Are cities venturing green? A global analysis of the impact of green entrepreneurship on city air pollution

Small Bus Econ
https://doi.org/10.1007/s11187-023-00764-4

Are cities venturing green? A global analysis of the impact of green entrepreneurship on city air pollution

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Accepted: 22 March 2023

Abstract Situated at the intersection between environmental entrepreneurship and urban sustainability, our paper seeks to investigate the links between city-level green venture ecosystems and the ability of urban centres to reduce air pollution. Using a large dataset of 12,834 urban centres from around the world and their associated yearly average particulate matter (PM2.5), we show that an increase in the cumulative number of green start-ups drives the lowering of PM2.5 levels. Looking closely at the subsectors that drive the results, we observe that the urban centres which hosted increased numbers of innovators in smart grid technologies, energy efficiency and wind energy generation (the low carbon energy sector overall) also experienced a decrease in air pollution over the 2010–2019 period. Thus, our study is a global analysis of the environmental impact of green entrepreneurship on local air pollution.

Plain English Summary This research seeks to understand the link between green venture-backed start-ups and air pollution within urban centres around the world. We find that there is a direct link between the number of green start-ups, venture capital (VC) funding and air quality. The air quality of an urban area improves with the number of green

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Published online: 14 April 2023

start-ups and with the number of VC funding. We use multiple tests and the passing of legislations to determine the causality of that relationship.
We also run an analysis to determine the start-up sectors that have the highest impact on the air quality of their urban area, they were energy efficiency, materials, smart grid and wind start-ups. Surprisingly, some of the sectors from which we would have expected the highest impact, such as air quality start-ups, did not improve the quality of the air in their urban centres.

Keywords Urban entrepreneurship · Green entrepreneurship · Air pollution · Impact investing

JEL Classification Q53 · Q55 · Q58 · L26 · L31

1 Introduction

Air pollution causes harm to human health and other living beings. Ample evidence has shown that exposure to air pollution impacts health, cognitive performance, labour productivity and educational outcomes (Currie et al., 2014; Zhang et al., 2018; Zheng et al., 2019; Zivin & Neidell, 2012). Globally, air quality issues have resulted in protests and public outcry around the world (Zalakeviciute et al., 2021). Technological advances have been crucial to addressing the air pollution problem. The 1970 smog, for instance, brought in the "Clean Air Act" which led to significant investments into environmental technologies, specifically in the transport sector, and the invention of the catalytic converter (Palucka, 2015).

Hence, in the past decades, as governments have retreated from being providers of a wide range of environmental and social services, the spotlight has been on entrepreneurs to solve society's challenges through innovation (Malen & Marcus, 2017; York & Venkataraman, 2010). Entrepreneurs' response to this phenomenon was through "place-based" enterprise, which developed into purpose-driven urban entrepreneurship (Shrivastava & Kennelly, 2013; Cohen & Muñoz, 2015). These entrepreneurial ventures start with the sole purpose of solving a specific societal issue, be it environmental or not. The growing impact of environmental issues on the collective mind has pushed these ventures to become more environmentally aware. Indeed, green entrepreneurs and venture capital investors are now at the forefront of solving many environmental problems, investing and developing new materials and clean technologies that in theory, it should have a positive environmental impact (Vedula et al., 2021). This expectation from entrepreneurs has been also seeded by investors, as the concept of impact investing emerged in the aftermath of the financial crisis. In particular, the investment community was looking for a path to redemption in the general public's eyes, whereby investments would be needed to address environmental outcomes (Agrawal & Hockerts, 2019).

Although historically the literature on green entrepreneurship is rather limited in studying knowledge spillovers (Cojoianu et al., 2020b; Colombelli & Quatraro, 2017), the influence of social norms on green entrepreneurship entry (Meek et al., 2010; Vedula et al., 2018; York & Lenox, 2014), the growth and scalability of green ventures (Doblinger et al., 2019; Parker et al., 2019) and the prosocial intentions of entrepreneurs (Moroz et al., 2018), it has become apparent that there is a substantial gap in linking green entrepreneurship with real environmental outcomes (Vedula et al., 2021), and particularly within the spatial context in which impact occurs.

Situated at the intersection between environmental and urban entrepreneurship, our paper seeks to understand whether cities with VC-backed green are able to faster reduce their air pollution levels (proxied by the yearly average PM2.5 levels), for 12,834 urban centres around the world between 2010 and 2019.[1] As sustainable urban entrepreneurship is a novel topic, and the previous literature does not fully allow us to form strong convictions on hypotheses, similarly to Cojoianu et al., (2020a, 2020b), Feldman et al. (2019) and Moeen and Agarwal (2017), we employ an exploratory research design to unveil the impact of (green urban) entrepreneurship on an important and city-level relevant environmental indicator, air pollution.

[1] We use cities and urban centres as interchangeable in this paper, as we follow the OECD definition of a "functional urban area" which "encompass the economic and functional extent of cities based on daily people's movements". Source: Dijkstra et al. (2019). In addition, we use the term green VC cities as cities which have at least one green VC-backed start-up. Green venture capital deals are identified by the greenness of the start-ups that raise VC/PE financing — using the taxonomy developed by Cleantech Group.

By using the best-in-class venture capital and private equity datasets from Preqin and Cleantech Group (Appendix Table S9) comprising over 378,187 investment deals and 167,256 VC-backed start-ups, our paper finds that during the period 2010–2019, cities with a larger cumulative number of green start-ups have decreased their air pollution. We also find evidence, but slightly weaker, that the total cumulative number of VC-backed start-ups in an urban centre is also conducive to better air quality. Looking closely at the subsectors that drive the results, we observed that the urban centres which hosted increased numbers of innovators in smart grid technologies, energy efficiency and wind energy generation (the low carbon energy sector overall) also experienced a decrease in air pollution over the 2010–2019 period.

Our study is structured in the following way. In Sect. 2, we build the theoretical background for sustainable urban entrepreneurship and theorise how green entrepreneurs can influence environmental outcomes in the context of an urban centre. In Sect. 3, we detail the data and methodology, followed by the synthesis of results in Sect. 4. We discussed our findings and conclude in Sect. 5.

2 Theoretical background and research questions

2.1 The emergence of green entrepreneurship

Entrepreneurship is the discovery and creation of new goods, ventures and markets (Shane & Venkataraman, 2000) and relies on the creativity and problem-solving capabilities of individuals and firms (Hsieh et al., 2007). The global transition to sustainable development goals has prompted a new generation of entrepreneurship. Through business model, technological, financial and social innovation, these "green entrepreneurs" are agents for social and environmental change (Anderson, 1998), operating at the forefront of addressing some of the biggest challenges of our time (Malen & Marcus, 2017; York & Venkataraman, 2010).

