Eco-innovation and firm growth: Do green gazelles run faster?

Microeconometric evidence from a sample of European firms[1]

Alessandra Colombelli[a,c,d], Jackie Krafft[c] and Francesco Quatraro[b,c,d]

a) DIGEP, Politecnico di Torino
b) Department of Economics and Statistics Cognetti de Martiis, University of Torino
c) GREDEG, CNRS and University of Nice Sophia Antipolis
d) BRICK, Collegio Carlo Alberto

ABSTRACT. This paper investigates the impact of eco-innovation on firms' growth processes, with a special focus on gazelles, i.e. firms' showing higher than average growth rates. In a context shaped by more and more stringent environmental regulatory frameworks, we posit that inducement mechanisms stimulate the adoption of green technologies, increasing the derived demand for technologies produced by upstream firms supplying eco-innovations. For these reason we expect the generation of green technologies to trigger sales growth. We use firm-level data drawn from the Bureau van Dijk Database, coupled with patent information obtained from the OECD Science and Technology Indicators. The results confirm that eco-innovations are likely to augment the effects of generic innovation on firm growth, and this is particularly true for gazelles, which do appear to 'run faster' than other firms.

Keywords: Gazelles, Eco-Innovation, firms' growth, Inducement mechanisms, derived demand, WIPO Green Inventory.

JEL Classification Codes: L10, L20, O32, O33, Q53, Q55.

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1 Introduction

The relationship between firm's innovation and growth patterns received increased attention in the last year (Audrestch et al., 2014). The theoretical arguments build on Schumpeter's argument that firms that innovate enjoy better performance in the market based on a process of creative destruction (Schumpeter, 1942).

Recent policy debate on the importance of innovation has become ever more focused on the capacity to reconcile economic and environmental performance through the generation, adoption and diffusion of eco-innovations. These new technologies are identified with the restoration of competitiveness in advanced countries harmed by the economic crisis. Their emergence is supposed to create new jobs and introduce new perspectives for economic growth.

These arguments are based on the well-known Porter hypothesis (Porter and van der Linde, 1995), according to which innovations aimed at improving firms' environmental performance might also have positive effects on their economic performance due to the enhancement of products and processes engendered by adoption of the innovation[2].

However, most empirical analyses at the micro and macro-economic levels focus on the determinants of eco-innovations, and pay relatively little attention to their effects on economic and financial performances. In other words, the beneficial effects of eco-innovations are taken for granted and seen as motivating investigation of the mechanisms of their generation. There are some exceptions. These include Marin (2014), who proposes an extension of the Crepon-Duguet-

[2] According to the assumptions on the effect of regulation, the Porter hypothesis can be split into "narrow", "weak" and "strong" versions (Jaffe and Palmer, 1997). The Porter hypothesis remains controversial in empirical investigations (see, for instance, Lanoie et al., 2011).

Mairesse (CDM) model to investigate the effects of eco-innovation on productivity growth for a sample of Italian firms; Rexhauser and Rammer (2014) who use German CIS 2009 data to investigate the effects of different types of environmental innovations on the profitability of German firms; Ambec and Lanoie et al. (2011) who propose a framework to investigate the complete chain of causality from environmental regulatory stringency to environmental and financial performance through environmental innovation. This last work is based on a survey of 4,200 facilities in 7 OECD countries.

The present paper aims to contribute to this less explored field of inquiry by analyzing the effects of eco-innovations on firms' growth processes. In particular, we combine different strands of analysis comprising studies focusing on eco-innovations, and the literature that analyzes the determinants of firm growth, moving from the well-known Gibrat's law to investigate a particular firm type of high-growth firms (HGFs) or 'gazelles'. These HGFs have attracted renewed policy interest due to their role in the creation of new jobs, and hence in sustaining the economic development of regions and countries. A report by the Europe INNOVA Sectoral Innovation Watch (Mitusch and Schimke, 2011), points to the importance of eco-innovation to realize sustainable innovative development and trigger firm growth. Thus, environmental innovations can be strategic for gazelles. We qualify this argument by emphasizing that producing eco-innovations in markets that are shaped more and more by strict environmental regulation is likely to yield returns in terms of higher sales growth rates.

