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Equity Investments and Environmental Pressure: The Role of Venture Capital

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Abstract: This study investigates the global relationship between venture capital (VC) investments and environmental pressure in order to contribute to the literature on the influence of venture capital on sustainable development. Using a unique dataset covering VC activity and CO2 intensity in 131 countries from 2011 to 2021, the study employs a revised STIRPAT model—a stochastic model for assessing the environmental impact of human activities. The aim is to examine the potential negative correlation between VC investments and CO2 intensity. This motivation stems from previous findings, indicating that increased VC investments spur the diffusion of eco-efficient technologies. The main results affirm a significant negative correlation between VC investments and CO2 intensity, even after controlling for relevant variables and potential confounding factors (e.g., foreign direct investments), country, and year fixed effects, and addressing potential endogeneity through lagging independent variables. Exploring heterogeneity in the baseline results reveals that these findings are consistent only for VC investments in the Asia-Pacific region, in emerging and developing economies, and in areas where they can contribute more to the development of green technologies and innovations. This suggests that VC activity may impact environmental intensity primarily in countries where emission regulations are less stringent or where existing technologies exhibit lower efficiency in terms of energy consumption.

Keywords: equity investments; venture capital; environmental intensity; CO2; SMEs; sustainable finance

JEL Classification: G11; G15; G24; F21; F64; F65; Q56

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1. Introduction

As the year 2030 approaches, businesses face an imperative to curtail carbon dioxide (CO2) emissions in adherence with the United Nations Agenda. This Agenda outlines an ambitious program aimed at enhancing sustainable development across economic, social, and environmental dimensions. However, the transition to more sustainable production methods necessitates the adoption of novel technologies to optimize resource utilization. The development of such technologies is a costly and, at times, unsuccessful endeavor. A metric to gauge the efficacy of emerging technologies concerning carbon emissions is environmental intensity or eco-efficiency [1], which quantifies the environmental pressure per unit of economic output, usually adopting CO2 emissions over sales (e.g., [2]) or GDP (e.g., [3]) as proxies at the micro and macro levels, respectively. Entrepreneurs, displaying fortitude in pursuing success amid high demand, may encounter challenges in securing funding during the conceptual stage. This is where venture capitalists (VCs) step in, equipped with the resources to foster the growth of startups and the confidence that their investments may yield profitability.

This work aims to contribute to the existing literature on equity investments, environmental intensity, and sustainability through an empirical analysis spanning the period from 2011 to 2021. Specifically, we explore the relationship between venture capital activity and CO2 intensity at the worldwide level. We posit that an increase in venture capital investments would be related to a decrease in CO2 intensity. To the best of our knowledge, this is the first study to address this topic. A notable recent exception is Maiti (2022) who investigated the influence of total venture capital investments on CO2 productivity for a sample of 23 countries from 2007 to 2015 [4]. However, our paper differs from this work for the following reasons: (i) we focus on environmental intensity, not productivity, as the main variable of interest; (ii) we follow a global approach covering 131 countries; (iii) we focus on a more recent period, which also considers relevant policy objectives that have been put into place such as the Sustainable Development Goals (SDGs) resolution and the Paris Agreement in 2015. Moreover, we aim to explore any heterogeneous impact of VC investments across different macro-areas and income groups.

To address these questions, we conduct an empirical investigation by employing the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model, originally used to examine the environmental impacts of human activities. We find that VC investments contribute to a reduction in CO2 intensity. Our findings are robust to several model specifications and are not sensitive to the exclusion of single countries, nor to the exclusion of the pandemic period from the sample or to different specifications of the environmental intensity measure. When we move to heterogeneous analyses, we find that the influence of VC activity on CO2 intensity is concentrated in the Asia-Pacific region, among emerging countries, and where environmental awareness and green technology is nascent.

The rest of the paper is structured as follows. Section 2 presents the literature review and the development of the hypothesis to be tested. Section 3 describes the dataset and empirical strategy. Section 4 presents the main results, while Section 5 offers robustness tests. Section 6 explores underlying channels and mechanisms by investigating heterogenous effects. Lastly, Section 7 concludes the paper, providing some implications for policymakers and presenting avenues for future research.

2. Literature Review and Hypothesis Development

2.1. Literature Review

The scholarly discourse on the environmental implications of capital investments, specifically in the realm of clean technologies, yields mixed evidence. In the equity investment literature, some studies highlight a growing awareness of sustainable VC funds and the commitment to addressing environmental, social, and governance (ESG) concerns [5–7]. In broader terms, investors in equity and venture capital—which can be classified as one of the most relevant forms within the spectrum of equity investments, alongside angel financing, crowdfunding, and private equity [8]—are providing increasing support to the development of environmental-friendly startups [9–11]. At the same time, VC investments are recognized for contributing to the development of a green innovation ecosystem that supports the diffusion of green technologies [12,13].

Conversely, skepticism rooted in the 'pollution haven hypothesis' suggests that multinational corporations may relocate pollution-intensive industries to countries with less stringent regulations. On the other side, the alternative 'halo' hypothesis proposes that companies might export clean technologies, potentially mitigating CO2 emissions and intensity [14]. Notably, VC investments in clean technologies are acknowledged to carry elevated risks, with cleantech startups experiencing a failure rate exceeding 75%, in contrast to approximately 70% for software companies [15].

Environmental policies emerge as crucial determinants of venture capital funding, particularly for small and medium-sized enterprises (SMEs) and startups in the cleantech sector. Croce and Bianchini (2022) explore the relationship between environmental policies and VC investments in cleantech companies [16]. Institutional investors, driven by return maximization, selectively favor startups deemed most promising, while governmental investors demonstrate a propensity to support more mature companies, even with a higher probability of failure. Governmental venture capitalists, devoid of revenue-centric motives, exhibit a preference for companies operating in environments characterized by stringent policies. In contrast, institutional investors align their investments with the 17 SDGs outlined in the 2030 Agenda, reflecting a commitment to global sustainable development objectives [17].

