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# ‘Better late than never’: a longitudinal quantile regression approach to the interplay between green technology and age for firm growth

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## Abstract

This paper investigates the relationships between green/non-green technologies and firm growth. By combining the literature on eco-innovations with industrial organisation and entrepreneurial studies, this relationship is investigated by considering its dependence on the pace at which firms grow and the moderating role of age. Based on a sample of 5498 manufacturing firms in Italy for the period of 2000-2008, we estimate longitudinal fixed effects quantile models in which age is set to moderate the effects of green and non-green patents on employment growth. The results indicate a positive role of green technologies in growth greater than the effect of non-green technologies. This result is valid with the exception of struggling and rapidly growing firms: the relevance of moderately growing firms thus emerges in contrast to the more celebrated “elite of superstar” growing companies. Age plays a moderating role in the growth effects of green technologies. Not completely inconsistent with the extant literature, this moderation effect is positive, indicating the importance of firm experience in benefiting from green technologies in terms of growth, possibly relative to the complexity of their management.

**JEL Codes:** L26; O33; Q55.

**Keywords:** green technology; firm growth; age; quantile fixed effects

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## 1. Introduction

Firms' capacity to grow over time is closely related to their ability to master technological knowledge for the introduction of new products/services and processes and to capture the value of innovations (Mansfield, 1962; Scherer, 1965). Following the premises of the famous Gibrat's law (2003), innovation has thus been placed side by side with other determinants of firms' growth related to both their structural characteristics -- e.g., age and size -- and to their industrial and institutional environment -- e.g., market structure and geographical location (Sutton, 1998; Bottazzi and Secchi, 2006; Cefis et al., 2007; Lotti et al., 2009; Lee, 2010; Bottazzi et al., 2011; Coad and Holz, 2012).

While the relationship between innovation and firm growth appears today to have been nearly established, the picture becomes more scattered when the types of technologies through which it is substantiated are considered. In particular, little is known about the effects of mastering green technologies on firms' performances by introducing eco-innovations (EI) that reduce the negative externalities that they exert on the environment (Kemp and Pontoglio, 2007). Following the now famous 'Porter hypothesis' and the debate over "whether it pays to be green", it has been shown that, by complying with environmental regulations, adopting sustainable practices and eco-innovating, firms could become more competitive (Porter and van der Linde, 1995a, 1995b, Ambec and Lanoie, 2008; Ambec et al., 2013) if not even more profitable (Horváthová, 2010; Ghisetti and Rennings, 2014). In contrast, whether an advantage from green technologies could also accrue to firms in terms of growth has been only limitedly investigated in the existing literature.<sup>1</sup> In particular, supportive evidence has been mainly obtained by examining the relationships between eco-innovations and firm growth through the lens of the technology-jobs nexus, usually in non-longitudinal settings (e.g., Gagliardi et al., 2016; Pfeiffer and Rennings, 2001; Rennings and Zwick, 2002), thus losing sight of the inner complexity and dynamics of the phenomenon.

The present paper aims to close this gap. Specifically, we extend to the green realm the analysis of the relationship between technology and firm growth, which has flourished in innovation and industrial organisation studies. First, we draw from industrial organisation the idea that the growth potential related to the exploitation of technology can vary with the pace at which a firm grows, given the range of opportunities and threats that are affected by the growth rate (Coad and Rao, 2006). Developing on these premises, we investigate whether, also due to exploiting eco-

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<sup>1</sup> This issue is quite different from the relatively more investigated one of the (mainly policy) drivers of "green growth", meant as sustainable growth, that is, "resource-efficient, cleaner and more resilient" (Hallegatte et al., 2012, p. 2). Compared to this stream of the literature, our focus is on the "quantity", rather than on the "quality", of growth driven by green technologies.

innovations, the final growth outcome depends on the firm's pace of growth and, in turn, differs depending on whether the firm is struggling or instead is a rapidly growing firm. To address this first research question, we use quantile regression analysis but with a methodological advancement regarding many studies focusing on the firm growth effect of standard innovations (e.g., Coad and Rao, 2008; Coad and Rao, 2010; Coad et al., 2013): we combine the quantile approach with a fixed-effects estimation technique (Canay, 2011). In so doing, we are capable of capturing the potentially heterogeneous effects of green (and non-green) technology on firm growth across different growth rates, while controlling for unobserved heterogeneity.

Our second research question also connects green technologies to industrial organisation, focusing on the role of firms' ages in differentiating their growth capacities (e.g., Barba Navaretti et al., 2014; Distante et al., 2014). The literature has indicated age-dependent mechanisms that determine the capacity of firms to exploit standard innovation (Coad et al., 2016). In addition, specific aspects related to eco-innovations, such as their greater complexity and their higher need for technology experience to grasp them (Carrillo-Hermosilla and Konnola, 2010), can also cause the path of firm growth to be dependent on age. We thus investigate whether age moderates the manner in which firms benefit from green technology in terms of growth. Indeed, a supportive argument in this last respect can be found in an emerging stream of literature on 'sustainable entrepreneurship' (Hall et al., 2010)<sup>2</sup>, indicating both economic advantages and disadvantages that new business ventures have with regard to established incumbents in growing within sectors in which the amelioration of environmental and social disruptions represents a priority (Hockerts and Wüstenhagen, 2010) and of which 'green sectors' constitute an important typology (OECD, 2015).

By addressing these two original research questions, we aim to obtain new and more qualified evidence of the process through which green technologies can drive growth at the firm level. More precisely, using a novel longitudinal dataset comprising 5498 manufacturing companies from Italy over the period of 2000-2008, we run fixed-effects quantile estimations of a model in which age moderates the impact of green and non-green patents on these firms' employment growth.

