to receive more information to sustain these types of investments. Vismara (2019) analyses 345 equity crowdfunding campaigns in 2014 and 2015, finding that, although sustainable initiatives per se do not increase the probability of success of the equity offering, it does attract more "restricted investors" (members of the crowd), with higher sensitivity to a community logic. Hörisch and Tenner (2020) analyse the 320 campaigns to raise equity and debt launched by four platforms, two based in Germany and two in the USA. The authors identify social and environmental orientation of the projects to investigate the impact of these characteristics on the probability of success, numbers of founders and the amount collected. They find that environmental characteristics increase the probability of success and that their influence is mediated by the number of funders. In contrast, social orientation does not increase neither the probability nor the number of investors attracted by the campaign. Finally, Bergmann *et al.* (2021) provide analysis of the European public's perception of the viability of crowdfunding as a vehicle for renewable energy projects, outlining the opinions of 473 individuals from 30 countries. Authors find that for respondents, growth in crowdfunding was believed to be significantly more likely for renewable energy projects than for investments in general, and that this perception is stronger for those with relevant prior familiarity and engagement with crowdfunding platforms.

Despite the relevant numbers of studies on the relationship between equity financing and cleantech, the impact of policy implementation on investment decisions in cleantech companies by VC funds is largely uncovered. To the best of our knowledge, only Criscuolo and Menon (2015) and Cojoianu *et al.* (2020) focus on the role of environmental policies in fostering the VC investments in cleantech. Criscuolo and Menon (2015) analyse 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 tariffs, with long-term perspective and the ability to reduce the volatility of revenues, are effective instruments for favouring VC investments, whereas relative short-term fiscal policies are not. However, it is important to highlight that this study focuses its analysis only on the presence of environmental policies for VC and not the level of policy stringency. The mere presence of a policy, proxied by dummy variables or by the number of policies in a country, is not able to capture the effect of stringency level of policies between countries and over time. In a recent work, Cojoianu *et al.* (2020) utilise a novel measure of the stringency of cross-country environmental policy developed by the OECD (Botta and Kožìluk, 2014).[5] Authors underline that the OECD policy stringency index and its subcomponents is superior to proxies based on either dummy measures or indeed measures based on a count of policies. Based on the Crunchbase classification, authors identify green, grey and brown initiatives backed by VCs or companies seeking equity funds. They show that green start-up financing is negatively related to the stringency of environmental taxes and positively and significantly related to the generosity of feed-in tariffs, as well as to the stringency of emission standards regulations. Moreover, Cojoianu *et al.* (2020) find a counterintuitive exception: the generosity of green R&D subsidies is negatively related to new green start-up entry, discouraging risky start-up ventures.

Previous studies underline the relevance of mechanisms able to incentivise investments throughout the revenue channel: feed-in tariffs increase and stabilise revenues, fostering the development of cleantech initiatives. Nonetheless, evidence on the relationship between VC investments in the cleantech/green sector and the other types of environmental policies is not conclusive. The impact of R&D subsidies on green VC investment in Criscuolo and Menon (2015) is positive, whereas Cojoianu *et al.* (2020) find the opposite. Both show the positive impact, albeit limited, of regulation quantity mechanisms, while contrary evidence is found for environmental taxes, even if the aim of the two instruments coincides: internalise the cost of polluting through a tax payment or through more stringent product/process requirements.

[5]Botta and Kožìluk (2014) show that during the last few decades in almost all European countries, we observe an increase in the environmental requirements in almost all industries. Moreover, they provide evidence that not only the average level of policy stringency increased in all EU countries between 1990 and 2015, but also the variance between countries surges.

This mixed evidence found in previous literature suggests the need for a deeper analysis of this issue. A possible explanation refers to the non-linear impact of the implementation of environmental policies on the behaviour of economic agents. Several authors find a nonlinear relationship between introduction and a policy's stringency level on a company's response. Krass *et al.* (2013) demonstrate that, in the context of monopoly, an increase in environmental tax does not encourage, per se, companies to choose more sustainable technologies. Environmental tax increases may determine a non-monotone technology choice: sufficiently high tax rates may induce the choice of dirtier rather than cleaner technologies, whereas, for a medium level of environmental stringency, the socially optimal tax level induces the choice of green technology. Moreover, they find that subsidies are efficient instruments to encourage firms to select clean technology. The regulator, combining an environmental policy that uses taxes, subsidies and rebates, can reach the highest possible welfare for society through the implementation of green technology. Also, Leiter *et al.* (2011) show that the level of environmental stringency does not affect investments with a linear relationship. Above a specific stringency level, the costs for complying with environmental standards are well above the corresponding benefits. Authors find a positive and significant coefficient of the non-quadratic regulation terms, supporting the Porter hypothesis. Conversely, the significantly negative parameter estimates of the squared regulation terms imply that the positive impact of stringency levels on investments is not independent of the policy stringency level.