Corporate venture capital (CVC) investors engage in green startups not only for financial gains but also for strategic reasons. Hegeman and Sorheim (2021) underscore that CVC investments in cleantech are driven by strategic goals like competitiveness as well as an increase in SMEs' green responsiveness [18]. This responsiveness is linked to a perceived opportunity to embrace environmentally friendly practices, anticipating that clean technologies will become financially advantageous. The imposition of future costs, such as a potential carbon tax designed to limit greenhouse emissions, further motivates this shift [19].

The role of green finance, encompassing green credit and green venture capital, is highlighted in overcoming existing barriers to green investments, contributing to emissions reduction, especially in startups facing urgent needs for clean projects due to evolving environmental regulations [20]. However, merely labeling oneself as a green startup is insufficient for recognition as a green investment. Mrkajic et al. (2019) demonstrate a correlation between green startups and increased VC funding only when businesses rely on green technologies or products and position themselves within green sectors [13]. Similarly, Bellucci et al. (2023) reveal that VC firms are more attracted to startups with green patents, specifically those related to green technologies, rather than a general affinity for the overall sectoral greenness of the startup [12].

Despite the perceived risks and lower returns associated with VC investments in clean technologies, the nascent stage of the green sector presents an allure for early movers, offering the potential for competitive advantages. Media attention and governmental support further contribute to legitimizing this emerging sector. Entrepreneurs seeking VC support are increasingly eager to substantiate their commitment to environmental causes, emphasizing effective communication of their business's position [13].

The joint evolution of incumbents and startups in fostering sustainable market transformation is underscored by VC's role in providing funds for scaling eco-innovations and accelerating technological development. Knowledge transfer occurs through various channels, including alliances, mergers and acquisitions, and SMEs' investments [21]. The integration of knowledge hinges on firms' absorptive capacity, defined as the ability to recognize the value of external information, assimilate it, and apply it commercially [22]. Firms with higher absorptive capacity are better positioned to integrate external knowledge, leading to more rapid implementation of green innovations. The interaction during due diligence between the research and development (R&D) departments of the incumbent and the startup emerges as a crucial stage in the absorption of new knowledge [21].

Overall, VC investments not only facilitate startups in utilizing more green technologies but also contribute to increasing environmental responsibility among incumbents, fostering greater adoption of green technologies and providing a potential reduction in environmental intensity.

2.2. Hypothesis Development

Building upon the insights from the literature, we formulate the following hypothesis:

H1. *VC investments are negatively related to environmental intensity, proxied by CO2 over GDP.*

The primary hypothesis, H1, posits a negative correlation between VC investments and environmental intensity, measured as CO2 over GDP. This hypothesis draws substantial ex ante support from previous research analyzing the relationship between equity investments and CO2 productivity (e.g., [4]). Complementary evidence from Zhang and Zhou (2016) suggests that foreign direct investments' (FDIs) inflows contribute to a reduction in CO2 emissions in China [23]. Moreover, Li et al. (2012) empirically show that an elevated technology level corresponds to lower CO2 emissions [24], reinforcing the idea that VC-backed SMEs, through the provision of funds and technological expertise, challenge the pollution haven hypothesis advanced by Kim and Adilov (2012) [14].

The following empirical analysis also aligns with—and extends the work of—Dhayal et al. (2023), who present a systematic literature review of green venture capital from 2002 to 2022. The categorization into thematic clusters, namely, the transition toward green VC, the intersection of green venture capital with cleantech, sustainability considerations in green VC, and policy implications for green venture capital, provides a roadmap for our empirical analysis. Particularly, our work aims to contribute to Cluster 3, which elucidates how sustainable equity investments plays a pivotal role in the sustainable development of startups [25].

3. Data and Methods

3.1. Data

To test our hypothesis, we build a unique dataset which combines two main data sources for VC activity and CO2 emissions. The data source for the VC-invested amounts and the number of VC transactions is the commercial database Zephyr, a Bureau van Dijk product. Zephyr includes detailed information on past, current, and rumored deals, VC investors, deal nature and type, and investors' names and country codes, and it also provides further details about the market of the target company. On the other side, the data on CO2 emissions are extracted from Eurostat [26], while the values for the GDP—necessary to construct our main environmental intensity indicator—are retrieved from the World Bank.

Further information about the characteristics of each country is added to the dataset to be used as control variables. As demographic measures for each country, we consider both the population at the end of the year and the urbanization level, that is, the percentage of the urban population with respect to the total, both retrieved from the World Bank. To account for the technology level of a country, the variable Tech is introduced and computed as GDP over energy consumption (measured in tons of coal equivalent, TCE). Data regarding energy consumption are extracted from the work of Ritchie et al. (2022) [27], and then converted into TCE. A country with a high technology level is expected to generate more GDP from the used energy than a country with a low technology level. Having a high technology rate could also mean that the country pollutes less thanks to more efficient technologies. The value of foreign direct investments (FDIs) is also included in the dataset (source: World Bank), as it has been identified as one of the significant factors influencing CO2 intensity other than VC investments [23].

Overall, our dataset includes more than 1400 observations, with 131 countries and a time period that ranges from 2011 to 2021. Table 1 reports the descriptive statistics for each variable (the total number of observations used in the regression model is 1215 due to the combination of variables' missing values).

Table 1. Summary Statistics.