Research on green or environmental entrepreneurship has its roots in economic sociology as well as institutional economics (Dean & McMullen, 2007; Russo, 2001) and has been focused historically on explaining the emergence of market-based solutions to environmental problems that are the result of market failures and the inability of governments to regulate environmental externalities (Cohen & Winn, 2007; Cojoianu et al., 2020b; Dean & McMullen, 2007). A significant number of studies have investigated knowledge spillovers in the context of green entrepreneurship, and the inherent spatial dimension of these spillovers, often at the level of city, region or start-up cluster level (Audretsch & Feldman, 1996; Cojoianu et al., 2020b; Colombelli & Quatraro, 2017; Vedula et al., 2018). Knowledge spillover scholars have argued that entrepreneurship opportunities emerge due to an expected valuation asymmetry of uncommercialised knowledge between knowledge creators and potential entrepreneurs who seek new opportunities and have the absorptive capacity to integrate new knowledge created (Acs et al., 2009; Audretsch & Keilbach, 2007; Cojoianu et al., 2020b; Qian & Acs, 2013). Furthermore, the incentive to produce green knowledge and start new green ventures is unusual, as it is often characterised by the "double externality" issue, which has to do with the fact that green knowledge has positive externalities not only in the innovation stage but also in the diffusion stage, by reducing environmental harm compared to conventional technologies (Cainelli et al., 2015; Rennings, 2000).

Thus, in taking a first step to understand the impact of green ventures on society, entrepreneurship scholars have been interested in studying the prosocial intentions of entrepreneurs as an early indicator of green entrepreneurship (Pacheco et al., 2010). The source of these motives is understood to lie within the traits identity of entrepreneurs (Vedula et al., 2021; York et al., 2016), who may have both commercial and impact goals. These dual goals are not prevalent only in entrepreneurs themselves, but also within their funders. This has been the case with impact investors, which aims to simultaneously deliver two objectives: (i) social and environmental benefits and (ii) financial returns for a desired investment risk level (Cojoianu et al., 2021). Cojoianu et al. (2021) find impact investing firms to be younger than ESG investment firms and more labour-intensive. Impact investing firms are more likely to be owned by governments, particularly in Europe. They invest overproportionally in agriculture, cleantech and education sectors and partner with academia in particular to measure and track their impact. Barber et al. (2021) indicate that impact investors indeed balance both objectives and hence display a willingness to forgo return for social good and that they mainly invest in private financial markets such as venture capital and private equity.

Although the intention to generate extra-financial returns may be there, Vedula et al. (2021) warn that the "implicit assumption of many entrepreneurship researchers and practitioners is that entrepreneurship is an inherently positive process at the individual, organisational, and societal levels" (Vedula et al., 2021, p.36). However, this is not always the case (Baumol, 1996; Shepherd, 2019), leading to further environmental degradation such it in the case of fossil fuel entrepreneurship (Cojoianu et al., 2020b). Furthermore, studies focusing on green entrepreneurship have yet to link the process of entrepreneurship with actual societal impact (e.g. air pollution reduction, climate change mitigation, biodiversity conservation at the city-region level) and have focused mostly on drivers of entry, growth and innovation of green solutions, regardless of whether these make an actual difference or not. To some extent, the literature has recognised that the success of green entrepreneurs depends also on social movements (Meek et al., 2010; Vedula et al., 2018), policy interventions (Cojoianu et al., 2020b) and partnerships with different types of stakeholders: cities and municipalities, universities or corporate incumbents (Doblinger et al., 2019) but has yet to understand how green entrepreneurship results in positive environmental outcomes, in particular at the city-region level.

This research gap is significant, and addressing it has important policy implications. If entrepreneurship is indeed a key enabling channel to solve environmental issues, then in addition to more stringent environmental regulation (Cojoianu et al., 2020b), both national and more devolved levels of government should also promote entrepreneurship and benefit from the environmental spillovers they generate. Institutional theory contends that organisations are both grounded in and shaped in the regulatory, social and cultural environments that they operate in (Bruton et al., 2010; Scott, 1995). Besides knowledge spillovers and the characteristics of specific entrepreneurs, the formal regulatory setting (Cojoianu et al., 2020b) as well as local pro-environmental norms is a significant driver of green entrepreneurship (Vedula et al., 2018). To alleviate concerns that the same factors drive air pollution reduction in our empirical testing and not entrepreneurs themselves, we include a global proxy for air pollution legislation and design a difference-in-differences robustness test to understand whether indeed VC-backed green entrepreneurship is a statistically significant driver of local air pollution reduction.

In this light, in the next section, we explore the link between green and urban entrepreneurship and seek to understand potential mechanisms through which (green) entrepreneurs can improve the environmental outcomes at the city-region levels.

2.2 Green entrepreneurship and sustainable urban development

Cities have a huge role to play in fostering entrepreneurship. Innovators congregate in cities to benefit from economies of scale, agglomeration of economic activities and infrastructure (Brown, 1975; Dieperink & Nijkamp, 1987; Martin & Sunley, 1998). Skilled labour clusters towards urban centres, providing and drawing from knowledge spillovers that encourage innovation. As such, cities are centres of all knowledge including environmental innovation.

Urban centres are also foci of capital. Investors clusters in these regions to take advantage of economic opportunities, providing capital for innovation. The 2008 global financial crisis and concerns on climate change and resource scarcity prompted a global sustainable finance agenda which is an attempt by investors to regain societal trust through financing projects that deliver not only financial gains but also environmental and social outcomes (Agrawal & Hockerts, 2019; Benedikter & Giordano, 2011). In this light, urban centres are ideal testing grounds for new solutions at the intersection between human–environment interactions (Schroeder et al., 2013).

Green urban entrepreneurs, unlike traditional environmental entrepreneurs who focus on market-based solutions towards solving government failures, need a better appreciation of public versus private goods, how these are delivered at the neighbourhood, city, regional or global level and how commercial solutions can bridge the gap between governments, private sector actors and urban level environmental and social well-being (Cohen & Muñoz, 2015). In addition, entrepreneurship scholars acknowledge widely that entrepreneurs cannot succeed on their own and that they must work closely with other stakeholders, and in particular their clients, in order to unveil promising commercial opportunities (Cohen & Muñoz, 2015; Doblinger et al., 2019). Thus, partnerships with devolved levels of government including municipalities and cities are crucial to fulfil the promise of urban entrepreneurship as a place-based solution.