An additional explanation of mixed results by previous literature is related to the fact that previous studies have not taken into account the VC heterogeneity, that is, disentangling the effect of policies in fostering the investments separately for IVC and GVC investors. This heterogeneity may help in explaining why previous studies obtained mixed results about the role of policies in fostering VC investments. The rationale behind the government intervention in the cleantech segment through policies is primarily directed to correcting supply failures in VC markets. Mazzucato (2011), Auerswald and Branscomb (2003) show that IVCs often do 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 well-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 gas (GHG) emissions. As a consequence, environmental polices able to reduce the volatility of revenues such as feed-in tariffs and to support R&D through subsidies may incentivise IVC investments in this segment, reducing the investment risk profile and increasing the project return, which are two relevant investment drivers for IVCs. At the same time, IVCs investment strategy may follow a company's reaction to the stringency of environmental policies according to a non-linear pattern: within certain levels, the higher the stringency, the higher the investment flow to cleantech, but a very high level of policy stringency may discourage IVC investments.

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

> H1: Feed-in tariffs and subsidies foster IVC investments in the cleantech sector.
>
> H2: The relationship between the stringency of environmental taxes, emissions standards/limits and IVC investments in cleantech initiatives is not monotonic: a stringency level that is too high reduces investment flow by IVCs.

On the other hand, governments may play a role in fostering cleantech initiatives through direct intervention, that is, by GVC funds investing directly in cleantech companies. Previous studies evidence differences in investment strategy according to the type of VC. Colombo *et al.* (2016) show that, in contrast to 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" (pp. 11–12). Then, GVC plays an important role in underdeveloped seed and early-stage markets: the signalling effect of early-stage companies selected and invested in by GVC may reduce the risk aversion of IVC funds, characterised by huge asymmetry of information and a lack of specific industry knowledge. The signalling role of GVC is also investigated by Guerini and Quas (2016): the authors show that companies backed by GVC increase the likelihood of receiving funds from IVCs. The receipt of GVC reduces information asymmetries that typically affect high-tech entrepreneurial companies and facilitates their access to the IVC market.

Direct investments made by GVC in cleantech companies and indirect instruments to foster private investments, such as feed-in tariffs and R&D subsidies, may represent, thus, instruments of substitution to which governments resort to, in order to support cleantech initiatives. Clearly, rational governments should avoid any overlap of instruments with a common target: for example, in the presence of GVC funds, we expect that the public budget will be divided between public subsidies or feed-in tariff contributions and private equity capital toward cleantech initiatives. In addition, since GVC investment strategies differ with respect to those of IVC, the level of environmental policy stringency may affect GVC and IVC investments differently. On the one hand, GVC may act as a private investment fund, following the non-monotonic relationship discussed previously for IVCs. On the other hand, GVC investment strategies may follow a linear relationship with the level of policy stringency: the more the government is actively involved in contrasting climate change with stringent policies, the more the GVC may directly support cleantech initiatives.

Based on the above analysis, we put forward these two research hypotheses:

> H3: Feed-in tariffs and subsidies reduce GVC investments in the cleantech sector.

> H4: The relationship between the stringency of environmental taxes, emissions standards/limits and GVC investments in cleantech initiatives is monotonic: a high stringency level increases investment flow from GVCs.

3 Data and Model

3.1 VC Investments in Cleantech Initiatives

The identification of backed cleantech companies comes 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 Programme of the European Commission. 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). The VICO database includes data observed from 1994 to 2014 on invested companies at deal level located in 31 OECD countries. For each round of investment made by a VC, VICO includes information on the backed company and on the 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).[6]

The VICO dataset includes multiple types of VC deals: institutional, corporate, governmental, banking, business angel; we delimited our analysis focusing on independent professional investors, that is, Institutional VCs (IVC) and Governmental VCs (GVC).

[6]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 Marti (2011).