Variable	Unit	Obs.	Mean	SD	Min	Max	Median
EnvInt	ln(tons per USD)	1437	0.415	0.250	0.050	1.486	0.337
VC investments	ln(K USD)	1452	6.978	5.561	0.000	21.081	8.105
VC transactions	K units	1452	0.187	1.752	0.000	32.904	0.003
GDP	ln(USD)	1437	25.103	1.881	20.567	30.615	24.821
Population	ln(units)	1452	16.461	1.581	12.553	21.091	16.380
Tech	ln(USD/tons)	1323	8.221	0.686	4.743	11.738	8.282
FDI	ln(USD)	1327	21.416	2.099	10.821	26.857	21.335
Urb	%	1452	61.035	21.980	10.915	100	62.894
PCO2Index	ln(index (2000 = 100))	1223	4.944	0.479	3.803	6.519	4.917

3.2. Empirical Strategy

In the early 1970s, the IPAT (Impact of Population, Affluence, and Technology) model was extensively used to study the impact of human activities on the environment. However, its limitation lies in measuring the proportionate impact by changing one factor while holding others constant. To address these shortcomings, the model was reformulated into a stochastic one, named STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology). This modification enables the modeling of non-proportionate impacts of variables on the environment [24], as follows:

$$CE_t = aP_t^b A_t^c T_t^d e_t \quad (1)$$

where *CE* is the environment impact; *P* stands for population; *A* stands for affluence; *T* stands for technology; *a* is the constant; *b*, *c*, and *d* are the coefficients of the factors, which can be obtained through a regression; and *e* is the error term.

The STIRPAT model has been widely adopted in settings similar to those of our analysis, where environmental impacts from economic forces are predicted [28]. An increasing number of studies have applied this methodology to examine the impact of financial outcomes on environmental forces, such as financial development (e.g., [29]), foreign direct investments (e.g., [30]), capital expenditure (e.g., [31]), and remittances (e.g., [32]) on CO2 emissions or intensity. This strengthens the notion that this model can be appropriately applied to the case of studying the relationship between venture capital activity and environmental intensity. Moreover, by considering technological development as a key aspect to reduce environmental impact, the STIRPAT model also allows for the inclusion of other institutional and social factors [33], which could be strongly related to the environmental progress trend and associated policies.

For the sake of our empirical analysis, we modify the STIRPAT model (Equation (1)) in order to (i) account for both cross-sectional and time variation in a panel data setting and (ii) be specified as a log–log model, so that we can interpret the coefficients as the estimated percent change in the dependent variable for a percent change in the regressors. Hence, we obtain the following model:

$$EnvInt_{i,t} = \alpha + \beta VC_{i,t} + \gamma X_{i,t} + \phi_t + \phi_i + \varepsilon_{i,t} \quad (2)$$

where *I* refers to countries and *t* to years, in a panel data setting. *EnvInt* is the natural logarithm of environmental intensity built as the ratio between CO2 over GDP. *VC* is an indicator for the overall VC activities either in terms of invested volumes—taken in the natural logarithm—or number of transactions—taken in thousands. *X* is a vector of control variables accounting for heterogeneous characteristics of the economic systems such as the country level, including gross domestic product (*GDP*), the population at the end of the year (*Population*), the technology level (*Tech*), the amount of foreign direct investments (*FDIs*), and the percentage of urban population (*Urb*). Our model also includes both country (ϕ_i) and year (ϕ_t) fixed effects, to account for cross-sectional heterogeneity across countries and for shocks in different periods and common to all countries, respectively. In alternative specifications of the model, we substitute year fixed effects with time trends (*Year*) to control for the overall direction of the relationship between environmental intensity and VC activity. $\varepsilon_{i,t}$ is the error term, clustered at the country level. In alternative specifications, we replicate the baseline estimations using robust standard errors. The results, presented in Table A1 of the Appendix A, are consistent with baseline findings.

We estimate Equation (2) as an OLS panel fixed-effect model when using the natural logarithm of VC investments as the main regressor, while we adopt a fixed-effect Poisson model for the number of VC transactions to avoid potential biases in the results [34].

In order to test our main hypothesis (H1), we are interested at examining the sign and significance of the coefficient β associated with *VC*, which we expect to highlight a negative correlation between VC activity and CO2 intensity.

VC contributes to the development of the startups, mostly when companies are young and small and, usually, do not have high production capacity. The VC funds help develop not only the know-how but also the industrial processes; this may take some time, meaning that the effect on the quantity of carbon emissions produced is not immediate. At the same time, an estimation that considers the simultaneous effects of VC on CO2 intensity might suffer from potential issues of endogeneity and reverse causality.

Hence, to account for such issues, in different specifications, we also test a dynamic version of the model in Equation (2) that includes the one-year-lagged independent variables, as follows:

$$EnvInt_{i,t} = \alpha + \beta VC_{i,t-1} + \gamma X_{i,t-1} + \phi_t + \phi_i + \varepsilon_{i,t} \tag{3}$$

4. Results

4.1. Baseline Results (Static Model)

We first present the results (Table 2) of the estimation of Equation (2). We find that the coefficient of the VC investment volumes (column 1) is significant and enters negatively in the regression. As can be seen from column 2, the previous reasoning also holds for the number of VC transactions. These findings are also confirmed in sign, magnitude, and significance when we include yearly linear trends in the model instead of year fixed effects (columns 3 and 4). Overall, these results confirm our hypothesis (H1), indicating that an increase in VC activity reduces the level of environmental intensity.

Table 2. Baseline results (static model).