Cohen & Muñoz (2015) argued that while all entrepreneurs are embedded in a place, depending on the geographic scale at which an entrepreneur operates, either neighbourhood, city or global level, the opportunity context and interaction between entrepreneurs and cities varies. Urban entrepreneurs who operate at the neighbourhood level, while benefiting from enhanced social cohesion, tend to be project-based and relatively small-scale, although some projects or ventures may scale to provide city-level solutions. At the city level, urban entrepreneurs often require collaborations with civil society and most certainly the involvement of local city governments or municipalities. On the other hand, global urban entrepreneurs are those who are able to successfully scale solutions across cities, whether domestically and/or internationally, and are both locally embedded in their home cities as well as globally embedded in the cities they provide services to (Chen & Tan, 2009; Cohen & Muñoz, 2015). Therefore, to understand the role of green entrepreneurship in urban sustainability transitions, it is highly important that we understand the spatial embeddedness of entrepreneurs, the interactions between entrepreneurs, cities and other stakeholders involved in the delivery of environmental and social benefits to urbanites. (Yu & Gibbs, 2020).

For the purposes of our paper, we seek to investigate the impact that city-level as well as global green urban entrepreneurs have on their host cities. We contend that both city-level and global green urban entrepreneurs can influence their host cities (i.e. the cities they have been founded in) for the interactions that they have with numerous stakeholders within the city, through the commercial solutions they offer to cities and municipalities as well as through the green knowledge spillovers they generate within the local economy (Cojoianu et al., 2020b). Furthermore, as Cojoianu et al., (2020a, 2020b) have shown, green knowledge creation is appropriated not only by green entrepreneurs, but also by conventional entrepreneurs who want to incorporate green principles within their modus operandi (Isaak, 2016).

We look closely at air pollution, given its geographical contextuality and local relevance. The key drivers of air pollution differ across geographies. While our study is not able to test the mechanisms through which green urban entrepreneurship impacts the air pollution levels of an urban centre, we would like to take the opportunity to reiterate the most plausible channels. First and foremost, sustainable urban entrepreneurs can impact the air pollution level of their host urban centres through the products and services that they provide directly to cities and municipalities, by replacing the existing polluting infrastructure with less polluting and lower carbon alternatives such as it is the case in the energy sector (which drives the bulk of our results) or the transportation sector which has historically been responsible for a large part of the local air pollution problem. This may be possible as a result of more stringent air pollution legislations which can enable new entrants or new entrants seeking to change the legislative setting through policy entrepreneurship. This legislative change which allows for green entrepreneurs to flourish may need significant time till new entrants gain a critical mass, enough to be noticed and prioritised by policymakers (Georgallis et al., 2019). In countries such as China, in key economic areas, pollution is driven by coal, flat glass, coke and steel production. In less central economic areas, the reason for air pollution is known to be coal, coke and power generation (Wei et al., 2017). This shows that in both areas, the main sources of pollution in both areas are directly related to energy production as coal and coke are both strong persistent drivers. In Europe and the USA, as they are slowly phasing out coal and coke, other drivers such as transport become more salient (Colvile et al., 2001.; Gürçam et al., 2021; Oolen & Rothenberg, 2019). Thus, a first channel through which green entrepreneurship impacts air pollution is by directly replacing the polluting infrastructure of incumbents (e.g. Tesla electric cars replacing combustion engine vehicles).

Furthermore, green entrepreneurship can generate significant knowledge spillovers which are absorbed across different industries (Cojoianu et al., 2020b; Qian & Acs, 2013), which can occur through supply chain interactions, human capital mobility and other opportunities to exchange tacit and codified knowledge about the green sector. Environmental-specific knowledge, however, may be more complex and sophisticated than other types of knowledge (Cainelli et al., 2015), as green knowledge is often characterised by the "double externality issue" through the generation of positive (unmonetised) externalities at both the innovation as well as the diffusion stage (Cainelli et al., 2015; Rennings, 2000). It is entirely possible that green entrepreneurs generate knowledge spillovers which in turn translate into knowledge and commercial opportunities to tackle air pollution by existing incumbents themselves. While green entrepreneurship may fail in directly replacing polluting infrastructure, the knowledge they created on new technologies, less polluting products or processes may still be used by other commercial actors due to the knowledge spillover mechanism.

Another indirect mechanism through which green entrepreneurs and their financial backers may influence air pollution is by seeking to change institutional norms and formal legislation themselves (Cohen & Winn, 2007; Cojoianu et al., 2020b). Pacheco et al. (2010) document the case of Khosla Ventures which often promoted the elimination of oil subsidies and the introduction of carbon taxes to make it harder for polluting industries to compete and create a level playing field for the emerging cleantech sector. The strategies to influence government legislation include direct lobbying (Tesla's lobbying budget in 2021 was $560,000[2]) as well as softer public perception and information campaigns that may change voter preference towards politicians with a more environmentally progressive agenda (Pacheco et al., 2010). Given the many ways in which green venture capital can influence air pollution in urban areas, similarly to Cojoianu et al. (2020b), Feldman et al. (2019) and Moeen and Agarwal (2017), we employ an exploratory research design. Thus, our hypotheses are the following:

H1. Venture capital cities are more likely to reduce their air pollution than non-venture capital cities.
H2. Green venture capital cities are more likely to reduce their air pollution compared to non-green venture capital cities.
H3. The impact of green venture capital on air pollution in cities is moderated by the green technology financed.

[2] Source: opensecrets.org.

3 Data and methodology

3.1 Data

3.1.1 Dependent variable

Our dependent variable which proxies the average air quality within a city over a year is the average population mean exposure to PM2.5,[3] which was estimated by the OECD based on the Global Burden of Disease 2019 (GDB) project data. The input raster files, available at a resolution of 0.1×0.1 degree (approximately 11×11 km at the equator), provide for each grid cell and for each year the population-weighted average concentration in PM2.5 (in µg/m3). These raster files were combined with the urban centre geometries and the GHS 2015 population grid to compute the population-weighted average for each urban centre. The PM2.5 concentration grids were first multiplied by the population grid. The sum of all the cells intersecting the same urban centre was then divided by the population within the same urban centre (computed using the same population grid). In total, our dataset covers PM2.5 levels for 12,834 urban centres around the world for the years 1990, 1995, 2000 and 2005 and continuously between 2010 and 2019. Given the 5 year gaps up to 2010, as well as independent and control variable availability, we focus our study over the 2010–2019 period.