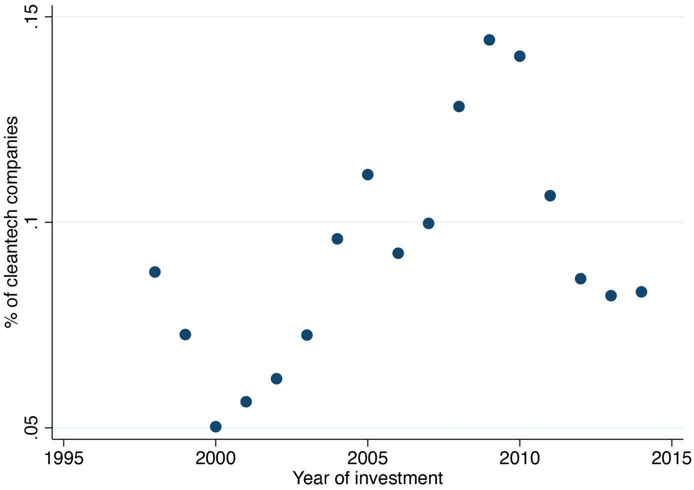

Figure 1

We then complemented the VICO database with multiple quantitative indicators of the stringency of government environmental policies, based on research by Botta and Kožìluk (2014) and the OECD database. The policy database developed by the OECD covers the period from 1998 to 2015, but does not include all countries represented in VICO; we then excluded 10 countries[7] out of 31, which account for 6.55% of the total companies in the VICO database. Moreover, we focused on the 1998–2014 period, thus excluding VC investments in VICO until 1997, covered by both VICO and the policy database. Secondly, in order to define cleantech companies, we employed a machine-learning algorithm based on the extensive business description of a company as detailed in the Online Appendix (Online Appendix A).

Figure 1 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 VCs backed over time. During the period analysed, the relative importance of this segment increased over time: between 1998 and 2003, on average it represents 6.42% of the entire sample, whereas in the 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 findings in other works: Migendt *et al.* (2017) show that renewable investments, at world level, reached their peak in 2011 and then dropped in subsequent years.

[7]Bulgaria, Croatia, Cyprus, Estonia, Israel, Latvia, Lithuania, Luxembourg, Malta, and Romania.

Table 1: Distribution of Cleantech/Non-cleantech VC-backed Companies by Country.

	Cleantech		Non-cleantech		% of cleantech investments
	N	%	N	%	%
United Kingdom	357	33.50	3,118	29.10	11.45
France	200	18.80	2,010	18.80	9.95
Germany	170	15.90	1,831	17.10	9.28
Finland	66	6.20	633	5.90	10.43
Spain	48	4.50	675	6.30	7.11
Netherlands	47	4.40	448	4.20	10.49
Sweden	40	3.80	490	4.60	8.16
Italy	35	3.30	284	2.70	12.32
Belgium	25	2.30	307	2.90	8.14
Denmark	22	2.10	222	2.10	9.91
Ireland	17	1.60	261	2.40	6.51
Poland	12	1.10	141	1.30	8.51
Norway	10	0.90	37	0.30	27.03
Czech Republic	6	0.60	30	0.30	20.00
Austria	5	0.50	105	1.00	4.76
Slovakia	4	0.40	10	0.10	40.00
Portugal	1	0.10	67	0.60	1.49
Slovenia	1	0.10	3	0.00	33.33
Greece	0	0.00	14	0.10	0.00
Hungary	0	0.00	16	0.10	0.00
Switzerland	0	0.00	1	0.00	0.00
Total	1,066		10,703		

Note: Pearson chi2(20) = 50.5683, Pr = 0.000.

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 the VC market is already well-developed (i.e., UK, France, Germany). For both cleantech and non-cleantech companies, we observe a high concentration in a small number of countries: the first ten countries (United Kingdom, France, Germany Finland, Spain, Netherland, Italy, Sweden, Belgium and Denmark) account for 93.7% of the total number of cleantech companies and 94.8% for the non-cleantech sample. The last column shows the relative weight of cleantech companies within each country, that is, the number of cleantech companies over the total number of VC-backed companies operating in the same country: descriptive statistics suggest that the countries in which the percentage of cleantech companies is higher are Slovakia, Slovenia, Norway and Czech Republic. Nevertheless, it is important to highlight that the low number of VC-backed companies included in our sample in these countries may influence the result.

Table 2 shows the sectoral distribution of cleantech/non cleantech companies. We can observe that cleantech companies are distributed across many sectors: 44.1% are classified within the general manufacturing sector and, surprisingly, only 8.8% of cleantech companies are included in the electricity & gas sector, one of the most relevant targets for clean technologies. The last column shows the relative weight of cleantech companies within each sector, that is, the number of cleantech companies from the total number of VC-backed companies operating in the same sector. Professional and scientific activities and wholesale and retail sectors show a relatively high proportion of cleantech initiatives. The former includes a wide range of different companies involved, for instance, in providing environmental solutions to increase customer's energy efficiency, biotech and biopharmaceutic research companies or initiatives in the field of water and air treatment. The latter includes companies involved in developing products based on recycled or sustainable raw materials. Not surprisingly in sectors characterised by high energy/natural resource usage intensity (electricity and gas, water, mining and construction), we observe a rather high proportion of cleantech initiatives backed by VCs. Conversely, even if the IT industry is the second sector in terms of the number of cleantech initiatives backed (131), the relative weight of backed cleantech companies within the sector is limited (3.20%).