Our results show a positive role for green technologies in growth, over and above the effects of non-green technologies. This result is valid with the exception of struggling and rapidly growing firms: the relevance of moderately growing firms thus emerges in contrast to the more celebrated "elite of superstar" growing companies. Age plays a moderating role in the growth effects of green technologies. Not completely inconsistent with the extant literature, this moderation effect is

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<sup>2</sup> As noted by Hall et al. (2010), the terms have often been ambiguously exchanged with similar terms, such as "environmental entrepreneurship", "ecopreneurship", and "green entrepreneurship".

positive, indicating the importance of firms' experience in benefiting from green technologies in terms of growth, possibly relative to the complexity of their management.

The remainder of the paper is structured as follows. Section 2 explores the background literature. Section 3 presents the empirical applications. Section 4 illustrates the results. Section 5 concludes the study.

## **2. Background literature and research questions**

Quite surprisingly, given its importance in the current policy debate over green and sustainable growth, the role of eco-innovations in driving firm growth has been quite under-investigated. If we compare the number of studies focusing on this relationship with those available on the growth effects of 'standard' innovations, a strong contrast emerges. On the one hand, technological innovations are generally recognised as contributing to firms' growth through a number of different mechanisms (for a review, see Coad, 2009). On the other hand, the evidence of a similar role for green technologies is scant and has mainly relied on survey-based data on employment changes and/or employment dynamics, the results of which can be generalised only with extreme caution.

Despite some exceptions (Rennings and Zwick, 2002; Cainelli et al., 2011), eco-innovations have generally been found to exert a positive effect on employment growth but to an extent much more dependent on their fields of applications (e.g., end-of-pipe vs. cleaner-technologies) than standard innovations and with little evidence of a differential impact between green and non-green technologies (Rennings et al., 2004; Horbach and Rennings, 2013; Licht and Peters, 2013). A notable exception in this last respect is represented by the recent work by Gagliardi et al. (2016), based on a patent-based dataset for Italy (2001-2008). Quite robustly, eco-innovations, which interestingly have been found to have higher costs than generic innovations, boost firms' employment growth over and above their non-green counterparts. Using a different theoretical framework, anchored in the inducement theory of innovation, a similar result was also obtained by Colombelli et al. (2015) with regard to the sales growth of more than 400,000 firms in Germany, France, Italy, Spain and Sweden over the period of 2002-2011: eco-innovators, still identified on the basis of green patents, grow on average more than 'generic' innovators.

Building upon this emerging literature, we investigate the role of green technology in firm growth. We expect firms investing in environment-related technological fields to pursue 'win-win' – environmental and extra-environmental – strategies, with a 'multiplied' performance impact *vis-à-vis* generic technological investments (Porter and van der Linde, 1995a; 1995b). In the extant literature, these green advantages have been related to different mechanisms, spanning from access

to emergent green markets and advantages from differentiating green products to savings in the form of lower material and energy costs (Ambec and Lanoie, 2008). In particular, although with important specifications, it has been shown that through these mechanisms firms are able to gain better performance in terms of higher revenues (e.g., Ambec and Lanoie, 2008), better financial indicators (e.g., Misani and Pogutz, 2015), and greater profits (Ghisetti and Rennings, 2014).

Our expectation is that the ‘extra returns’ that green technologies allow firms to obtain could also represent an additional opportunity for resource re-investment, which could also lead to better growth performance despite their higher costs of invention (Gagliardi et al., 2016). This expectation has also been supported by examining the specific nature of eco-innovations with regard to standard ones, given their greater dependence on (environmental) regulations and policy actions. Indeed, this ‘regulatory push/pull’ effect represents an ‘extra’ driver of growth relative to standard technologies, to the extent that final ‘polluting’ firms are legally forced to improve their environmental performances and, in so doing, ‘induce’ in the upstream producers of green technologies an additional element of ‘derived demand’ that fuels their own growth (Colombelli et al., 2015; Ghisetti and Quatraro, 2013).

While we address, from this extant literature, the argument of a relevant growth effect of green technologies, we originally claim that its occurrence depends on two aspects that should be carefully considered: i) the pace at which firms grow; and ii) the firm age.

The former aspect is today an established result with regard to standard innovations, obtained by several studies that have examined using quantile regression the distribution of the observed firms in terms of growth. Coad et al. (2016) showed how the fastest-growing firms only benefit from standard innovation in terms of employment growth, while this return is negative for the slowest-growing firms in the distribution. These results are consistent with an innovation-adapted version of the famous ‘job-creation argument’ stimulated by the seminal work of Birch (1981), according to which fast-growing firms would create most of the jobs in an economic system. Indeed, fast growing firms are marked by entrepreneurial, strategic and firm-specific characteristics that place them in a favourable position based on the exploitation of their technologies. As documented by Almus’ (2002) review, these firms possess key features that provide advantages. First, they are generally smaller and, thus, are more prone to commercialising their innovations. Second, they are younger, and accordingly more in need of investing to collect the knowledge that they miss at the beginning of their businesses, beyond their new technologies. They often operate in technology-intensive sectors and are thus endowed with a larger knowledge base. They also have a limited liability legal form; thus, they show greater incentives for riskier but also more rewarding,

innovations. They are closely connected to suppliers, customers and competitors, enabling them to benefit from an open innovation approach. Finally, they are equipped with qualified human capital and thus also with technological skills and experience.

All of the previous aspects are apparently invariant with regard to the nature of the relevant technologies. For this reason, they can equally apply to the exploitation of green technologies as well. Accordingly, distinguishing rapidly from slowly growing firms might be relevant when investigating the effects of green and non-green technologies on firm growth. This expectation is corroborated by recent empirical evidence about the role of eco-innovations in leading the growth of ‘normal’ vs. fast-growing firms (Colombelli et al., 2015). The growth differential between green and generic technologies that emerges from a dynamic parametric estimation of Gibrat’s law is apparently greater for those firms that grow more than ‘the average’ relative to the ‘simple’ growing firms. This finding indicates a phenomenon in which a quantile estimation approach, of the type used for standard innovation, would be better able to account for what we accordingly adopt in our empirical applications.