3.1.2 Independent variables

Our key explanatory variables are obtained from merging two leading commercial research providers: Preqin, one of the top global providers of robust data on private financial markets, which is increasingly used in academia (Ang et al. 2018; Barber et al. 2019; Harris et al. 2014; Nadauld et al. 2019). This dataset is complemented by CleantechGroup, which is a data provider specialised in green venture capital and private equity start-ups and deals around the world

[3] PM2.5 — "stands for particulate matter (also called particle pollution): the term for a mixture of solid particles and liquid droplets found in the air.[…] Particulate matter contains microscopic solids or liquid droplets that are so small that they can be inhaled and cause serious health problems". Source EPA: https://www.epa.gov/pm-pollution/particulate-matter-pm-basics

(Doblinger et al., 2019). Both datasets have coverage of start-ups and deals since early 2000; however, the data completeness is particularly enhanced for our study period 2010–2019.

Using the two data providers above, and the green taxonomy provided by CleantechGroup, using ArcGIS, we match each of our 167,256 start-ups and their addresses with the 12,834 urban centres in our database. Based on this, for each urban centre, we build six key independent variables: the number of cumulative green start-ups,[4] cumulative green start-up funding ($), the number of total cumulative green start-ups, cumulative total start-up funding ($), the number of new start-ups founded in a given urban centre (lagged 1 year) and the amount of new funding received by all start-ups in the urban centre (lagged 1 year). Our identification of green urban entrepreneurs relies on the definition of CleantechGroup, which encompasses entrepreneurs in the following sectors: advanced materials, agriculture, air pollution, biofuels, biomass, energy efficiency, energy storage, fuel cells, geothermal, nuclear, recycling, solar, transportation, water and wind energy.

3.1.3 *Control variables*

For a select number of cities (1572), we are able to collect additional control variables from Mergent Online: yearly GDP per capita, total workforce and the unemployment rate for the largest urban centres in our database.

3.2 Model specification

In this paper, we use a fixed effects OLS model as our primary model with standard errors clustered at the city level and further complement our analysis by employing a Mundlak model (as explained below). For robustness purposes and to test for reverse causality, we employ Godfrey et al. (2020)'s reverse causality minimisation procedure and also employ longer lags in our independent variables. Our main findings also hold for these alternative specifications.

Fixed-effects models can only provide an estimation of within-cluster variation (in our case within regional variation), and cannot estimate the effect of the average variation between regions (Cojoianu et al., 2020a; Schunck & Perales, 2017). Random effects models, on the other hand, assume that the within-cluster variation and between-cluster variation are statistically the same. However, when this is not the case, the results of the random effects model are often meaningless (Bell et al., 2019). The solution to these issues is to estimate a random effect model which features time-varying covariates expressed as deviations from the individual-specific means. This estimation strategy allows us to differentiate within- and between-regional effects, and thus, we can leverage the strengths of both random- and fixed-effects models (Bell et al., 2019; Schunck & Perales, 2017). A between-within estimator used to estimate our econometric models is specified by Eq. 1 below:

$$y_{i,t} = \beta_W\left(x_{i,t} - \overline{x}_i\right) + \beta_B\overline{x}_i + \mu_t + \varepsilon_{i,t} \tag{1}$$

In Eq. 1, the effect of the independent variable $x_{i,t}$ on $y_{i,t}$ is divided in β_W which represents the average within-region variation of $x_{i,t}$, and β_B which explains the remaining between region average variations. The model in Eq. 1 can be re-written in a mathematical equivalent form as shown in Eqs. 2 and 3, so that the resulting coefficient on $\overline{x}_i$ represents the contextual effect (the average between region effect while keeping $x_{i,t}$constant), and β_W can be still interpreted as the average within-region variation of $x_{i,t}$. The model written in the form of Eq. 3 is also known as the correlated random-effects model (Wooldridge, 2010) or the Mundlak model (Mundlak, 1978; Schunck & Perales, 2017).

$$y_{i,t} = \beta_W x_{i,t} - \beta_W\overline{x}_i + \beta_B\overline{x}_i + \mu_t + \varepsilon_{i,t} \tag{2}$$

$$y_{i,t} = \beta_W x_{i,t} + (\beta_B - \beta_W)\overline{x}_i + \mu_t + \varepsilon_{i,t} \tag{3}$$

Hence, we follow the Mundlak (1978) model (Eq. 3) and report both within urban centre effects (β_W) and contextual between urban centre effects ($\beta_B - \beta_W$), to understand the source of the variation that explains the variation in air pollution across our dataset.

4 Synthesis of results

Figure 1 depicts the distributional change in air pollution between 1990 and 2019. Overall, air quality has

[4] Our cumulative calculation include all the start-ups and deals from the year 2000 onwards.

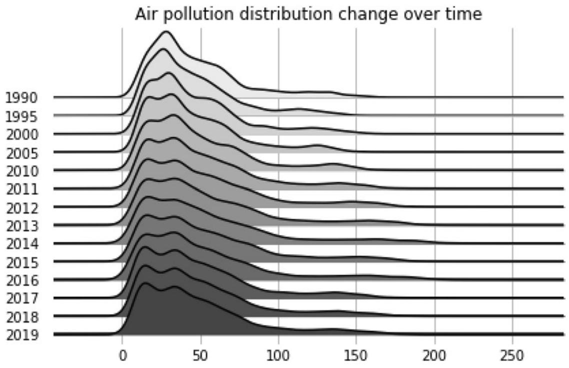

Fig. 1 Air pollution distribution change over time between 1990 and 2019

Over time, however, air pollution problems are improving in some regions and deteriorating in others. Figure 3 shows the difference in the global distribution of air pollution change by cities between 2019 and 2010. Here, we observe a different perspective. The green areas indicate regions of air quality improvement, namely Europe, North America and mid and south China are experiencing better air quality. In India, coastal regions of South America, Ethiopia, Indonesia and Saudi Arabia on the other hand, air quality is worsening at an alarming rate. In the 1990s, there was a limited investment in clean technologies. Advanced materials and energy efficiency were popular choices. In the 2000s, biofuels, biochemicals and