The empirical analysis is carried out on a sample of more than 400,000 firms located in Germany, France, Italy, Spain and Sweden, over the time span 2002-2011. Our results show that on average, firms producing eco-innovations are characterized by higher growth rates than those generating generic innovations. Moreover, if we focus on HGFs, we find that green gazelles, i.e.

gazelles generating environmental innovations, grow faster than other HGFs. Our results are robust to different specifications, and in particular to the implementation of least absolute deviation (LAD) estimators, which are better suited to empirical contexts where the distribution of the dependent variable is close to a Laplace.

The rest of the paper is organized as follows. Section 2 outlines the theoretical framework underpinning the empirical analysis. Section 3 describes the dataset, the methodology and the variables. Section 4 presents the results of the econometric estimations and the robustness checks. Section 5 concludes by emphasizing some implications for industrial and environmental policy.

2 Firm growth and the generation of eco-innovations

Understanding of the relationship between the generation of eco-innovations[3] and firm growth is grounded on the notions of induced innovation and derived demand. The inducement hypothesis in the domain of environmental economics points to the moderating role played by regulation on the generation of green technologies. Stringent policy is conceived as an additional cost, increasing firms' production costs by changing relative factor prices. This stimulates firms to commit resources to introduce innovations aimed at reducing this increased cost, e.g. emissions-reducing technologies. The relevance of these mechanisms has been investigated using patent data to test whether regulation affects knowledge generation (e.g. Lanjouw and Mody,

[3] There are various definitions of eco-innovation. Kemp (2010: p. 398) notes that "The absence of a common definition led the European Commission to fund two projects on measuring eco-innovation: Measuring Eco-Innovation (MEI) and Eco-Drive. The eco-innovation definition of the Eco-Drive is «a change in economic activities that improves both the economic performance and the environmental performance». The definition of MEI is «the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives»".

1996; Brunnermeier and Cohen 2003; Jaffe and Palmer, 1997; Popp, 2006) and by using survey data to test whether regulation pushes and/or pulls environmental innovations (e.g. Frondel et al, 2008; Horbach et al., 2012, Rennings and Rammer, 2011; for a review see Del Rio, 2009). In both cases, the results support the idea that regulation triggers innovation through a genuine mechanism of creative response *à la* Schumpeter (1947).

However, although the distinction between the different phases of generation, adoption and diffusion of innovation is becoming more and more blurred, we would stress that polluting firms subject to stringent regulation may be willing to adopt green technologies but may not have the necessary competences to generate them. In such cases, environmental pressures (in both strong and weak regulatory frameworks) can engender *derived demand* for green technologies. This translates into increased production of eco-innovations to confront increased demand, by firms operating in downstream sectors. Following the interplay between price-inducement and derived demand-pull mechanisms, the generation of new technologies is likely to be triggered by the derived demand of polluting firms for technologies that improve their environmental performance (Ghisetti and Quatraro, 2013).

Therefore, the interaction between classical inducement mechanisms and derived demand-pull dynamics (Schmookler, 1954) provides the main underpinnings to the relationship between the production of eco-innovations and higher sales growth rates. Drawing on the literature on firm growth to analyze eco-innovation can produce substantial implications. Going from the seminal contribution by Gibrat (1931), there is a large body of work on the dynamics of firm growth and its possible determinants (Sutton, 1997; Geroski, 1999; Bottazzi and Secchi, 2006; Cefis et al., 2007; Acs and Mueller, 2008; Lotti, Santarelli and Vivarelli, 2009; Coad, 2007, 2009; Lee, 2010; Parker et al., 2010; Bottazzi et al., 2011; Coad and Hölzl, 2011).

Among the studies that deal explicitly with innovation/growth links at firm level, many are inspired by Mansfield (1962) which was the first rigorous empirical assessment of the complex relationship between growth and innovation at firm level. Positive links were found also by Scherer (1965), Mowery (1983) and Geroski and Machin (1992). Innovation is assumed to be 'good' for growth and survival insofar as firms are able to capture the value from innovation (Nelson and Winter, 1982; Teece, 1986). More recently, a wave of empirical studies has rejuvenated interest in the impact of innovation on firm growth (Cainelli et al., 2006; Coad and Rao, 2008; Cassia and Colombelli, 2008; Cassia et al., 2009; Colombelli et al., 2013). This work provides some general evidence in favor of a positive and significant relation between firm innovation and firm growth, a finding that is consistent across the use of different proxies for innovation. However, to our knowledge there are no studies that systematically investigate the impact of green technologies on firm growth.