Dependent Variable	**Environmental Intensity**			
Model Specification	**(1)**	**(2)**	**(3)**	**(4)**
VC investments	−0.0013 **		−0.0013 **	
	(0.0006)		(0.006)	
VC transactions		−0.0052 ***		−0.0055 ***
		(0.0016)		(0.0017)
GDP	−0.1834 ***	−0.3783 ***	−0.1750 ***	−0.3577 ***
	(0.0677)	(0.1151)	(0.0662)	(0.1142)
Population	0.3323 ***	0.5791 ***	0.3495 ***	0.6155 ***
	(0.1064)	(0.1839)	(0.1108)	(0.1920)
Tech	−0.1356 *	−0.2599 **	−0.1392 *	−0.2649 **
	(0.0774)	(0.1285)	(0.0785)	(0.1317)
FDI	0.0024	0.0020	0.0025	0.0018
	(0.0016)	(0.0033)	(0.0017)	(0.0033)
Urb	0.0067	0.0196 ***	0.0065	0.0155 ***
	(0.0047)	(0.0068)	(0.0047)	(0.0069)
Year			−0.0031	−0.0135 ***
			(0.0020)	(0.0030)
Observations	1215	1215	1215	1215
Number of Countries	131	131	131	131
Adj. R-squared	0.6367	-	0.6352	-
Pseudo R-squared	-	0.0960	-	0.0959
Country fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	No	No

Note: The analysis covers 11 years from 2011 to 2021 and 131 countries. All variables are in the natural logarithm, except Urb (percentage) and venture capital transactions (number). VC investments and VC transactions are the variables of interest, referring to the amount of VC activity and the number of operations, respectively. GDP is the gross domestic product; Population is the population at the end of the year; Tech is the technology level; FDI is the amount of foreign direct investments; Urb is the percentage of population living in the urban area; Year is a linear yearly trend. The table reports coefficient estimates followed by clustered standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

All the other variables (*GDP*, *Population*, *Tech*, *Urb*) have significant coefficients, with the exception of *FDI*. Zhang and Zhou (2016) showed that the coefficient related to FDI is significant and has a negative sign; this difference is related to the change of the dependent variable [23]. In our model, we treated the natural logarithm of CO2 over GDP as a dependent variable, while they conducted the regression using only the natural logarithm of CO2 emissions. As expected from how the dependent variable is built, increases in GDP are negatively correlated with environmental intensity. Additionally, an increase in the natural logarithm of the technology level (*Tech*) reduces the CO_2 intensity. Urbanization (*Urb*) and population (*Population*) present positive coefficients. These results are in line with the idea that a higher level of population—especially when concentrated in cities—increases the CO2 intensity.

4.2. Results with Lagged Regressors (Dynamic Model)

We now examine the results of the dynamic model specification that introduces lags on all independent variables, with the aim of addressing potential endogeneity and reverse causality. Results are presented in Table 3. The coefficients for both the amount of VC investments and the number of VC transactions are still significant and negative based on this specification, both using year fixed effects or trends. This confirms our previous findings and supports the idea that the relationship between VC activity and CO2 intensity goes into the expected (causal) direction.

Table 3. Results—baseline results (dynamic model).

Dependent Variable	**Environmental Intensity**			
Model Specification	**(1)**	**(2)**	**(3)**	**(4)**
VC investments	−0.0010 **		−0.0014 ***	
	(0.0005)		(0.0005)	
VC transactions		−0.0065 ***		−0.0077 ***
		(0.0017)		(0.0022)
GDP	−0.1224 **	−0.2467 **	−0.0995 *	−0.1970 *
	(0.0566)	(0.1030)	(0.0550)	(0.1019)
Population	0.3682 ***	0.7000 ***	0.3859 ***	0.7359 ***
	(0.1000)	(0.1934)	(0.1042)	(0.2031)
Tech	−0.1015 *	−0.2129 *	−0.1032 *	−0.2125 *
	(0.0603)	(0.1091)	(0.0618)	(0.1119)
FDI	0.0021	−0.0002	0.0022	0.0007
	(0.0024)	(0.0058)	(0.0024)	(0.0057)
Urb	0.0045	0.0129 *	0.0039	0.0110
	(0.0043)	(0.0075)	(0.0043)	(0.0076)
Year			−0.0053 **	−0.0167 ***
			(0.0020)	(0.0036)
Observations	1215	1215	1215	1215
Number of Countries	131	131	131	131
Adj. R-squared	0.4089	-	0.3805	-
Pseudo R-squared	-	0.0938	-	0.0936
Country fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	No	No

Note: The analysis covers 11 years from 2011 to 2021 and 131 countries. All variables are in the natural logarithm, except Urb (percentage) and venture capital transactions (number). VC investments and VC transactions are the variables of interest, referring to the amount of VC activity and the number of operations, respectively. GDP is the gross domestic product; Population is the population at the end of the year; Tech is the technology level; FDI is the amount of foreign direct investments; Urb is the percentage of population living in the urban area; Year is a linear yearly trend. All regressors are taken as one-year-lagged indicators. The table reports coefficient estimates followed by clustered standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

5. Robustness Tests

5.1. Country Outliers

We now test the robustness of our baseline findings, checking if they are sensitive to the exclusion of single countries. Hence, we estimate again our baseline model several times, by dropping one country each time. Figure 1 shows the estimated coefficients—and their 90% confidence interval—which highlight a substantial consistency of these results with those of our baseline model. Hence, we conclude that the relationship between VC activity and environmental intensity does not seem to be driven by any specific country.