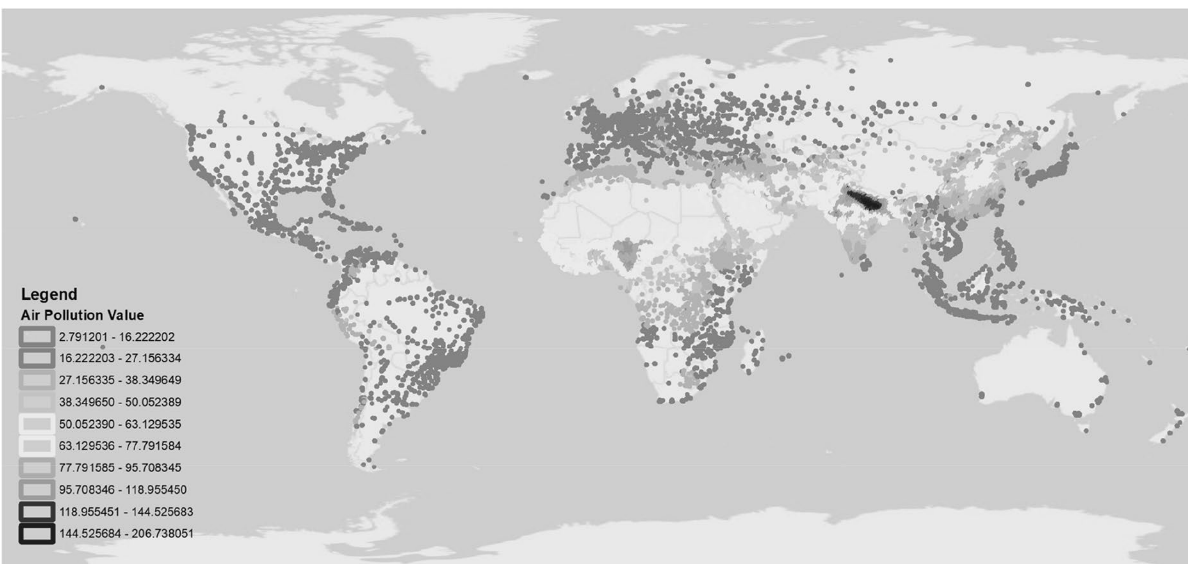

Fig. 2 Global distribution of air pollution by cities in 2019, as measured in PM 2.5. Total number of cities included: 11,134. Data from the OECD and the Joint Research Centre of the European Commission

improved slightly over time. However, there are significant regional differences. Most notably, the highest value of air pollution increased to above 200 PM in the mid-2000s, compared to below 200 PM in the 1990s. Figure 2 shows the global distribution of air pollution by cities more clearly. In 2019, the distribution of air pollution hotspots in the world concentrate along the equator, most notably in central Africa, south Asia and east Asia. Countries such as India, Pakistan, Bangladesh, China and Nigeria have some of the worst air pollution problems.

solar investments took off, reaching 4.7 billion and 2.1 billion USD respectively. The financial crisis in 2008 resulted in a dip in green investment, although the impact did not last long. Investment in clean technologies increased significantly to over 40 billion by 2012, where wind and solar technologies became the focus. Between 2013 and 2019, a second wave of investment in green technologies occurred. During this period, investors shifted towards transportation, agriculture and food-related green technologies with an impressive 64 and 16.5 billion USD respectively in 2018.

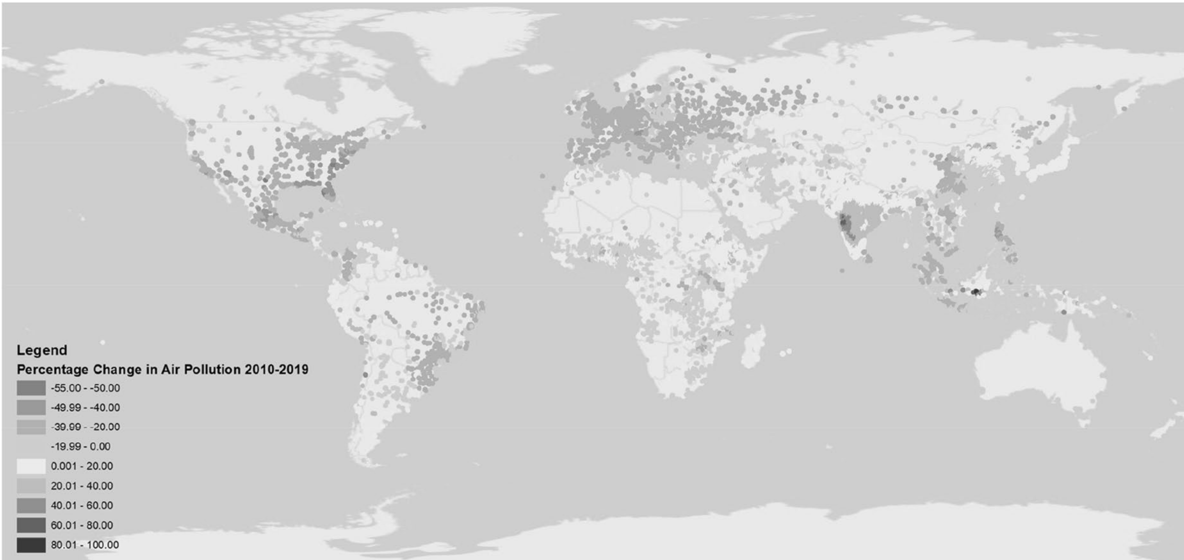

Fig. 3 Difference in global distribution of air pollution change by cities between 2019 and 2010, as measured in PM 2.5. Data from the OECD and the Joint Research Centre of the European Commission

The geography of global green venture capital centres is not surprising (Table 1); however, Table 2 shows novel insights into cities with the most progress in air quality improvement, which shows that the majority of the Top 20 is monopolised by the USA.

Our statistical models (Table 3) show that urban centres that have a higher historical number of VC-backed green start-ups are associated with a lower air pollution level over the period 2010–2019 (Models 1–7). The regressions are log–log models; hence, the coefficients are to be interpreted as elasticities. Model 1 suggests that a 50% increase in the average cumulative green start-ups within a city is related to a 25% reduction in air quality over the 2010–2019 period. The statistical significance of the coefficient holds when controlling for the total cumulative number of start-ups in a region, the amount of VC/PE funding an urban centre is receiving and region-city economic variables (Appendix Table 10). The decrease in air quality is related to city-level increases in GDP and total labour, which shows the relationship between economic activity and air pollution. We investigate further and show that the variation in air quality is driven by the difference in cumulative green start-up numbers between cities, and less so (although still statistically significant) by the increase in cumulative

Table 1 Top 20 cities with most cumulative green start-ups (2000–2019). Data from Preqin and CleantechGroup

City/urban area	Number of green start-ups founded
San Jose	1303
Paris	1055
Los Angeles	800
Sao Paulo	477
London	462
New York	451
Boston	362
Toronto	356
Delhi [New Delhi]	323
Mumbai	306
Berlin	298
Rotterdam [The Hague]	261
Guangzhou	256
Dortmund	224
Singapore	220
Tel Aviv	219
Amsterdam	190
Tijuana	187
Seattle	181
Vancouver	180

Table 2 Top 20 cities with most air pollution reduction (2000–2019)