We expect to contribute to a better understanding of the relationship between green technologies and firm growth referring to a second aspect: the stage of the firm’s life at which green technologies are exploited and yield a growth effect. As is well known, the role of age in firm growth is a recognised argument in the industrial organisational literature, with a twofold specification. On the one hand, age has been found (along with size) to be an important determinant of a firm’s growth potential, with a large (although not yet conclusive) body of evidence for younger firms being more dynamic and thus more effective in spurring growth (Haltiwanger et al., 2013; Lawless, 2014). On the other hand, and with greater relevance to our research question, age has emerged (along with other characteristics) as a crucial moderating factor of the impact of innovative activity on firms’ growth (Audretsch et al., 2014). This effect holds particularly true for employment growth, as was recently shown by Coad et al. (2016), who found that young firms obtain more employment growth per unit of standard innovation (i.e., R&D expenditure).

In contrast with this abundant body of literature, the role of age in the relationship between green technologies and growth has received little emphasis thus far. Attention has nearly exclusively concentrated on processes of eco- and, more generally, ‘sustainable entrepreneurship’, within sectors in which the amelioration of environmental and social disruption represents a priority (Dean and McMullen, 2007) and in which the adoption of environmental innovations is typically located during, although not limited to, the start-up phase of a company. Furthermore, combined analysis of new start-ups (‘young’ firms) and incumbent (‘old’) firms engaged in sustainable sectors have been

very rare and usually anecdotal, and they have mainly focused on specific areas (e.g., green electricity and microfinance), making it difficult to make general arguments about the role of age in affecting the growth effects of green technologies (Hockerts and Wustenhagen, 2010). Nevertheless, the picture that emerges from these studies is not unambiguous. On the one hand, in agreement with standard industrial organisation, start-ups in the green realm ('Emerging Davids') have shown greater growth potential than established companies ('Greening Goliaths'), mainly due to their greater environmental and/or social commitment and their consequent attractiveness to sustainable consumers and customers; the case of organic food represents a notable example in this regard (Hockerts and Wustenhagen, 2010). On the other hand, green start-ups often fail to translate their niche market potential into a broad mass market, when they even attempt doing so. Furthermore, they must face the competition that they themselves create in the 'greening' established companies, which respond later by developing their 'inner' form of corporate sustainable entrepreneurship; the reaction of incumbents to the diffusion of start-ups in the sector of green electricity and their co-evolution over time represent an example with diffuse international evidence (e.g., Bird et al., 2002; Stenzel and Frenzen, 2008). All in all, a sort of "sin of youth" seems to emerge from this sustainable entrepreneurial evidence.

However, more generally, little is known about the application of green technology in the broad spectrum of innovation and learning mechanisms with regard to which young (and not just started up) companies differ from old ones in the standard technology literature, in which age has been indicated to be responsible for important differences in terms of its growth effects (for a recent review, see Coad et al., 2016). Nevertheless, some age-related insights emerging from environmental studies are worth considering. First, the greater multidimensionality and complexity of green knowledge (Carrillo-Hermosilla and Konnola, 2010) and the lengthier experience that it accordingly requires of innovators naturally provide older firms with an advantage in mastering their applications and exploitation in terms of growth, driving them along the experience curve. Related to this insight is the fact that green technologies are often in the early stages of their life cycles (Consoli et al., 2016) and are marked by greater uncertainty. This actually represents an aspect that is extremely relevant in the green realm, the age-specific nature of a firm's capacity to evaluate technological uncertainty/risk and the marketability of undertaken innovations (Audretsch, 1995; Taymaz, 2005), with evident implications in terms of growth. Furthermore, and still related, one should recall the implications of the greater uncertainty of green projects regarding their financing and the greater need for collateralisation and information signals that they might accordingly have when we consider the financial implications of R&D and innovation (Hall et al., 2016). Accordingly, a better access to finance (Schneider and Veugelers, 2010) could allow older

firms to cope with the higher cost of eco-innovations without crowding out other growth-driving investments. Finally, given the relevance that has also been found for them in the analysis of eco-innovations (e.g., Cainelli et al. [2015]), older age can also involve differences in the extent to which firms are capable of strengthening their available resources (e.g., through economies of scale) to increase their economic green returns, as well as in their capacity (e.g., through reputation and market position) to form alliances for external resources for this strengthening to occur. Similarly, the relevance of an open innovation mode for EIs (Ghisetti et al., 2015) makes it relevant for them to consider experience advantages associated with firm maturity in accessing the external realm of the firm, particularly advantages in accessing new and foreign markets (e.g., Autio et al., 2000). All in all, similar insights to those provided by the literature on “sustainable entrepreneurship” – about the disadvantages (advantages) of being young (old) – seem to emerge also by examining the relatively unexplored aspects of environmental studies related to age and its role in the exploitation of EIs. Indeed, this issue appears to require further investigation.

Examining the previous aspects, our study is a first attempt to address the growing interest in different streams of the economics literature (i.e., industrial organisation, economics of innovation and entrepreneurship) on the growth potential of green technologies. Our work investigates the above relationship and considers two relevant, but largely overlooked, factors that we expect to characterise better the relationship between green technologies and firms’ growth, i.e., the entire conditional distribution of a firm’s growth and the moderating role of the firm’s age. We address the above issues by providing empirical evidence for the following research questions: (1) To what extent do green technologies affect firms’ growth compared to non-green technologies and to what extent does this association between eco-innovations and growth vary along the conditional distribution of growth rates? And (2) What is the role that a firm’s age plays in the relationship between green technologies and growth, as well as in considering the conditional role of the initial growth rate (sub 1)?