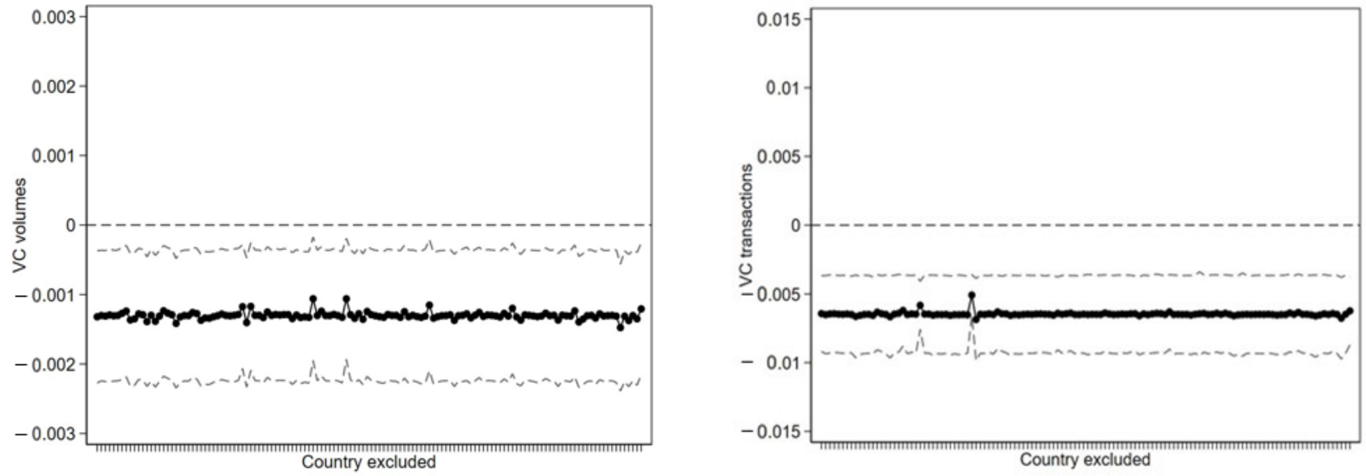

Figure 1. Country Outliers. The figure presents coefficient estimates (in dark grey) and their 10% confidence intervals (in light grey) for 131 different estimations, each excluding one country at a time. The analysis covers 12 years from 2011 to 2021 and 131 countries. *VC Volumes* is a continuous variable built as the natural logarithm of VC-invested volumes in a specific country and year. *VC Transactions* is a continuous variable counting the number of VC transactions in a specific country and year. All the control variables and the whole set of fixed effects are included in the estimations, and standard errors are clustered at the country level.

5.2. Alternative Definition of Environmental Intensity

In the previous analyses, we have adopted as the main dependent variable the ratio between CO2 emissions and GDP, one of the most used proxies for environmental intensity. For the sake of robustness, we now estimate again our baseline model using as an alternative proxy, *PCO2Index*, the production-based CO2 emissions index released by the OECD. This indicator accounts for the amount of CO2 emissions specifically related to production and so provides insights into the net environmental flows resulting from the final domestic demand [35]. The results of these estimations, presented in Table 4, are in line with those of our baseline findings and highlight the robustness of our empirical strategy and findings.

Table 4. Robustness—alternative definition of CO2 intensity.

Dependent Variable	Production-Based CO2 Intensity			
Model Specification	**(1)**	**(2)**	**(3)**	**(4)**
VC investments	−0.0023 *		−0.0024 *	
	(0.0014)		(0.0014)	
VC transactions		−0.0008 ***		−0.0010 ***
		(0.0002)		(0.0003)
GDP	0.4805 ***	0.0895 ***	0.5266 ***	0.0991 ***
	(0.0366)	(0.0262)	(0.0356)	(0.0263)
Population	0.7073 ***	0.1350 ***	0.7889 ***	0.1522 ***
	(0.1152)	(0.0311)	(0.1149)	(0.0339)
Tech	−0.3623 *	−0.0678 **	−0.3778 ***	−0.0705 **
	(0.0268)	(0.0330)	(0.0268)	(0.0343)
FDI	−0.0025	−0.0006	−0.0022	−0.0006
	(0.0051)	(0.0009)	(0.0051)	(0.0010)
Urb	0.0238 ***	0.0045 ***	0.0242 ***	0.0045
	(0.0045)	(0.0013)	(0.0045)	(0.0014)
Year			−0.0154 ***	−0.0033 ***
			(0.0022)	(0.0005)
Observations	1059	1059	1059	1059
Number of Countries	116	116	116	116
Adj. R-squared	0.3286	-	0.3126	-
Pseudo R-squared	-	0.0117	-	0.0117
Country fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	No	No

Note: The analysis covers 11 years from 2011 to 2021 and 116 countries. All variables are in the natural logarithm, except Urb (percentage) and venture capital transactions (number). VC investments and VC transactions are the variables of interest, referring to the amount of VC activity and the number of operations, respectively. GDP is the gross domestic product; Population is the population at the end of the year; Tech is the technology level; FDI is the amount of foreign direct investments; Urb is the percentage of population living in the urban area. Data for PCO2Index—available here https://stats.oecd.org/index.aspx?queryid=77867#—is available for 116 of the countries included in our sample. The table reports coefficient estimates followed by standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

5.3. Confounding Factors—Exclusion of Pandemic Times

The global landscape has been deeply impacted by the COVID−19 pandemic. In an effort to reduce the transmission of the coronavirus, individuals and businesses were subjected to lockdown measures which precipitated a rapid and severe economic downturn (e.g., [36,37]) with impact on equity investors' behavior (e.g., [38,39]). Concurrently, the lockdowns stemming from the pandemic brought about significant shifts in energy consumption patterns, leading to a notable reduction in CO2 emissions on a global scale [40]. Hence, given that the pandemic affected VC investment, CO2 emissions, and GDP, we should check whether our baseline findings are affected or not by this relevant shock.

To test this hypothesis, which could represent one relevant confounding factor in our empirical strategy, we estimate our baseline model by limiting the sample to the pre-pandemic period (2011–2019). Reassuringly, the results of these estimations (displayed in Table 5) are consistent both in terms of sign, magnitude, and significance to those of the baseline, thus confirming our main findings.

Table 5. Robustness—exclusion of pandemic times.