City/urban area	Country	Air pollution 2000	2019	% change
Greensboro	USA	17	8	−53.87%
Tampa	USA	13	6	−52.15%
Bradenton	USA	11	5	−51.92%
Durham	USA	16	8	−51.77%
San Angelo	USA	15	7	−51.18%
Winston-Salem	USA	16	8	−50.96%
Cary	USA	16	8	−50.39%
Spring Hill	USA	11	6	−49.87%
Raleigh	USA	15	8	−49.51%
Tï¿½xpam	Mexico	36	19	−49.00%
Palm Bay	USA	9	5	−48.87%
Cocoa	USA	10	5	−48.76%
Fayetteville	USA	15	8	−48.57%
Tuscaloosa	USA	17	9	−47.59%
Mestre	Italy	44	23	−47.40%
Roanoke	USA	14	7	−47.37%
Poza Rica	Mexico	35	19	−47.36%
Baguio	Philippines	41	22	−47.10%
Orlando	USA	11	6	−47.09%
Pensacola	USA	14	7	−46.89%

[*]Air pollution to two significant numbers

green start-ups within cities (Table 4). Interestingly, we do not find that VC centres in general are more likely to reduce their air pollution, as the reduction is driven primarily by the presence of green start-ups and not by an overall start-up ecosystem. This means that cities are very unique in terms of their industry composition and the population exposure to PM2.5 and this uniqueness explains to a great proportion the variation over our sample. That being said, although the average exposure to PM2.5 across cities can be very different, the year-on-year variation and downward/upward trending over time can be statistically significantly explained by the variation in the presence/absence of VC-backed green entrepreneurship.

At the sub-technology level (Table 5), we find that only green VC centres that have historically developed their green start-up ecosystems around the grid, energy efficiency, wind and low-carbon material sectors are those that are driving the overall results. While we expected for clusters that specifically had air pollution and transportation start-ups to also exhibit a strong air pollution reduction potential, this was not statistically significant when we implement our full models.

We conduct further robustness tests that seek to alleviate endogeneity concerns, particularly with respect to reverse causality and missing variable issues. As cities themselves run numerous programmes to attract green entrepreneurs and given that it is possible that green urban entrepreneurs are attracted by leading cities that tackle air pollution in the first place (Cohen & Muñoz, 2015; Yu & Gibbs, 2020), through the methodology presented further, we seek to isolate the effect that cities that lead in air pollution reduction have on green entrepreneurship from the impact of green entrepreneurship on urban air pollution.

To do so, we use the method developed by Godfrey et al. (2020), who proposed a Granger-style reverse causality minimisation procedure, which can be used in the absence of a natural experiment. The method involves the following steps: First, we regress cumulative green entrepreneurship$_{i,t-1}$ on lagged air pollution$_{,t-2}$, to separate green entrepreneurship into two components, one which is driven by city air pollution, and one which is unrelated to city air pollution. The latter is the sum of the intercept and the disturbance term of the regression. We name this term orthogonalised cumulative green entrepreneurship. We confirm that orthogonalised green entrepreneurship$_{i,t-1}$ obtained this way has two very important properties: (i) it has a zero (or very close to zero) correlation to air pollution and (ii) a Granger causality F-test for air pollution$_{,t-2}$ causing orthogonalised green entrepreneurship$_{,t-1}$ is insignificant. As a final step, we regress air pollution$_{i,t}$ on our orthogonalised cumulative green entrepreneurship measure$_{i,t-1}$ and the associated control variables. We find that the effect of cumulative green entrepreneurship on urban air pollution retains its sign and significance as in our main models. We conduct an analogous process to disentangle the effect that air pollution has on the overall start-up ecosystem from the effect of cumulative start-ups on air pollution (Table 6).

In addition, to further check our results' reliability, we conduct a difference-in-differences analysis around new air pollution legislation passed around the world between 2009 and 2020, coinciding with

Table 3 The impact of (green) VC centres on urban air pollution

Dependent variable: Log(PM2.5)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log(cumulative green start-ups)	− 0.493***	− 0.159***	− 0.111***	− 0.098***	− 0.045***	− 0.049***	− 0.021**
	(0.018)	(0.007)	(0.006)	(0.007)	(0.008)	(0.008)	(0.008)
Log(cumulative green start-up funding)				− 0.003***	− 0.002***	− 0.002***	− 0.000
				(0.000)	(0.000)	(0.000)	(0.000)
Log(cumulative VC-backed start-ups)					− 0.106***	− 0.105***	− 0.008
					(0.006)	(0.006)	(0.007)
Log(cumulative VC/PE funding)						− 0.002***	0.000
						(0.000)	(0.000)
Log(new start-up funding)						0.001***	− 0.000
						(0.000)	(0.000)
Log(new number of start-ups)						0.007***	− 0.002
						(0.002)	(0.002)
Log(GDP per capita)							0.050***
							(0.006)
Log(total labour force)							0.006*
							(0.003)
Log(unemployment rate)							0.011**
							(0.005)
Constant	3.703***	3.670***	3.665***	3.666***	3.680***	3.680***	2.538***
	(0.006)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.065)
Observations	128,340	128,340	128,340	128,340	128,340	128,340	15,760
No. of cities	12,834	12,834	12,834	12,834	12,834	12,834	1576
City fixed effects	No	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
R-squared	0.0894	0.9900	0.9920	0.9921	0.9921	0.9921	0.9927

Robust standard errors in parentheses

***$p<0.01$, **$p<0.05$, *$p<0.1$

The model is OLS with city and year fixed effects with standard errors clustered at the city level. The dependent variable is the natural logarithm of the yearly average PM2.5 concentration at the city level. Independent variables are logged and lagged one year. In Models 5–7, the cumulative green start-ups (count) and cumulative green start-up funding variables are orthogonalised with respect to the number of cumulative VC-backed start-ups. Hence, for these models, the results can be interpreted as the effect of the excess cumulative green start-ups and funding on city-level air pollution. A similar orthogonalisation process has been conducted for cumulative VC/PE funding, new start-up funding and the new number of start-ups with respect to the cumulative number of VC-backed start-ups to avoid multicollinearity concerns

our dataset. To obtain these legislations, we manually map and investigate air pollution legislation data from Ecolex, an online database that keeps track of all environmental legislation passed worldwide, particularly at the national level. Out of all the countries in our sample period, 65 had passed legislation about air pollution or air pollution after 2009. We define the shock as any new law passed between 2009 and 2020. We explore the differences in the air pollution reduction after the introduction of new legislation in a given country, between green VC cities and non-green VC cities. A green VC city is a city that has hosted at least one green start-up between 2000 and the year of legislation change, and a non-green centre is an urban area that does not have a single green start-up. Using propensity score matching, we match these two city types using the cumulative number of start-ups across sectors within the city. The matches are limited to within the country and rebalanced every year until the legislation change event. To get the best estimate of the impact of the laws, and due to the constraint of matching within the same