The distribution of VC-backed companies reported in Table 3 exhibits differences between cleantech and non-cleantech companies by their year of foundation. Based on the trend of investment in cleantech companies, the dataset is divided in three subperiods: a period of relevant increase in VC investment in cleantech between 2004 and 2010, subsequent and antecedent to two periods of less attention to this segment. Results indicate a higher percentage of VC-backed cleantech companies (83.02%) founded before 2010, whereas in the same period, 75.8% of non-cleantech companies were founded. Moreover, in this period, the % of cleantech companies from the total number of companies backed by VC founded in the same period is higher: 10.03% compared to companies founded before 2001 (8.98%) and companies founded after 2007 (8.12%).

Table 4 summarises the characteristics of cleantech and non-cleantech deals in terms of numbers of investments received, amounts invested per deal and age of companies at the time of the first investment. In terms of deals, the cleantech segment represents 8.44% of the entire sample: 2,615 cleantech deals out of 31,012 associated with companies with business description. According to Cumming *et al.* (2016), cleantech initiatives tend to be very capital intensive and face greater technology risks than typical VC investments. Accordingly, data in Table 4 show that the average amount invested in each deal is greater than the average based on the whole sample, confirming the capital intensity

Table 2: Distribution of Cleantech/Non-cleantech VC-backed Companies by Industry.

Industry	Cleantech		Non-cleantech		% of cleantech investments
	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 management	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 services	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 activities	4	0.38	95	0.89	4.04
Accommodation and food service activities	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	1,066		10,703		

Note: Pearson chi2(19) = 30.128, Pr = 0.000.

of this segment, even though this difference is not statistically significant. 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,

Table 3: Distribution of Cleantech/Non-cleantech Companies by Year of Foundation.

Period of establishment	Cleantech		Non-cleantech		% of cleantech investments
	Num.	%	Num.	%	%
Before 2004	469	44.00	4861	45.42	8.80
Between 2004 and 2010	416	39.02	3251	30.37	11.34
After 2010	181	16.98	2591	24.21	6.53
Total	1,066		10,703		

Note: Pearson chi2(2) = 45.2189, Pr = 0.000.

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 time first investment received (mean)	4.24***	3.53	3.60

Note: t-test H0: difference from overall value – sig: ***99%, **95%, *90%.

which is found to be statistically significant at a 1% confidence level, seems to confirm the higher risk profile of cleantech companies, which forces VCs to invest in companies with higher maturity in order to reduce this risk.

Table 5 reports the characteristics of VC investments by category of investors. The data shows that GVCs invest more frequently than IVCs in cleantech technologies: the 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, a higher amount of capital, both compared with the amount invested in other segments and to investments by GVC. However, the t-test shows that for IVC, the 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 decisions made by IVCs are largely related to specific characteristics of cleantech initiatives.

Descriptive statistics on a company's age at the time of the first investment are peculiar: if IVCs, compared to GVCs, invest in more mature companies in the non-cleantech sector, for cleantech we can observe the opposite behaviour. Cleantech companies invested in by IVCs at the first round of investment

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 time first investment received (mean)	4.17***	3.56	3.62	4.61*	3.34	3.47

Note: Note: t-test H0: difference from overall value – sig: ***99%, **95%, *90%.

Table 6: 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

Note: sig: ***99%, **95%, *90%.

are 7.2 months older than non-cleantech companies and this value increases to 15.2 months for GVC investments. These tendencies provide a picture that may be interpreted as follows: Colombo *et al.* (2016) highlighted that, if we look at a risk-return paradigm, IVCs have superior selection expertise compared to GVCs. On the other hand, GVCs may have different investment objectives, seeking not only pure financial return but also positive externalities and spillover effects to the (local) economy. This different approach may influence the characteristics of cleantech companies in which VC funds may decide to invest: when IVCs select cleantech companies, they invest only in the most promising ones and, moreover, they invest a significant amount of money to sustain their development. Conversely, GVCs seem to support more mature cleantech companies not able to overcome the “valley of death” phase.