Dependent Variable	**Environmental Intensity**			
Model Specification	**(1)**	**(2)**	**(3)**	**(4)**
VC investments	−0.0010 *		−0.0012 **	
	(0.0005)		(0.0005)	
VC transactions		−0.0072 ***		−0.0078 ***
		(0.0018)		(0.0021)
GDP	−0.1291 **	−0.2590 **	−0.1199 **	−0.2401 **
	(0.0570)	(0.1030)	(0.0561)	(0.1025)
Population	0.3707 ***	0.6881 ***	0.3666 ***	0.6859 ***
	(0.0996)	(0.1955)	(0.1000)	(0.1973)
Tech	−0.0952	−0.2047 *	−0.0920	−0.1953 *
	(0.0580)	(0.1080)	(0.0568)	(0.1063)
FDI	0.0012	−0.0013	0.0009	−0.0011
	(0.0024)	(0.0064)	(0.0024)	(0.0062)
Urb	0.0050	0.0140 *	0.0047	0.0133 *
	(0.0042)	(0.0076)	(0.0042)	(0.0076)
Year			−0.0038 *	−0.0129 ***
			(0.0022)	(0.0039)
Observations	1087	1087	1087	1087
Number of Countries	131	131	131	131
Adj. R-squared	0.3711	-	0.3508	-
Pseudo R-squared	-	0.0928	-	0.0927
Country fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	No	No

Note: The analysis covers 11 years from 2011 to 2019 and 131 countries. All variables are in the natural logarithm, except Urb (percentage) and venture capital transactions (number). VC investments and VC transactions are the variables of interest, referring to the amount of VC activity and the number of operations, respectively. GDP is the gross domestic product; Population is the population at the end of the year; Tech is the technology level; FDI is the amount of foreign direct investments; Urb is the percentage of population living in the urban area. All regressors are taken as one-year-lagged indicators. The table reports coefficient estimates followed by clustered standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

6. Heterogeneous Effects

We look at potential heterogeneous characteristics of VC investments across geographies and levels of income.

First, we categorize countries into their respective continents to investigate potential geographical differences with respect to the global approach adopted in the baseline estimations. Divergences might arise due to different available infrastructures and technologies, especially in the green innovation field; different environmental policies and regulations [16], which could be more or less favorable to green investments; and the different availability of natural resources, which can influence the ability to adopt renewable energy sources or low-carbon technologies. More specifically looking at the level of income, we then divide the countries in two different groups by following IMF's country classification (i.e., advanced economies vs. emerging and developing economies) and estimate two separate specifications of the models to test potential differential behaviors. Last, we test whether VCs play a tangible role in countries where the level of 'green' technologies is low, leveraging their experience in more technologically mature markets.

6.1. Geography

To test whether our baseline findings show heterogeneous performances based on geographical macro-areas, we construct a categorical indicator which uniquely identifies continents as follows: (i) Asia-Pacific, (ii) Europe, (iii) Americas, and (iv) Africa.

We then estimate our baseline model on each of the four sub-samples. Table 6 reports the results of these regressions. We find that the negative and statistically significant relationship between VC activity and CO2 intensity seems to be concentrated in the Asia-Pacific continent, with Europe, Americas, and Africa showing not significant results. This test can indicate that the effects of VC activity might be less relevant in geographical areas where the attention to the environment is already high (such as Europe and the Americas), and the production methods are already focused on lowering emissions.

Table 6. Heterogenous findings based on geography.

Dependent Variable	Environmental Intensity			
Model Specification	**Asia-Pacific**	**Europe**	**Americas**	**Africa**
VC investments	−0.0017 *	−0.0020	0.0002	−0.0009
	(0.0009)	(0.0013)	(0.0007)	(0.0007)
GDP	0.0154	0.0140	−0.1117 ***	0.0225
	(0.0600)	(0.1259)	(0.0233)	(0.0364)
Population	0.0164	0.4618 **	0.1500	0.2416
	(0.0918)	(0.2076)	(0.4184)	(0.1900)
Tech	−0.3154 ***	−0.3012 **	−0.0101	−0.1602 ***
	(0.0586)	(0.1227)	(0.0070)	(0.0279)
FDI	0.0118 *	0.0023	−0.0022	−0.0062 *
	(0.0066)	(0.0018)	(0.0053)	(0.0035)
Urb	−0.0089 *	0.0049	0.0094 **	0.0079 *
	(0.0047)	(0.0076)	(0.0040)	(0.0044)
Observations	337	318	197	286
Number of Countries	37	37	22	34
Adj. R-squared	0.4665	0.6563	0.4533	0.2811
Country fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes

Note: The analysis covers 11 years from 2011 to 2021 and 131 countries. All variables are in the natural logarithm, except Urb (percentage). VC investments is the variable of interest, referring to the amount of VC activity. GDP is the gross domestic product; Population is the population at the end of the year; Tech is the technology level; FDI is the amount of foreign direct investments; Urb is the percentage of population living in the urban area. All regressors are taken as one-year-lagged indicators. The table reports coefficient estimates followed by clustered standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

6.2. Income Groups

We now investigate any potential heterogeneity in the relationship between VC activity and CO2 intensity based on income levels. Specifically, leveraging the IMF classification, we divide countries between advanced and developing economies. Our findings (Table 7) show that the effect on the environmental intensity of VC investments is significant only for developing economies.

The differences highlighted by the heterogeneity test show that in less advanced economies, VC investments play a role in reducing environmental intensity. On the other side, in advanced economies, where environmental regulations might already be stringent, companies may have adopted low-emission practices independently. However, ref. [16] indicates that institutional VC investments are more prominent in places with laxer policies and lower taxes. This raises questions about how governments can find the sweet spot: encouraging VC investments without creating unnecessary obstacles through overly strict regulations.