### **3. Data and methods**

#### **3.1 Data**

The empirical analysis is based on a longitudinal dataset comprising 5498 Italian manufacturing companies observed over the period of 2000-2008. It combines data from three different sources. The first source is the ASIA database of the Italian National Statistical Office (ISTAT), which contains information on the structural characteristics of the population of Italian companies. We retrieved information related to the industrial sector, the number of employees and the date of birth for the population of Italian business firms over the period of 2000-2011. Due to the data

availability of the other relevant data sources (see Table 1), we restricted the period of interest to 2000-2008. Moreover, building upon other firm-level studies (Geroski et al., 2010; Mata and Portugal, 2002; Coad and Rao, 2011) we considered a firm to have ceased operation if absent from the records for three consecutive years. Our second source of data refers to balance sheet information -- investments in tangible and intangible assets -- obtained from the Bureau van Dijk AIDA database for the period of 2000-2008. Finally, we rely on the Worldwide Patent Statistical Database (PATSTAT) to retrieve patent data information for the names of the assignees, filing dates and International Patent Classification (IPC) technological classes.<sup>3</sup>

We combined the information collected from the three data sources described above, and we restricted our sample to manufacturing companies (Section D of NACE Rev. 1.1) that filed at least one patent application in the period of 1977-2008. Our resulting sample is an unbalanced panel comprising 5498 firms observed over the period of 2000-2008.

### 3.2 Methodology

As discussed in the theoretical section, we are interested in examining the relationship between ‘being green’ and firm growth, as well as the moderating effect of a firm’s age on this relationship. More formally, the relationship we investigate is the following:

$$Growth_{it} = \alpha + \beta_1 Pat\ Green_{i,t-1} + \beta_2 Pat\ Nongreen_{i,t-1} + \beta_3 Age_{i,t-1} + \beta_4 (Pat\ Green\ X\ Age)_{i,t-1} + \beta_5 (Pat\ Nongreen\ X\ Age)_{i,t-1} + \mathbf{z}'_{i,t-1}\gamma + \mathbf{d}'_t\delta + \mu_i + \varepsilon_{it} \quad (1)$$

where  $\mathbf{d}_t$  indicates a series of time controls;  $\mathbf{z}_{i,t-1}$  is a vector of firm-specific control variables;  $\mu_i$  denotes the unobserved firm specific effects; and  $\varepsilon_{i,t}$  is the error term.

Building upon the approach adopted in several empirical works, which focused on the relationship between growth and innovation, we employ a quantile regression approach (Coad and Rao, 2008; Kesidou and Demirel, 2012). When investigating firms’ growth, quantile analysis is preferred over standard least squares for a number of reasons (Buchinsky, 1998). First, the distribution of growth rates is recognised to be highly non-linear and considerably heavy-tailed (Bottazzi and Secchi, 2003). The quantile approach allows for richer characterisation of the data, and it helps to disentangle the relationships between our independent variables and firm growth at different quantiles of the distribution of the rates of growth, rather than at the conditional mean only. Finally,

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<sup>3</sup> We assigned patents to firms following a procedure based on firms’ name associations between AIDA and PATSTAT (Lotti and Marin, 2013). We were able to allocate 89% of all Italian patent applications present at the EPO in the period of 1977-2008.

the quantile approach provides a more robust and efficient alternative to OLS when the error term is non-normal, as well as in the presence of outliers.

Most of the applied literature adopting a quantile regression approach has done so in cross-sectional settings, and for this reason, it has been unable to control for problems of endogeneity arising from unobserved heterogeneity. Conversely, we follow recent developments in a stream of the applied econometrics literature that has attempted to overcome this major limitation (Koenker, 2004; Galvao, 2011; Canay, 2011). Specifically, we implement the procedure suggested by Canay (2011), who developed a method to estimate fixed effects quantile regression for panel data. The solution proposed consists of a two-step estimator. In the first step, we estimate equation (1), above, as a standard linear panel regression model via the within estimator (Wooldridge, 2010). From this model, we obtain the predicted value depurated from the unobserved heterogeneity component:

$$\hat{y}_{it} = Growth_{it} - \hat{\mu}_i \quad (2)$$

where  $\hat{\mu}_i = E[Growth_{it} - \widehat{Growth}_{it}]$  is an estimate of the unobserved heterogeneity term. In the second step, a standard quantile regression model is implemented in which the transformed dependent variable above ( $\hat{y}_{it}$ ) is regressed on our relevant independent variables (Koenker and Hallock, 2001). Robust standard errors are obtained via bootstrap replications (1000 replications).

In summary, exploiting the panel nature of our data, we investigate our research questions with a set of quantile fixed effects regressions that control for unobserved heterogeneity. Our main focus is on whether a firm's growth is affected by its age, the orientation of the firm toward green technologies and the interaction between the two.

### 3.3 Variables

We measure company growth using data on the number of employees retrieved from ASIA. Specifically, our dependent variable is the growth rate of employees. Firm growth can be investigated using a wide variety of measures (Delmar et al., 2003). Employment growth is considered to be an adequate measurement of firm performance; different from other measures, such as sales growth, employment growth is able to capture growth performance in recently constituted firms (Clarysse et al., 2011). Building upon previous works in the field, growth of employees is calculated as the difference between the logarithm of employees in year  $t$  and the logarithm of employees in year  $t-1$  (Coad and Rao, 2006; Coad, 2010; Wennberg et al., 2011). To remove common time trends for firms operating in the same sector (e.g., inflation, business cycles,

etc.), we normalised growth rates, subtracting for each year the sectoral mean growth rate at the 2-digit NACE (Rev. 1.1) codes (Bottazzi et al., 2011; Coad and Rao, 2010).<sup>4</sup>

Our main independent variables measure the stock of green and non-green technologies, that is, the amounts of ‘inventive knowledge’ developed in environmentally friendly and non-environmentally friendly technologies. Most of the recent research on environmental innovation has relied upon patent data because they are a more robust indicator of environmental innovation than questionnaire-based measures (Arundel and Kemp, 2009; Berrone et al., 2013). As described in the data section, we retrieved information about the patenting activities of the companies contained in our sample from PATSTAT for the period of 1977-2008. We define patents as having environmental content (‘green’ patents) if they are part of the classification provided by the OECD Indicator of Environmental Technologies (OECD 2015). The OECD classification lists IPC subclasses that are considered to describe environmentally friendly technologies, and this classification has been increasingly adopted in recent works attempting to identify technologies with environmental content (e.g., Nesta et al., 2014).