3.2 Environmental Policy Stringency Measures

To evaluate policy stringency effect, we utilised indicators developed by Botta and Koźìluk (2014). These measures identify, on a 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 schemes of environmental certificates (ETS), environmental taxes (Taxes) and feed-in tariff (FIT) mechanisms. Non-market based policies are emission limits and R&D subsidies. A detailed description of these indicators and principal descriptive statistics are reported in the Online Appendix (Online Appendix B).

Table 6 shows preliminary evidence on the relationship between environmental policies and the number of cleantech VC investments in the five most representative countries (78.9% of the total VC investment sample). The correlation between the 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 such as taxes or FIT show volatility, both in terms of significance and signs of correlation: taxes and FIT seem to foster investments in some countries while hindering them in others.

Table 7: 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^{**}

Note: sig: ***99%, **95%, *90%.

When we examine according to types of VC (Table 7), we observe that, for both GVCs and IVCs, there is a statistically significant relationship between the number of deals and policy indicators, independent 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.

3.3 Model Specification

The aim of our study is to look at the policy determinants of VC investments in cleantech initiatives. We investigate the relationship between cleantech VC investments and environmental policies, aggregating the available deal-level information into year-country data. The impact of environmental policies on VC investments is analysed by considering two different dimensions of investments: the number of deals and the amount invested by VCs.

In the first equation (Equation 1) the dependent variable is the total number of VC deals in cleantech companies at year y, in country c. 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, it is then possible to identify the number of cleantech and non-cleantech deals made by VCs. Since we count events over a different number of geographical areas, we resort, in particular, to a population-averaged model. Our measure of exposure is the number of VC investments in country c and year y.

The model we estimate is thus the following:

$$
\begin{aligned}
&N^{\circ}cleantech\,VC\,deals_{y,c}\\
&\quad = \alpha + Taxes_{y-1,c} + Taxes^2_{y-1,c} + ETS_{y-1,c} + ETS^2_{y-1,c}\\
&\qquad + Emission\_limit_{y-1,c} + Emission\_limit^2_{y-1,c} + FIT_{y-1,c}\\
&\qquad + R\&D\_subsidies_{y-1,c} + +EPI_{y-1,c} + Oil\_price_{y-1} + D_y + D_c \quad (1)
\end{aligned}
$$

Taxes, ETS, FIT, Emission limit and R&D subsidies are the policy indicators described in Section 3.2. According to Krass *et al.* (2013) and Leiter *et al.* (2011), the firm's response to taxation may be non-monotonic higher levels of taxes may induce dirtier rather than cleaner technology. Based on these findings, we assume a non-monotonic behaviour of the three taxation mechanisms in our model by including their squared terms, namely environmental taxes, ETS and emission limits. These three instruments determine the increase in costs for pollutants: directly through taxes or ETS certificates that companies must acquire/obtain, or indirectly through the emission limits imposed on companies. Conversely, FIT and R&D subsidies are included with only linear terms, since these instruments increase margins through revenue increase (FIT) or cost reduction (R&D subsidies).

With regard to control variables, we first include the $EPI_{y-1,c}$, the Environmental Performance Index in each country that, as highlighted by Butticè *et al.* (2019), 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 in the previous year . Oil_price_{y-1} is the price of oil in each given year and represents a proxy of market momentum for cleantech initiatives. According to Cumming *et al.* (2016), the price of energy commodities, proxied by oil price, affects the level of cleantech investments. Environmental policies, the 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 the typical investment decision process of VC funds which lasts several months. Year and country dummies are finally included as further controls for the development of VC markets across countries and years.

As in Criscuolo and Menon (2015), the relationship between the number of deals and policies (Equation 1) is estimated via a Negative Binomial model.[8]

In the second equation (Equation 2), the dependent variable is the total amount of equity invested by VCs in cleantech companies in logarithm at year

[8]The Negative Binomial model allows us to deal with the count dependent variable, with non-negative integer values characterised by overdispersion with respect to a theoretical Poisson distribution. The number of cleantech deals includes a significant share of zeros, which rules out the possibility of a logarithmic transformation and determines overdispersion. Since the estimated coefficients correspond to semi-elasticities in the Negative Binomial model, 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 numbers reported in the tables of results relate to marginal effects calculated at the mean.

y, in country c:

$$\begin{aligned} &Amount\_invested\_cleantech_{y,c} \\ &\quad = \alpha + Taxes_{y-1,c} + Taxes^2_{y-1,c} + ETS_{y-1,c} + ETS^2_{y-1,c} + FIT_{y-1,c} \\ &\qquad + Emission\_limit_{y-1,c} + Emission\_limit^2_{y-1,c} \\ &\qquad + R\&D\_subsidies_{y-1,c} + EPI_{y-1,c} + Oil\_price_{y-1} + D_y + D_c \qquad (2) \end{aligned}$$