Table 4 Mundlak model — the impact of green entrepreneurship on urban air pollution

Dependent variable: log air pollution (PM2.5)	(8)		(9)		(10)	
	Within city variation	Between city variation	Within city variation	Between city variation	Within city variation	Between city variation
Log(cumulative green start-ups)	−0.111***	−0.390***	−0.047***	−0.301***	−0.022***	−0.052*
	(0.006)	(0.019)	(0.008)	(0.019)	(0.008)	(0.030)
Log(cumulative VC-backed start-ups)				−0.095***	0.001	−0.019
				(0.007)	(0.009)	(0.021)
Log(GDP per capita)					0.049***	−0.343***
					(0.006)	(0.016)
Log(total labour force)					0.006**	0.225***
					(0.003)	(0.012)
Log(unemployment rate)					0.011**	−0.272***
					(0.005)	(0.020)
Constant	3.687***		3.693***		3.433***	
	(0.006)		(0.006)		(0.230)	
Loglikelihood	114,044		114,406		15,279	
Observations	128,340		128,340		15,760	
Number of groups (cities)	12,834		12,834		1576	

Cluster (city) robust standard errors in parentheses ***$p<0.01$, **$p<0.05$, *$p<0.1$. OLS log–log regression

country, we opted for replacement matching. The results confirm that green VC cities reduce their air pollution faster than non-VC cities following legislation change (Table 7). This effect is most prominent across African and Latin American cities (we are unable to test this in North America as we could not observe country-level legislation changes as these are enacted mostly at the state level, e.g. USA). We also re-run our initial models by introducing the number of all air pollution legislations in force for a given year and country as an independent variable, which we also lag 1 year (this was run across all countries), and the effect remains unchanged (Table 8).

5 Discussion and conclusions

In responding to the call of Vedula et al. (2021) and Acs et al. (2021)[5] to further the research agenda on how entrepreneurship delivers environmental and/or social returns, in particular, related to the sustainability of urban centres, our paper seeks to understand whether green VC-backed entrepreneurs have positively impacted air pollution levels in the urban centres they have been founded. On an extensive sample of 12,834 urban centres from around the world, we show that during the period 2010–2019, cities with a larger cumulative number of green start-ups have decreased air pollution (proxied by PM 2.5) more than those with no green start-up ecosystems. Looking closely at the subsectors that drive the results, we observed that the urban centres which hosted increased numbers of innovators in smart grid technologies, energy efficiency and wind energy generation (the low carbon energy sector overall) also experienced a decrease in air pollution over the 2010–2019 period. Our difference-in-differences analysis suggests that this effect is particularly prominent in African and Latin American cities.

Our study builds on the emerging literature on sustainable urban entrepreneurship, in particular on the framing of Cohen & Muñoz (2015), by analysing how VC-backed green entrepreneurs, who operate both at the city level as well as the global city network level, influence the air pollution of their host urban centres. In addition, we expand the literature on green entrepreneurship

[5] Small Business Economics Special Issue on Entrepreneurship and Sustainable Cities: https://resource-cms.springernature.com/springer-cms/rest/v1/content/18498788/data/v2

Table 5 Subsectoral analysis

Dependent variable: Log(PM2.5)	(11) Materials	(12) Agriculture	(13) Air pollution	(14) Biofuels	(15) Biomass	(16) Eeff	(17) Storage	(18) Fuel cells	(19) Geothermal
Log(cumulative green sub-sector start-ups)	−0.025**	0.010	−0.025	−0.017	0.005	−0.043***	−0.007	−0.013	0.049
	(0.010)	(0.007)	(0.017)	(0.015)	(0.026)	(0.009)	(0.012)	(0.018)	(0.057)
Observations	15,760	15,760	15,760	15,760	15,760	15,760	15,760	15,760	15,760
No. of cities	1576	1576	1576	1576	1576	1576	1576	1576	1576
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Total cumulative start-up no. and funding	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Total new start-up no. and funding	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.9927	0.9927	0.9927	0.9927	0.9926	0.9927	0.9926	0.9926	0.9927
Dependent variable: Log(PM2.5)	(20) Hydro	(21) Nuclear	(22) Misc	(23) Recycling	(24 Smart grid	(25) Solar	(26) Transportation	(27) Wastewater	(28) Wind
Log(cumulative green sub-sector start-ups)	−0.009	−0.003	−0.008	−0.011	−0.029**	0.009	−0.013	−0.017	−0.040**
	(0.023)	(0.021)	(0.006)	(0.011)	(0.012)	(0.014)	(0.008)	(0.014)	(0.016)
Observations	15,760	15,760	15,760	15,760	15,760	15,760	15,760	15,760	15,760
No. of cities	1576	1576	1576	1576	1576	1576	1576	1576	1576
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Total cumulative start-up no. and funding	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Total new start-up no. and funding	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.9926	0.9926	0.9927	0.9926	0.9927	0.9926	0.9927	0.9927	0.9927

Robust standard errors in parentheses

***$p<0.01$, **$p<0.05$, *$p<0.1$

Model is OLS with city and year fixed effects with standard errors clustered at the city level. The dependent variable is the natural logarithm of the yearly average PM2.5 concentration at the city level. Independent variables are logged and lagged one year. An orthogonalisation process has been conducted for cumulative VC/PE funding, new start-up funding and the new number of start-ups with respect to the cumulative number of VC-backed start-ups to avoid multicollinearity concerns

which so far has not analysed the real environmental and social impacts that entrepreneurship has on society but was rather limited in studying knowledge spillovers (Cojoianu et al., 2020b; Colombelli & Quatraro, 2017), the influence of social norms on green entrepreneurship entry (Meek et al., 2010; Vedula et al., 2018; York & Lenox, 2014) and the growth and scalability of green ventures(Doblinger et al., 2019; Parker et al., 2019).