Table 7. Heterogenous findings based on income group.

Dependent Variable	Environmental Intensity	
Model Specification	**Advanced Economies**	**Developing Economies**
VC investments	−0.0010	−0.0010 *
	(0.0015)	(0.0006)
GDP	−0.1095 *	−0.1323 **
	(0.0543)	(0.0623)
Population	0.2353 *	0.3700 ***
	(0.1238)	(0.1225)
Tech	−0.0950	−0.1010
	(0.0631)	(0.0637)
FDI	−0.0001	0.0031
	(0.0011)	(0.0036)
Urb	−0.0004	0.0046
	(0.0039)	(0.0047)
Observations	300	848
Number of Countries	35	96
Adj. R-squared	0.7053	0.3619
Country fixed effect	Yes	Yes
Year fixed effect	Yes	Yes

Note: The analysis covers 11 years from 2011 to 2021 and 131 countries. All variables are in the natural logarithm, except Urb (percentage). VC investments is the variable of interest, referring to the amount of VC activity. GDP is the gross domestic product; Population is the population at the end of the year; Tech is the technology level; FDI is the amount of foreign direct investments; Urb is the percentage of population living in the urban area. All regressors are taken as one-year-lagged indicators. The table reports coefficient estimates followed by clustered standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

6.3. Levels of Environmental Innovation

So far, our analyses have shown that the negative and significant relationship between VC activity and CO2 intensity is concentrated in developing economies and the Asia-Pacific area. This provides suggestive evidence that VC is driving the effect in those areas where (i) environmental policies are not fully in place while CO2 emissions are rising, and (ii) technologies are not at the best efficiency level in terms of CO2 emissions compared to those available worldwide. Hence, VCs could play a tangible role in these areas to develop 'greener' technologies, leveraging their experience in more technologically mature markets.

We now want to test whether VC activity reduces CO2 intensity in areas where the level of environmental innovation is still limited. The underlying idea is that if environmental-related (or 'green') technology is not developed in a certain country, VCs could invest in startups with projects aimed at making technologies greener for economic purposes. An improvement in technologies toward more environmentally sustainable processes, in turn, would be beneficial to environmental intensity.

While our dataset lacks information at the VC-backed company level regarding the greenness of technology (e.g., green R&D expenditure or green patents), we focus on information available at the country level. Specifically, to test this hypothesis, we obtain data from the OECD on 'Environment-related technologies as a percentage of total technologies' and 'Environment-related technologies relative advantage', both at the country level. The first indicator is a proxy for the importance of green innovation in a country's innovation portfolio, while the second one is an indicator of the specialization in environmental innovation of a given country with respect to the world value. We use these data for 2010, as we aim for the available information not to be endogenously determined by VC activity measured in our time sample, given that we want to investigate whether VCs invest in areas where they can finance green improvements, ultimately making a beneficial impact on environmental intensity. We then construct two binary indicators, *EnvTechPerc* and *EnvTechRel*, being equal to 1 for countries in the top quartile of the distribution (i.e., 'green innovators') and zero otherwise. We estimate Equation (1) twice for each indicator, once for green innovator countries and once for the others, based on *EnvTechPerc* and *EnvTechRel*, respectively.

Our findings, presented in Table 8, highlight that the reduction effect of VC activity on environmental intensity is focused on countries that, at the beginning of the sample period, had fewer green technologies both with respect to domestic and global portfolios. These results provide suggestive evidence that VC activity contributes to the reduction in environmental intensity by financing startups in areas where they can contribute more to the development of new green technologies and innovations. These findings could have practical implications for entrepreneurs of startups who plan to develop green technologies/patents and aim to be financed by venture capitalists.

Table 8. Heterogenous findings based on level of environmental innovation.

Dependent Variable	**Environmental Intensity**			
Model Specification	**(1)**	**(2)**	**(3)**	**(4)**
VC investments	−0.0009	−0.0013 **	−0.0009	−0.0013 **
	(0.0008)	(0.0006)	(0.0009)	(0.0006)
GDP	−0.1984 *	−0.1064 *	−0.1990 *	−0.1061 *
	(0.0962)	(0.0593)	(0.0974)	(0.0592)
Population	0.6930 ***	0.3184 ***	0.6881 ***	0.3182 ***
	(0.2097)	(0.1073)	(0.2080)	(0.1070)
Tech	−0.1482 *	−0.0996	−0.1521 *	−0.0995
	(0.0787)	(0.0607)	(0.0802)	(0.0605)
FDI	0.0139	0.0011	0.0146	0.0011
	(0.0111)	(0.0024)	(0.0115)	(0.0024)
Urb	−0.0039	0.0057	−0.0037	0.0057
	(0.0056)	(0.0049)	(0.0055)	(0.0049)
Observations	1087	1087	1087	1087
Adj. R-squared	0.5040	0.3966	0.5087	0.3968
EnvTechPerc	1	0	-	-
EnvTechRel	-	-	1	0
Country fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes

Note: The analysis covers 11 years from 2011 to 2021 and 131 countries. All variables are in the natural logarithm, except Urb (percentage). VC investments is the variable of interest, referring to the amount of VC activity. GDP is the gross domestic product; Population is the population at the end of the year; Tech is the technology level; FDI is the amount of foreign direct investments; Urb is the percentage of population living in the urban area. All regressors are taken as one-year-lagged indicators. The table reports coefficient estimates followed by clustered standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

7. Conclusions, Policy Implications, and Future Research

7.1. Summary of the Main Findings

Venture capital activity has traditionally focused on innovative technologies with the potential for global changes and substantial returns. By directing attention toward advancements in green technologies, equity investments can align with environmentally friendly objectives, contributing to the realization of a net-zero emission economy by 2050, as outlined in the United Nations Sustainable Development Agenda. A primary deterrent hindering venture capitalists from exclusively pursuing green investments is the pronounced failure rate of startups in the clean technology sector, exceeding 75% [15]. The anticipation of benefits, such as lower taxes and the positive social impact associated with adopting green practices, provides an incentive for companies to embrace clean technologies. Conversely, non-clean technologies face additional costs, such as the imposition of a carbon tax designed to curtail greenhouse emissions from firms [19].