The interaction between inducement and derived demand-pull provides a useful theoretical framework to investigate the links between eco-innovations and firm growth. From this perspective it should be noted that some studies frame investigation of the determinants of growth in terms of the differential effects on HGFs (Colombelli and Quatraro, 2014; Colombelli et al., 2014; Coad and Rao, 2008, 2010; Hölzl, 2009). The interest in gazelles derives from Birch's (1979, 1981) work which suggests that they are the main source of job creation in the economic system (Henrekson and Johansson, 2010). Analysis of the contribution of eco-innovation to exceptionally high growth rates helps to explain the conditions that can transform firms into gazelles in pursuit of the so-called '20-20-20' targets. This also allows identification of other channels through which gazelles could contribute to the dynamics of aggregate economic growth and should help policymakers to design targeted supporting policy measures (Nightingale and Coad, 2014).

In view of the arguments outlined so far, we can refine our working hypotheses.

The increasingly stringent regulatory framework concerning the sustainability of production processes is likely to engender a creative response in polluting firms which will be more and more willing to adopt technologies to improve their environmental performance, and in particular, to reduce their polluting emissions. This inducement dynamics implies a surge in the derived demand for eco-innovations, such that firms producing green technologies are likely to experience increasing growth rates. Ceteris paribus, by the same token, gazelles producing green technologies are expected to grow faster than gazelles producing generic innovations.

3 Data, Variables and Methodology

3.1 The Dataset

Our analysis of the relationship between eco-innovation and firm growth relies on two data sources. Balance sheet data were drawn from the Bureau van Dijk (BVD) ORBIS database (July 2012) which also contains information on firms' patenting activities, and assigns patent numbers to BVD id numbers. This information was matched with data from the OECD RegPat Database (July 2014) in order to assign priority years and technological classes to each patent.

Firm-level data were extracted by focusing on firms operating in manufacturing sectors (NACE rev. 2 C section) in six European countries, i.e. France, Italy, Germany, Spain, United Kingdom and Sweden. The first available year for balance sheet data in ORBIS is 2002. Since we used the 2012 release, we decided to take the time span 2002-2010 in order to rule out the risk of incomplete data in the last available year. This resulted in an initial dataset of 953,479 firms[4].

We dropped records with missing data on sales, and those that did not report a sector classification. This left an unbalanced panel of 456,240 firms. Tables 1 and 2 provide the country and sector distribution of the sampled firms, before and after cleaning for missing information.

>>>INSERT TABLES 1 AND 2 ABOUT HERE <<<

3.2 The variables

The empirical analysis employs dependent and the explanatory variables constructed based on the dataset described above. In what follows we provide details on the construction of each variable.

3.2.1 The dependent variable

Consistent with the basic research question underlying this study, the dependent variable used in the empirical estimations is the growth rate of deflated sales for each firm. There are different alternatives available to measure growth, that involve assets, employment or sales (see Coad and Hölzl (2011) for a discussion of the pros and cons of each proxy). However, the

[4] Note that distribution by size class reveals an important weakness of the ORBIS database; in the case of more than 18 million companies there is no information on employment. This is due to the fact that employment is not a mandatory variable in balance sheet data. Also, ORBIS is based on data collected by national Chambers of Commerce, i.e. concerning companies that are registered and are liable for VAT. This implies that small firms are likely to be underrepresented. However, for the purposes of this paper this problem is minimal since patenting behavior is also biased towards larger firms.

theoretical discussion in Section 2 points directly to use of sales growth insofar as the main link between eco-innovation and growth is expected to be channeled by the derived-demand pull dynamics.

In order to proceed with the analysis, we can define sales growth rate as follows:

$$Growth_{i,j,k,t} = \ln\left(X_{i,j,k,t}\right) - \ln\left(X_{i,j,k,t-1}\right) \tag{1}$$

where X is measured as the sales of firm *i* in country *j* and sector *k* at time *t*. Following previous empirical works (Bottazzi et al., 2011; Coad, 2010), in each year growth rate distributions have been normalized around zero by removing the means as follows:

$$s_{i,j,k,t} = Growth_{i,j,k,t} - \frac{1}{N}\sum_{i=1}^{n} Growth_{i,j,k,t} \tag{2}$$

where N is the total number of firms in country *j* and sector *k* at time *t* in the sample. This procedure effectively removes average time trends common to all the firms caused by such factors as inflation and business cycle.