Our research has multiple and important implications. For entrepreneurship researchers and urban scholars, our study lays the foundation towards understanding the real environmental impacts of green entrepreneurship on their local environment. Our study further adds to the emerging literature on impact investing, which changes the paradigm on the study of entrepreneurial ventures from financial success only, to considering both financial and extrafinancial returns as equally important (Barber et al., 2021; Cojoianu et al., 2021). Our study further frames VC-backed green entrepreneurship as

Table 6 Reverse causality minimisation procedure (Godfrey et al., 2020)

Dependent variable: Log(PM2.5)	(29)	(30)
Granger orthog cumulative green start-ups	−0.015**	−0.013*
	(0.007)	(0.007)
Granger orthog cumulative total start-ups	0.055***	0.054***
	(0.008)	(0.008)
Observations	102,672	102,672
No. of cities	12,834	12,834
City fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Total cumulative start-up funding	No	Yes
Total new start-up no. and funding	No	Yes
R-squared	0.9927	0.9927

Robust standard errors in parentheses

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 7 Difference-in-differences specification (green VC cities vs. non-green VC cities)

Dependent variable: Log(PM2.5)	(33) World	(34) Africa	(35) Asia	(36) Latin America	(37) Europe
Treatment × post	−0.029*	−0.083**	−0.023	−0.072***	0.016
	(0.016)	(0.035)	(0.018)	(0.021)	(0.013)
Constant	2.586***	3.404***	3.567***	2.783***	2.552***
	(0.007)	(0.006)	(0.008)	(0.007)	(0.006)
Observations	4,998	219	182	366	3,691
No. of cities	341	34	16	41	220
City fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
R-squared	0.9980	0.9788	0.9983	0.9906	0.9877

Robust standard errors in parentheses

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

a key generator of positive environmental externalities which are manifested at the local level. This opens up the opportunity for further theoretical and empirical studies that study in depth the mechanisms through which entrepreneurs impact the natural environment (Demirel et al., 2019; Ghisetti, 2018). The paper is highly relevant for the global policy environment around sustainable finance regulation and green taxonomies, which aim to clarify which economic activities substantially contribute to environmental objectives such as pollution prevention or climate change.[6] Thus, it prompts policymakers to consider new entrants as substantial contributors to positive environmental change and move away from a policy objective that optimises for "greening" incumbents. Our research also moves away from the intention and goals of new ventures of generating extra-financial returns to empirically testing whether these can be materialised in the case of impact on air pollution (Vedula et al., 2021). This has important implications for public policy, as Cojoianu et al. (2021) show that many captive investment arms of government institutions are looking to deploy capital in start-ups that make a difference to the environment or to social issues and, in addition, to have sound commercial business models. The paper suggests that as many governments around the world have retreated from providing environmental and social benefits, these responsibilities have been shifted onto market agents and lower tiers of government authority (Clark, 2012; Cojoianu et al., 2021; OECD, 2010). This paper fills the research gap to understand whether economic actors could contribute to the mitigation of environmental externalities of business.

Our study is not without its limitations. While we deal with the issue of reverse causality through Godfrey et al. (2020) and our study is robust to longer lags and alternative model specifications, our empirical setup is not necessarily causal, although we provide further robustness tests on the impact of air pollution legislation on cities with green VC start-ups vs. those without green start-ups. Secondly, we are only able to collect

[6] E.g. The EU Green Taxonomy legislation in Europe as well as the numerous other green taxonomies emerging around the world.

Table 8 Relationship between air pollution, legislation and GDP per capita

Dependent variable: Log(PM2.5)	(31)	(32)
Granger orthog cumulative green start-ups	−0.017**	−0.017**
	(0.008)	(0.008)
Granger orthog cumulative total start-ups	−0.002	−0.003
	(0.007)	(0.007)
Log(GDP per capita)	0.580***	0.496***
	(0.057)	(0.053)
Log(GDP per capita) # Log(GDP per capita)	−0.029***	−0.026***
	(0.003)	(0.003)
Log(country air pollution legislation)		−0.083***
		(0.007)
Constant	0.271	0.818***
	(0.268)	(0.252)
Observations	15,760	15,760
No. of cities	1576	1576
City fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
R-squared	0.9928	0.9930

Robust standard errors in parentheses

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

additional control variables for just over 12% of our sample cities, but we are reassured that the results hold. Finally, measuring air pollution across geography and space is inherently hard to do; hence, we rely on the proxies developed by the OECD and the Joint Research Centre European Commission. Finally, our study lacks the partnerships data or public procurement datasets which could have further provided insights on the mechanisms through which green urban entrepreneurs impact the quality across urban centres. We leave these worthwhile endeavours to future research.

Funding This work has been supported by funding from the ClimateWorks Foundation, Science Foundation Ireland (Award 19/FIP/AI/7539), the International Network for Sustainable Financial Policy Insights, Research, and Exchange (INSPIRE), the IRC and the EU Horizon 2020 Marie Sklodowska-Curie grant agreement No. 713279 (CLNE/2018/202), the European Union's Horizon 2020 research and innovation programme for research on Fintech (Grant No. H2020-ICT-825215), and the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No. 681337)—CityNet Project and Fintech Project Grant No 825215. Authors are listed alphabetically. All remaining errors are our own.

Appendix

Table 9 Variable description

Variable name	Variable description	Data source
Cumulative green start-ups	No. of cumulative green start-ups founded within an urban centre between 2000 and the lagged current year value	Preqin and CleantechGroup
Cumulative green start-up funding	Amount of cumulative green start-ups funding received by start-ups with HQ within an urban centre between 2000 and the lagged current year value	Preqin and CleantechGroup
Cumulative VC-backed start-ups	No. of cumulative total start-ups founded within an urban centre between 2000 and the lagged current year value	Preqin and CleantechGroup
Cumulative VC/PE funding	Amount of cumulative total start-ups funding received by start-ups with HQ within an urban centre between 2000 and the lagged current year value	Preqin and CleantechGroup
New start-up funding	Amount of new total start-ups funding received by start-ups with HQ within an urban centre the year before	Preqin and CleantechGroup
New number of start-ups	No. of new start-ups founded within an urban centre (lagged)	Preqin and CleantechGroup
GDP per capita	GDP per capital	Mergent Online Cities Database
Total labour force	Total labour force	Mergent Online Cities Database
Unemployment rate	Unemployment rate	Mergent Online Cities Database

Table 10 Descriptive statistics

Variables	*N*	Min	Max	Mean
Cumulative green start-ups	128,340	0	1303	0.715973
Cumulative green start-up funding ($bn)	128,340	0	73.39757568	0.015423
Cumulative VC-backed start-ups	128,340	0	8843	5.113558
Cumulative VC/PE funding ($bn)	128,340	0	660.8927457	0.239147
New number of start-ups	128,340	0	905	0.357067
New start-up funding ($bn)	128,340	0	93.7797873	0.027315
GDP per capita ($/cap)	15,760	2.37	209,493.23	20,533.75
Total labour force	15,760	5076	16,494,643	677,116.6
Unemployment rate (%)	15,760	0.1	60.68	6.505364
Number of active air pollution laws	128,340	0	42	1.87

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