While environmental policies can serve as incentives for the adoption of green technology, excessively stringent regulations may dissuade institutional VC investors, typically drawn to ventures promising substantial returns. In such scenarios, governmental VC intervention becomes pivotal [16], where governmental VC, driven by non-revenue motives, tends to support cleantech companies in regions with more stringent policies. Building on previous evidence that suggests a positive association between VC activity and green growth (e.g., [4]), our hypothesis posits a negative relationship between VC investments and environmental intensity (proxied by CO2 emissions over GDP).

This study utilizes a unique dataset, structured as panel data observing VC activity and environmental intensity for 131 countries spanning the years 2011 to 2021. It employs the STIRPAT theoretical model—a stochastic reformulation of the IPAT model—to examine the impact of VC activity on environmental intensity. The baseline results confirm our hypothesis, suggesting that VC activity can serve as a financial instrument for reducing environmental intensity at the worldwide level.

Our baseline empirical model incorporates country and year fixed effects (and yearly linear trends in alternative specifications), an extensive set of control variables, and one-year-lagged regressors, addressing unobserved characteristics and potential endogeneity issues. Robustness testing, conducted by omitting one country at a time from the regression, excluding the pandemic period from the analysis, and using alternative definitions of environmental intensity, reaffirms the consistency of our results.

When the baseline model is stratified by continents, we find that the impact is concentrated in the Asia-Pacific region. Furthermore, the division into advanced economies versus emerging and developing economies reveals the significance of the VC value coefficient only for the latter group. These heterogeneity analyses underscore emerging geographical differences, potentially driven by variations in environmental and green finance policies. Advanced economies exhibit heightened attention to CO2 emissions, with widespread use of clean technologies, while developing and emerging economies employ less environmentally friendly methods. In this setting, we find that venture capitalists contribute to the reduction in environmental intensity mostly in countries showing a lower initial level of 'green' technologies, potentially leveraging their experience in more technologically mature markets.

These results address research questions posed by Dhayal et al. (2023) in their systematic review of green venture capital [25], providing a foundation for more in-depth analyses of VC investments' influence on green growth and highlighting geographical disparities influenced by VC activity.

7.2. Policy Implications

Our findings provide relevant insights for policymakers. While VC investors contributing know-how and clean technologies to emerging countries can impact CO2 intensity, their interest might be positively influenced by policies supportive of their activities. Recognizing the diverse impact of venture capital activity on environmental intensity across regions, policymakers may tailor strategies to the unique needs and conditions of each area. An optimal policy mix that fosters green VC investments while preserving essential environmental regulations could be explored. Integrating VC investments into a comprehensive, long-term strategy for environmental sustainability is another relevant consideration to address. Lastly, a crucial aspect involves continuously monitoring and adapting policies based on ongoing research and the ever-evolving global conditions.

7.3. Limitations and Future Research

Despite the suggestive insights, this study comes with some limitations. First, the sample could be expanded to include more countries, improving generalization and incorporating recent years for a more comprehensive understanding of environmental progress. Second, other alternative measures for CO2 intensity as dependent variables could enhance robustness testing. Third, detailed analyses considering country-specific divisions could offer valuable insights for national policymakers. Fourth, the empirical analysis could be replicated on other forms of equity investments, such as private equity. Lastly, exploring the heterogeneous responses of VCs to different policy rules is left for future research.

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Appendix A

Table A1. Baseline estimations (Static Model) with robust standard errors.

Dependent Variable	Environmental Intensity			
Model Specification	**(1)**	**(2)**	**(3)**	**(4)**
VC investments	−0.0013 ***		−0.0013 ***	
	(0.0005)		(0.0004)	
VC transactions		−0.0052 ***		−0.0055 ***
		(0.0012)		(0.0014)
GDP	−0.1834 ***	−0.3783 ***	−0.1750 ***	−0.3577 ***
	(0.0583)	(0.0814)	(0.0572)	(0.0809)
Population	0.3323 ***	0.5791 ***	0.3495 ***	0.6155 ***
	(0.0698)	(0.1026)	(0.0751)	(0.1078)
Tech	−0.1356 *	−0.2598 ***	−0.1392 *	−0.2649 ***
	(0.0713)	(0.0958)	(0.0721)	(0.0976)
FDI	0.0024 *	0.0020	0.0025 *	0.0018
	(0.0015)	(0.0025)	(0.0015)	(0.0025)
Urb	0.0067 **	0.0196 ***	0.0065 **	0.0186 ***
	(0.0031)	(0.0042)	(0.0031)	(0.0042)
Year			−0.0031 **	−0.0135 ***
			(0.0012)	(0.0016)
Observations	1215	1215	1215	1215
Number of Countries	131	131	131	131
Adj. R-squared	0.6367	-	0.6352	-
Pseudo R-squared	-	0.0960	-	0.0959
Country fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	No	No

Note: The analysis covers 11 years from 2011 to 2021 and 131 countries. All variables are in the natural logarithm, except Urb (percentage) and VC Transactions (number). VC investments and VC transactions are the variables of interest, referring to the amount of VC activity and the number of operations, respectively. GDP is the gross domestic product; Population is the population at the end of the year; Tech is the technology level; FDI is the amount of foreign direct investments; Urb is the percentage of population living in the urban area; Year is a linear yearly trend. The table reports coefficient estimates followed by robust standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

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