Technological variables are defined as stocks (rather than flows) because we expect a firm’s rate of investment in technology to be affected by the cumulated stocks of knowledge and not only by current or lagged flows (Bloom and Van Reenen, 2002; Hall et al., 2005). In this framework, we follow the literature, and we compute all of the stock variables for the period of 2000-2008 using the perpetual inventory method and assuming a constant depreciation rate of 0.15 (Blundell et al., 1995; Hall, 1993).<sup>5</sup> Specifically, the stock variables are  $Pat\ Green_{i,t-1}$ , which is the logarithm of the stock of environmentally friendly technologies (plus 1), filed by firm  $i$  in year  $t-1$ .  $Pat\ Nongreen_{i,t-1}$  measures instead the logarithm of the stock of non-environmentally friendly technologies (plus 1), filed by firm  $i$  in year  $t-1$ . Our third explanatory variable is  $Age_{i,t-1}$  which measures the (log transformed) age of company  $i$  at time  $t-1$ .

We then control for a set of variables that are often included in growth rate regression models: investment in tangible ( $Inv\ Tang_{i,t-1}$ ) and intangible ( $Inv\ Intang_{i,t-1}$ ) assets, and a measurement of size ( $Emp_{i,t-1}$ ). Investments are recognised as important explanatory factors when explaining firms’ growth (Hall, 1987).  $Inv\ Tang_{i,t-1}$  ( $Inv\ Intang_{i,t-1}$ ) is calculated as the yearly net acquisition of

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<sup>4</sup> We also run the estimates using non-normalised growth rates and growth rates normalised to 4-digit NACE (Rev. 1.1) industry codes. All attempts (available from the authors upon request) yield results that are not qualitatively different from those presented here.

<sup>5</sup> Patent stocks are computed using information for the whole period for which patent data are available (1977-2008). We adopt the standard approach found in the relevant literature and calculate it using the following formula:  $K_t = K_{t-1}(1 - \delta) + P_t$  where  $K_{t-1}$  is the stock of patents at year  $t-1$ ,  $\delta$  is the depreciation rate assumed at 15%, and  $P_t$  is the number of new patents in year  $t$ .

tangible (intangible) assets plus the amortisation<sup>6</sup> (Grazzi et al., 2015). Moreover, based on Gibrat's law and other works on firms' growth (e.g., Audretsch et al., 2012), we control for firm size measured as the number of employees of firm  $i$  at time  $t$ . Investment indicators are measured in thousands of euros, and together with the number of employees, they are log transformed (plus 1). Finally, we include a set of eight dummy variables to control for year effects. TABLES

Table 1 briefly describes the variables included in the analysis and their sources.

[TABLE 1 ABOUT HERE]

Descriptive statistics of the variables employed in the empirical exercise are reported in Table 2. Table 3 reports the bivariate correlations of the variables considered in the analysis. There is no indication of significant multicollinearity amongst the independent variables (i.e., the Variance Inflation Factor ranges from 1.02 to 2.62, well below the threshold level of 5).

[TABLE 2 AND TABLE 3 ABOUT HERE]

#### **4. Results**

The results emerging from the quantile fixed effect estimates are presented in Table 4 and

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<sup>6</sup> Investments are deflated by adopting the ratio of current prices to chained-linked prices (reference year 2005) at the higher level of disaggregation, as provided by the Italian National Institute of Statistics (ISTAT) at the NACE 2-digit industrial level.

Table 5. Table 4 focuses on the effects of green and non-green technologies on firms' employment growth.

Table 5 instead shows the results of a model that incorporates the role of age as a moderating factor in the relationship between environmental (or non- environmental) patents and firms' employment growth.

Before coming to the core of our analysis, we briefly present the results concerning the controls employed in our econometric specification. As expected, based on the empirical literature on growth and industrial organisation (e.g., Coad and Holz, 2012), both tangible and intangible investments significantly drive firm growth, suggesting its reliance on capital endowment of a different type. The firm's (initial) size confirms its role as a growth driver. Notably, smaller companies in our sample show greater growth opportunities and capacities, in agreement with the entrepreneurship literature (Acs and Audretsch, 2006). As far as age is concerned, the results of the standard literature on the growth advantages of newly/recently created companies (Coad et al., 2013; Barba Navaretti et al., 2014) are not confirmed and are even reversed. Indeed, older companies grow more than younger ones, and the positive and significant effect of a firm's age on employment growth holds across all quantiles. While the specificities of our sample (i.e., innovation-oriented Italian firms) and methodological approach could account for this result to a certain extent, the benefits accruing to firms with age appear to more than compensate for its disadvantages in our case. That older firms are more transparent than younger firms in informational terms, that is, are more easily searchable by interested investors and, thus, more attractive in terms of financing options for growth (e.g., public equity and long-term debt vs. insider funding) (Gregory et al., 2005; Hartarska and Gonzalez-Vega, 2006), is a first aspect to consider in the financial realm. Second, the plethora of experiential advantages that have been associated to firm maturity should be recalled here, particularly those in accessing new and foreign markets (e.g., Autio et al., 2000).

We now come to the core of our analysis. The positive and significant coefficients of both *Pat Nongreen* and *Pat Green* across the whole set of percentiles extend to the green realm the role of technology as a driver of firm growth. Although eco-innovations might have higher costs (Gagliardi et al., 2016), our evidence indicates increased economic performance induced by green technologies, which translates into firms' employment growth. This finding resonates well with the emerging evidence on the business-environmental win-win situations enhanced by environmental practices, which can either increase the value of products (e.g., through market penetration and product differentiation) or reduce production costs (e.g., through resource and material efficiency) (Ambec and Lanoie, 2008).