Explanatory variables are the same as in the first equation. Our measure of exposure in this model is the total amount of VC investments in country c and year y. The model is estimated through a generalised linear model (GLM). In accordance with Papke and Wooldridge (1996), we do not opt for the Tobit regression model, a censored model that is not applicable where values beyond the censoring point are infeasible.[9]

4 Results and Discussion

We estimate Equations (1) and (2), as described in the previous section, for all VC investments and separately for IVC and GVC investments in order to test our four research hypotheses. Starting from the VC investments' database at deal level, we aggregate transactions to build the dependent variable identifying the number and value of investments made by IVC and GVC. The aggregation process must consider one peculiar aspect of VC investments: the syndication.[10] Syndication can be formed by IVC or GVC alone or a combination of them. To analyse the effect of environmental policies on the two subsets 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 Equation (1), we count the numbers of IVC-only, GVC-only and co-invested deals in each country for a given year. For Equation (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

[9]For purposes of robustness, we perform a Tobit estimation with the same functional form. The model provides results in line with those presented in Section 4. They have been omitted for the sake of brevity but are available from the authors upon request.

[10]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 (Gompers and Lerner, 2002; Cumming *et al.*, 2017). In this context, given the aim of portfolio diversification, VCs utilise 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 the 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.

Table 8: Number of VC Deals.

	All samples	IVC-only	GVC-only	Co-invest
ETS	−0.162	−1.842**	−0.122	3.796*
	(1.684)	(0.920)	(0.302)	(2.181)
ETS^2	0.034	0.094	0.102***	−0.132
	(0.257)	(0.151)	(0.032)	(0.232)
Taxes	13.289	16.556***	−1.573**	2.088
	(8.405)	(5.358)	(0.643)	(3.842)
$Taxes^2$	−2.283	−3.134***	0.326***	−0.326
	(1.569)	(1.092)	(0.112)	(0.774)
Emission limit	−6.456	−0.976	−1.150***	−2.510
	(4.776)	(2.300)	(0.419)	(3.948)
Emission $limit^2$	0.848	0.039	0.145**	0.304
	(0.665)	(0.313)	(0.063)	(0.483)
FIT	0.360	0.606**	0.024	−0.519**
	(0.458)	(0.267)	(0.078)	(0.245)
R&D subsidies	0.405	0.965*	−0.206***	−0.295
	(0.666)	(0.531)	(0.069)	(0.553)
Oil price	0.064	0.089	−0.005	0.015
	(0.100)	(0.055)	(0.008)	(0.045)
EPI	−0.041	0.198	−0.038	−0.156
	(0.447)	(0.270)	(0.058)	(0.374)
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 as measure of exposure in a given country/year. Robust standard errors clustered at country level in parentheses.

by one type of investor or a round where a VC invests alone in the funded company.

Table 8 shows the results of the Negative Binomial model of Equation (1). 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 the co-investment round where at least one GVC and one IVC are funding the company. All estimates also include unreported controls such as country and year dummies. Regression coefficients of the Negative Binomial model are expressed as marginal effects.

Results in the first column of Table 8 show a weak relationship between the whole sample and environmental policies: none of explanatory variables are significant.

Table 9: Amount Invested.

	All samples	IVC-only	GVC-only	Co-invest
ETS	−0.236	−0.769**	3.850***	0.482
	(0.373)	(0.369)	(1.022)	(0.675)
ETS^2	0.036	0.103	−0.296*	0.143**
	(0.046)	(0.050)	(0.171)	(0.066)
Taxes	1.261**	5.547**	−3.237**	−2.402
	(0.636)	(2.301)	(1.365)	(2.299)
Taxes^2	−0.293**	−1.598**	1.426***	1.351**
	(0.138)	(0.751)	(0.310)	(0.665)
Emission limit	−0.177	0.888	−99.935***	−2.319
	(0.805)	(0.837)	(37.234)	(2.208)
Emission limit^2	0.113	−0.064	9.617***	0.285
	(0.100)	(0.086)	(3.594)	(0.184)
FIT	0.103	0.039	0.042	−0.319***
	(0.099)	(0.079)	(0.189)	(0.078)
R&D subsidies	0.157	0.561***	−0.848***	−0.343
	(0.126)	(0.177)	(0.294)	(0.299)
Oil price	−0.014	0.031**	1.249***	0.007
	(0.014)	(0.013)	(0.472)	(0.022)
EPI	−0.051	−0.214*	0.666	−0.100
	(0.102)	(0.113)	(0.504)	(0.195)
N. obs	103	96	40	55

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 total amount invested by VCs as measure of exposure in a given country/year. Robust standard errors clustered at country level in parentheses.