However, what is the role of green technologies compared to non-green technologies? Addressing this question is crucial for ascertaining whether green technologies provide a growth premium with regard to standard technologies or whether, instead, the effects of green and non-green patents are not different. We thus analyse the difference in the coefficients of *Pat Green* and *Pat Nongreen* by running appropriate statistical tests on the difference between the two coefficients. It emerges that, for the 25<sup>th</sup>, 50<sup>th</sup> and 75<sup>th</sup> percentiles, green technologies exert a significantly higher effect (at a 99% level of confidence) on employment growth than standard technologies. This finding does not occur for extreme percentiles (10<sup>th</sup> and 90<sup>th</sup>), for which green and non-green patents have statistically comparable effects on employment growth. This is the first and most important result of our study. It confirms the idea that green technologies provide firms with opportunities for job creation that extend beyond those offered by non-environmental technologies (Gagliardi et al., 2016). Moreover, we better qualify this idea, with the growth premium of green over non-green technologies is not infinite. Indeed, it seems to fade away when innovation efforts are pursued either to survive (struggling firms) or to remain among the growth ‘superstars’ (gazelles).

[TABLE 4 ABOUT HERE]

The picture emerging from the previous results appears more nuanced when we introduce interaction terms to capture the interplay between technology, both green and non-green, and a firm’s age in driving employment growth (

Table 5). While *Pat Nongreen* remains positive and significant, except for the 10<sup>th</sup> percentile in which growth rates are largely negative, *Pat Green, per se*, is not positive anymore. In fact, for the 50<sup>th</sup> and 75<sup>th</sup> percentiles, its coefficient is negative and (weakly) significant. Hence, only non-green technologies *per se* exert positive effects on firm growth. However, the effect of *Pat Green* emerging from Table 5 only apparently contradicts the evidence depicted above when the interaction terms are not included because the overall effect of green technologies is always positive<sup>7</sup>. This is due to the positive contribution of the interaction between *Pat Green* and *Age*, which is always positive and significant with the exclusion of the percentile consisting of struggling firms. The evidence related to the moderating effect of age is the second important result of our study. Not only do older firms grow faster, as noticeable from the positive coefficient of *Age*, but they also have the exclusive capacity to exploit the opportunities of green technologies and turn them into employment growth.

At the outset, this result seems to corroborate and extend to the green realm previous arguments about the greater capacity of older firms to translate innovation into growth. First, older firms are better equipped to evaluate the uncertainty/risk and the actual marketability of their innovations (Audretsch, 1995; Taymaz 2005), which is true irrespective of their likely disadvantages in terms of organisational inertia and learning impediments (Majumdar, 1997; Sorensen and Stuart, 2000; Criscuolo et al., 2012). Second, older firms seem to possess greater capacity to exploit economies of scale to increase their innovation returns, and to engage in alliances to externally source the resources necessary for innovative activity (Herriott et al., 1985; Levitt and March, 1988). Finally, mature firms have arguably acquired more diversified experience in dealing with technology over time (Hashai, 2015).

All of the above arguments can also contribute to explaining the ability of companies to transform the adoption of green technologies into growth. Evidently, all of the previous ‘general’ aspects should be integrated by considering the specific nature of green technologies. First, older firms might have greater pressures and incentives for renewing their older capital vintages in an eco-sustainable manner. Second, maturity can provide firms with greater opportunities to grasp the greater complexity and multi-purpose nature of eco-innovations (e.g., joining production, environmental and institutional objectives), relying on diverse knowledge (Ghisetti et al., 2015). Third, better access to finance (Schneider and Veugelers, 2010) can allow older firms to cope with the higher cost of eco-innovations without crowding out other growth-driving investments

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<sup>7</sup> This can be obtained by adding the “direct” effect of *PatGreen* and the effect moderated by age, captured through the interaction of *PatGreen* x *Age*. Even when the coefficient of *PatGreen* is negative and significant, i.e., at the 50<sup>th</sup> and 75<sup>th</sup> percentiles, the overall effect of green technology is positive, starting with *Age* equal to 1.

(Gagliardi et al., 2016). Finally, the greater uncertainty that characterises green technologies, often in the early stages of their life cycles (Consoli et al., 2016), could exacerbate the pressures related to the well-known ‘liability of newness’ (Freeman et al., 1983). This uncertainty would make young companies, facing a higher risk of failure, less likely to pursue green technology-based growth.

Indeed, while positive with regard to older firms, the implications of our results for the issue of entrepreneurial growth are quite discouraging. Our evidence suggests that green innovations do not offer a viable strategy for the growth of young firms, at least in the short run. This lack is likely driven by the additional efforts of time and financial resources, such as those associated with signalling, labelling and certification, which are often required to extract value from investment in green innovations (Ambec and Lanoie, 2008). When attempting to pursue the heavily uncertain path of growth (e.g., Coad et al., 2013), young companies might instead obtain some short-term gains from standard innovations, which do not target external benefits associated with environmental protection and are arguably less distant from the traditional industrial knowledge base (Ghisetti et al., 2015). Quite interestingly, these gains occur for the central quantiles of the distribution, as can be noticed from the negative and significant coefficients on the interaction term *Pat Nongreen X Age* in the 25<sup>th</sup> and 50<sup>th</sup> percentiles, while for rapidly growing or struggling companies, age does not moderate the growth-driving effects of non-green technologies.

[TABLE 5 ABOUT HERE]

## 5. Conclusions

The possibility of achieving sustainable economic growth is of paramount importance and is centrally positioned among policy-making objectives (e.g., European Commission, 2010). Whether a business can flourish based on green behaviours (e.g., strategies and technologies) is a question that has recently attracted significant attention from the academic literature as well. It has been shown that firms’ orientations towards environmental sustainability can open windows for ‘win-win’ situations, in which the environmental harm of industrial activities is reduced, and superior business performance is achieved (e.g., Porter and van der Linde, 1995; Ambec and Lanoie, 2008).

In this paper, we have explored the combination of environmental and business objectives at the firm level, and we have examined in particular the capacity of green technologies to sustain firm growth. We have built upon the idea that the firm’s capacity to grow is intimately related to the ability to master technological knowledge and to capture the value of innovation (Mansfield, 1962; Scherer, 1965). While an extensive literature on economics (in both industrial organisation and innovation studies) has addressed the growth impact of technology (e.g., Audretsch et al., 2014),

only very rare insights have been available on the relationship between green technologies and firm growth. We have contributed to this stream of the literature by providing novel insights in two regards. First, we have assessed whether green technology, compared to non-green technology, affects the growth of firms characterised by different growth paces (e.g., struggling or rapidly growing). Second, we have considered whether green-based growth is affected by a firm's age.

To shed light on these aspects, we have adopted a novel econometric approach, which combines panel fixed effects with quantile regression estimations. In so doing, we have simultaneously controlled for unobserved heterogeneity (which is likely to affect firm growth) and for the heterogeneity of the growth process, along with the distributions of growth rates.

Our results confirm the crucial role of technology, both green and non-green, in fostering firm growth, as measured by the growth of employment. Moreover, our evidence corroborates the 'win-win' situation emerging from green technologies: compared to non-green technologies, environmental technologies exert superior effects on the rate of growth. The possibility to enter green markets and to decrease production costs, due to greater resource efficiency (e.g., reduced material and energy use), can justify this result. However, our analysis shows that the positive effect of green technology on growth does not occur for extreme percentiles of the growth rate distribution. When innovation serves the purpose of surviving or staying among the rapidly growing elite, green orientation does not result in superior performance compared to non-green technologies.

The second main contribution of our work relates to the moderating effects of age. We have shown that the green growth path is mainly taken by mature firms, with the exception of the slowest growing ones. Hence, our results suggest that more mature companies are better equipped to transform green technology into growth. Although further research is required to investigate which firms-level factors drive this difference in green-premium growth, we contend that greater experience, fewer financial constraints and exemption from issues related to the liability of newness allow them to embark on more complex and uncertain technological projects, such as environmentally oriented ones. These results are partially balanced by the positive effects on young companies of non-green technologies, which trigger short-term firm growth (for the central quantiles), possibly in light of their less complex and costly nature.

These results offer relevant implications for management. Extracting value from green technology and transforming it into higher growth do not appear to constitute a 'one fits all' strategy for firms. The superior growth-driving performance is not in place for the worst and best performing companies. On the one hand, for firms that are struggling to survive, engaging in green innovations

might not be a viable strategy given their greater complexity and higher cost, compared to non-green technology. On the other hand, the growth premium of green technology is not in place for the elite group of fast growing companies because for them the ‘simple’ green orientation does not add to their portfolios of already outperforming, and possibly unique compared to their competitors, technological capabilities. As said, our results suggest that the process of green-led growth is a complex and costly one: only older companies are sufficiently broad shouldered to pursue a growth path based on environmental technology. In this regard, our results suggest the adoption of a strategy consisting of an initial commitment to overcoming the hurdles related to the liability of newness with the imperative of survival (Freeman et al., 1983; Bartelsman et al., 2005), possibly exploiting standard technologies. It is only when companies are ‘grown up’ that they can successfully combine green technology and high growth.

Building upon our evidence, we also believe that our results have relevant implications for policy makers. If the objective of policy makers is to maximise the short run social impact of public moneys invested in support of the transition towards greener forms of production, the main beneficiary group should be made of relatively mature firms, rather than young ventures. This aspect should be considered when implementing policies in favour of innovative start-ups (e.g., Mason and Brown, 2013; European Commission, 2014). To be sure, ours is a first attempt to provide empirical evidence for the relation between firm growth and green technology, and further research is needed related to this topic. Specifically, from a policy implications perspective, future research with more refined data is required to investigate the mechanisms on which we advanced some tentative arguments making green growth particularly problematic for young companies.

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## TABLES

**Table 1: Variables description**

| Variable name              | Description   | Source     |
|----------------------------|---|------------|
| Growth <sub>it</sub>       | growth of employees of firm <i>i</i> in year <i>t</i> ( $\ln\text{size}_{it} - \ln\text{size}_{it-1}$ ) | ASIA Istat |
| Pat Green <sub>it</sub>    | stock of green patents of firm <i>i</i> in year <i>t</i> (log transformed)                              | PATSTAT    |
| Pat Nongreen <sub>it</sub> | stock of non-green patents of firm <i>i</i> in year <i>t</i> (log transformed)                          | PATSTAT    |
| Age <sub>it</sub>          | number of years since constitution of firm <i>i</i> in year <i>t</i> (log transformed)                  | ASIA Istat |
| Emp <sub>it</sub>          | number of employees of firm <i>i</i> in year <i>t</i> (log transformed)                                 | ASIA Istat |
| Inv Tang <sub>it</sub>     | investment in physical capital of firm <i>i</i> in year <i>t</i> (log transformed)                      | AIDA BvD   |
| Inv Intang <sub>it</sub>   | investment in intangible capital of firm <i>i</i> in year <i>t</i> (log transformed)                    | AIDA BvD   |

**Table 2: Descriptive statistics for the pooled sample (n=30670)**

| Variable     | Mean     | Median  | S.D.      | Min.   | Max.    |
|--------------|----------|---------|-----------|--------|---------|
| Growth       | -0.006   | -0.024  | 0.225     | -4.336 | 5.945   |
| Pat Green    | 0.143    | 0.000   | 1.223     | 0.000  | 43.329  |
| Pat Nongreen | 2.123    | 0.614   | 15.027    | 0.000  | 961.138 |
| Age          | 23.949   | 24      | 13.622    | 1.000  | 141     |
| Emp          | 171.510  | 53      | 675.774   | 0.080  | 29144   |
| Inv Tang     | 2854.694 | 297.096 | 29183.460 | 0.001  | 3115048 |
| Inv Intang   | 1031.039 | 48.698  | 15892.520 | 0.001  | 1617583 |

All values are reported before log-transformation.