Nonetheless the result on the overall sample is biased by the heterogeneity of VCs as will be discussed in what follows. When we explore whether responses to policies are different between IVC and GVC investments, results, reported in columns II and III of Table 9, show that policies play an important role as drivers of investments for IVCs and GVCs, but the drivers of investments are different between different classes of investors. As assumed in the hypothesis 1, IVC investors are positively driven by monetary incentives: R&D subsidies and FIT can increase the activity of IVCs in the cleantech segment.

The regression on IVC confirms hypothesis 2 since, as predicted by Krass *et al.* (2013), environmental taxes show an inverted U-shaped dynamic: moderate-level policy stringency fosters IVC investment, whereas high level of stringency discourages investments. More in details, the negative effect of environmental taxes on IVC investments arises for very high level of taxation.[11] To provide an evaluation of this impact in economic terms, we compare the marginal effects at the 25th percentile and at the 75th percentile of the environmental tax index: result indicates a significant increase in the number of cleantech companies invested by IVC equal to 55.45 units. If we concentrate on the within countries variation, our estimates suggest that the difference between the average tax index in the first year of analysis and the average tax index in the last one is associated to an increase in IVC investments equal to 13.41 units. This result confirms that the trend of more stringent environmental tax framework along European countries supported the development of IVC investments in cleantech. FIT and R&D subsidies foster the investments by IVC, but with limited impact in economic terms, compared to environmental taxes: the increase from the 25th to 75th percentile of FIT and R&D subsidies indexes determines a marginal increase of cleantech backed by IVC equal, respectively, to 2.06 and 1.91 units. ETS, on the contrary, shows a negative linear relationship: the higher the ETS price, the lower the number of VC investments in cleantech companies.

Moreover, as predicted by Cumming *et al.* (2016), IVC investors may be influenced by the market momentum: oil price has a positive, but insignificant, impact on the number of IVC deals.

As for GVC investments, results confirm hypothesis 3 that venture capital investments by the government are implemented as an indirect driver of development of cleantech investments: investments by GVCs are negatively correlated with R&D subsidies' supply-side mechanisms. The estimates show that the increase from the 25th to 75th percentile of R&D subsidies stringency index determines a reduction in cleantech companies backed by GVC equal to 0.56 units.

The GVC reaction to the stringency of ETS, environmental taxes and emission limits is opposite with respect to IVC. Initially, environmental policies' stringency does not foster investment by GVCs, the positive effect becomes evident only for a high level of stringency. This result can be interpreted as a consequence of country commitment to reach environmental targets: in countries with clear and strong environmental targets and a high level of stringency, the GVC investment strategy is coherent with governmental attention to environmental aspects. GVCs are active in countries where a government is already implementing policies towards clean technologies: the higher the policy stringency level, the higher the role of GVCs with direct investment support, thus providing support for hypothesis 4.

The presence of both IVCs and GVCs as co-investors determines a more complex relationship with policy indicators. Since the VICO database does

[11] In unreported analysis we identify the turning point of the inverted U-shaped curve between the 90th and 95th percentile of the distribution.

not identify the lead investor, co-investment is a mix of rounds where IVCs or GVCs lead the syndication of investors. In this context, it 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. Conversely, the FIT mechanism negatively affects the number of co-investments. Even if the lead investor is unknown, we can infer that co-investments are heavily influenced by the presence of a GVC: reaction to environmental policies is coherent with GVC-only analysis.

It is interesting to explore the results when the amount invested is considered as a dependent variable (Equation 2). Table 9 reports the marginal effects of these same policies on the total amount of VC funding across country-year, conditional on the value being positive. As for estimates in Table 9, we estimate four different models: Column I refers to estimates on the whole sample, column II refers to IVC-only investments, column III reports the analysis restricted to the sample of GVC-only investments while the last column refers to co-investment a round where at least one GVC and one IVC are funding the company.

Results in the first column of Table 9 suggest that environmental polices affect the 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-shaped behaviour, with an initial positive effect of this instrument in fostering VC investment in cleantech, and a subsequent negative effect in the presence of extremely high taxation levels, corresponding to the highest 5% of the observations. Dividing the whole sample in IVC and GVC deals, reported respectively in Column II and III, it emerges that for both types of investors, market momentum appears relevant and positive. The amount invested by IVCs is also driven by market-push policies: both R&D subsides and FIT are positive, but only the R&D variable is also significant. IVCs confirm the U-shaped behaviour of environmental taxes on the amount invested, with an initial positive impact and a subsequent negative effect. The analysis of the amount invested confirms that governmental VC funds are developed in countries where market-push instruments 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 acting as an incentive for GVC ones.