**Table 3: Correlation matrix (n=30670)**

|              | Growth  | Pat Green | Pat Nongreen | Age    | Emp    | Inv Tang |
|--------------|---------|-----------|--------------|--------|--------|----------|
| Pat Green    | 0.001   |           |              |        |        |          |
| Pat Nongreen | -0.0249 | 0.2571    |              |        |        |          |
| Age          | -0.1264 | 0.0095    | 0.1033       |        |        |          |
| Emp          | -0.1741 | 0.1811    | 0.3652       | 0.302  |        |          |
| Inv Tang     | -0.0103 | 0.1586    | 0.2815       | 0.2115 | 0.7361 |          |
| Inv Intang   | 0.0078  | 0.144     | 0.3109       | 0.0644 | 0.5068 | 0.4613   |

**Table 4: Quantile regression with fixed effects: firm growth's determinants**

|               | <i>q10</i>             | <i>q25</i>             | <i>q50</i>             | <i>q75</i>             | <i>q90</i>             |
|---------------|------------------------|------------------------|------------------------|------------------------|------------------------|
| Age           | 0.0982***<br>[0.0023]  | 0.0878***<br>[0.0012]  | 0.0805***<br>[0.0007]  | 0.0730***<br>[0.0011]  | 0.0607***<br>[0.0022]  |
| Pat Green     | 0.0175***<br>[0.0057]  | 0.0231***<br>[0.0025]  | 0.0232***<br>[0.0017]  | 0.0269***<br>[0.0023]  | 0.0258***<br>[0.0055]  |
| Pat Nongreen  | 0.0088***<br>[0.0022]  | 0.0132***<br>[0.0009]  | 0.0145***<br>[0.0007]  | 0.0146***<br>[0.0010]  | 0.0195***<br>[0.0022]  |
| Emp           | -0.4208***<br>[0.0017] | -0.4331***<br>[0.0009] | -0.4432***<br>[0.0008] | -0.4539***<br>[0.0010] | -0.4687***<br>[0.0018] |
| Inv Intang    | -0.0008<br>[0.0006]    | 0.0018***<br>[0.0003]  | 0.0037***<br>[0.0002]  | 0.0055***<br>[0.0003]  | 0.0081***<br>[0.0005]  |
| Inv Tang      | 0.0159***<br>[0.0011]  | 0.0155***<br>[0.0006]  | 0.0157***<br>[0.0004]  | 0.0173***<br>[0.0006]  | 0.0209***<br>[0.0010]  |
| Constant      | 1.0849***<br>[0.0121]  | 1.2083***<br>[0.0062]  | 1.3069***<br>[0.0042]  | 1.3934***<br>[0.0068]  | 1.4908***<br>[0.0117]  |
| Firm-year obs | 30670                  |                        |                        |                        |                        |
| Firm obs      | 5498                   |                        |                        |                        |                        |

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ . Year dummy variables have been included in all of the models. Bootstrapped standard errors are reported in parentheses. They are based on 1000 replications of the data.

**Table 5: Quantile regression with fixed effects: firm growth's determinants – interaction effects**

|                    | <i>q10</i>             | <i>q25</i>             | <i>q50</i>             | <i>q75</i>             | <i>q90</i>             |
|--------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
| Age                | 0.0972***<br>[0.0029]  | 0.0873***<br>[0.0014]  | 0.0798***<br>[0.0008]  | 0.0718***<br>[0.0013]  | 0.0597***<br>[0.0028]  |
| Pat Green          | 0.0227<br>[0.0195]     | -0.0054<br>[0.0083]    | -0.0090*<br>[0.0049]   | -0.0183*<br>[0.0105]   | -0.0392<br>[0.0245]    |
| Pat Nongreen       | 0.0103<br>[0.0100]     | 0.0203***<br>[0.0043]  | 0.0208***<br>[0.0028]  | 0.0192***<br>[0.0045]  | 0.0264**<br>[0.0110]   |
| Pat Green X Age    | -0.0009<br>[0.0061]    | 0.0093***<br>[0.0027]  | 0.0104***<br>[0.0017]  | 0.0145***<br>[0.0033]  | 0.0209***<br>[0.0074]  |
| Pat Nongreen X Age | -0.0004<br>[0.0031]    | -0.0024*<br>[0.0013]   | -0.0022***<br>[0.0008] | -0.0016<br>[0.0014]    | -0.0025<br>[0.0033]    |
| Emp                | -0.4210***<br>[0.0017] | -0.4331***<br>[0.0009] | -0.4431***<br>[0.0007] | -0.4539***<br>[0.0011] | -0.4687***<br>[0.0018] |
| Inv Intang         | -0.0009<br>[0.0006]    | 0.0018***<br>[0.0003]  | 0.0038***<br>[0.0002]  | 0.0055***<br>[0.0003]  | 0.0081***<br>[0.0005]  |
| Inv Tang           | 0.0161***<br>[0.0011]  | 0.0153***<br>[0.0006]  | 0.0157***<br>[0.0004]  | 0.0173***<br>[0.0006]  | 0.0208***<br>[0.0010]  |
| Constant           | 1.0874***<br>[0.0132]  | 1.2119***<br>[0.0068]  | 1.3088***<br>[0.0043]  | 1.3975***<br>[0.0073]  | 1.4947***<br>[0.0136]  |
| Firm-year obs      | 30670                  |                        |                        |                        |                        |
| Firm obs           | 5498                   |                        |                        |                        |                        |

\* p<0.10, \*\* p<0.05, \*\*\* p<0.01. Year dummy variables have been included in all of the models. Bootstrapped standard errors are reported in parentheses. They are based on 1000 replications of the data.