5 Conclusion

In recent years, the debate on strategies to reach climate targets is crossing over academic and governmental boundaries and it is becoming prominent in most OECD countries. Nonetheless, BENF data from 2018 shows that governments around the world are not able to increase financial sources for innovation and

R&D in cleantech industries: the amount invested varies between 4.5 and 5 billion US dollars since 2009. If direct public investment remains constant, also due to government 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 signing the Paris agreement, the European Commission established the EU High-Level Group on Sustainable Finance (HLEG) to advise on how to address the flow of capital towards sustainable investments and deploy these policies on a pan-European scale. The HLEG has focused its attention on financial reforms but recognises that these will only fulfill 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 the 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 which, starting from a full sample of VC deals, identifies cleantech and non-cleantech companies through a supervised machine-learning algorithm. Cleantech companies represent 9% of backed companies of the VICO dataset and they are characterised by higher average equity investment with respect to non-cleantech backed companies, and a higher average age at the time of 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 compared to all other VC investments.

In our analysis, we study the role of IVCs and GVCs in supporting cleantech. Firstly, they invest with different aims: when IVCs select cleantech companies, they seem to invest only in the 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.

A separate analysis of the two class of investors aims to explain the role of policies in the context of PoH. Our results confirm the findings of previous studies: revenues support mechanisms, such as feed-in tariffs and R&D subsidies, can foster private VC investments in cleantech. However, we also provide evidence able to explain the apparent contradictory results in Criscuolo 2015 and Cojoianu (2020).

In our analysis, we control for VC heterogeneity and, according to Krass *et al.* (2013) and Leiter *et al.* (2011), we assume a nonlinear relationship between policy stringency measures and VC response. After controlling for these two characteristics, we provide evidence that all policy stringency instruments affect VC investments coherently with the PoH. Results of our analysis show that, as predicted by Krass *et al.* (2013) and Leiter *et al.* (2011), environmental taxes evidence a U-shaped relationship with the number of IVC investments and the amount invested in the cleantech sector, with an initial positive effect of these instruments in fostering VC investment in cleantech and a subsequent negative effect in the presence of extremely high taxation levels: a moderate level of environmental taxes fosters innovation and provides an incentive for private venture capital funds to invest in clean technologies.

The results also confirm the different rationale between GVCs and IVCs: GVC investments are not driven by revenue support mechanisms such as FIT, and these investments are alternatives to R&D subsides. Governments allocate resources to cleantech either directly through GVC funds or indirectly through the support of R&D activity. Moreover, GVC investments in cleantech increases in line with the increase in the level of policy stringency instruments, such as ETS, emission limits and environmental taxes. In countries characterised by a low level of environmental stringency, GVCs' investment strategies are not focused on supporting clean technologies either. Conversely, GVCs support the industry in countries where the government also appears to consider the environmental target to be relevant, setting more stringent policies.

The lessons for governments are manifold. The interaction between environmental policies and institutional investor behaviours is complex and influenced by the heterogeneity of VC funds. Investment strategies of IVCs and GVCs are both driven by environmental policies, but the different ownership structure implies a specific role of each class of environmental policies.

Fostering sustainable investments by private VCs is not only a matter of public funds allocated to incentivse investors. If FIT and R&D subsidies, able to increase operating margins of backed companies, increase the probability of IVC support, taxes and emission limits can also act as a driver of cleantech development. According to PoH, policies aimed at setting explicit costs of negative externalities of pollution act as instruments to support innovation to more sustainable technologies. Nonetheless, governments must design a balanced set of policies able to maximise the response of IVC: on the one hand, if FIT and R&D subsidies linearly increase the probability of support by IVC, they deteriorate public budget. On the other hand, governments cannot transfer the entire costs of pollution to the private sector: as predicted by Krass *et al.* (2013) a level of direct and indirect taxation that is too high may reduce investment flow by institutional players.

Conversely, GVCs' investment strategy is affected not only by the allocation of public resources between direct investments (through GVCs) and indirect support (through R&D subsidies and FIT), but also by a government's attitude towards a real alternative to non-sustainable technologies. GVCs invest more in contexts characterised by more stringent environmental policies that penalise pollutant technologies with direct and indirect taxation mechanisms.

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