Figure 1 shows the distribution of firm growth rates. It can be seen that the empirical distribution of growth rates for our sample seems closer to a Laplacian than a Gaussian distribution. This is in line with previous studies analyzing the distribution of firm growth rates (Bottazzi et al., 2007; Bottazzi and Secchi, 2006; Castaldi and Dosi, 2009).

>>>INSERT FIGURE 1 ABOUT HERE<<<

This evidence suggests that standard regression estimators, such as ordinary least squares (OLS), assuming Gaussian residuals may perform poorly if applied to these data. To cope with this, a viable and increasingly popular alternative is to implement the LAD technique which is based on minimizing the absolute deviation from the median rather than the squares of the deviation from the mean. We provide more detail in Section 3.3.

3.2.2 Explanatory variables

The first explanatory variable aims at controlling for firm size. For this reason we include in the regression the natural logarithm of firm sales at time t-1 ($SALES_{i,t-1}$). We control also for firm age by taking the logarithm of the difference between the year of observation and the year of the firm's birth as reported in the dataset ($AGE_{i,t-1}$).

Our focal explanatory variables are related to firms' innovation efforts, and eco-innovations in particular. We use patent statistics to derive a measure of the firm's stock of technological knowledge. Note that we made each patent 'last' three years in order to cope with the intrinsic volatility of patenting behavior. This means that a patent application submitted by firm i in 2003 will be assigned to that same firm in 2004 and 2005.

The firm's knowledge stock ($KSTOCK_{i,t}$) is computed by applying the permanent inventory method (PIM) to patent applications. We calculate it as the cumulated stock of past patent applications using a rate of obsolescence of 15% per annum:

$$KSTOCK_{i,t} = \dot{h}_{i,t} + (1-\delta) KSTOCK_{i,t-1} \quad (3)$$

where $\dot{h}_{i,t}$ is the flow of patent applications and δ is the rate of obsolescence. The choice of rate of obsolescence raises the question of what is the most appropriate value. There are several studies including Pakes and Schankerman (1984) and Schankerman (1998) which try to estimate the patent depreciation rate. However, in this paper we follow the body of work based on Hall et al. (2005) which applies to patent applications the same depreciation rate as that applied to R&D

expenditure (see e.g. McGahan and Silverman, 2006; Nesta, 2008; Laitner and Stolyarov, 2013; Rahko, 2014).

Calculating the knowledge stock is a crucial step in estimating the effects of eco-innovation. These effects are estimated by building an indicator variable ($GREEN_{i,t}$) which is equal to 1 if the firm *i* has produced at least one patent that can be described as 'green' at time *t*, and 0 otherwise. Patents are then labeled *environmental* on the basis of the World Intellectual Property Organization "WIPO IPC green inventory", an International Patent Classification that identifies patents related to so-called "Environmentally Sound Technologies" and categorizes them into technology fields (Tab. A1), with the *caveat* that it is not the only possible classification of green technologies, and similar to other available classifications, has some drawbacks (Costantini et al., 2013)[5].

Table 3 provides a summary of the variables and their main descriptive statistics.

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3.3 Methodology

The baseline specification to model firms' growth as a function of firm innovation follows the original logarithmic representation in Gibrat's Law:

$$\ln\left(X_{i,t}\right)=\lambda_1+\lambda_2\ln\left(X_{i,t-1}\right)+\beta Z_{i,t-1}+\sum\omega_j+\sum\psi_t+\varepsilon_{i,t} \quad (4)$$

[5] Although interesting, it is beyond the scope of the current work to test systematically for the differences that can arise from the choice of classification. Due to the wide scope of our analysis which encompasses many kinds of green technologies, we choose to rely on the WIPO Green Inventory, which is nonetheless the most widely used and established classification of green technologies.

where $X_{i,t}$ and $X_{i,t-1}$ represent sales (deflated) for firm *i* at time *t* and *t-1*, respectively, and $Z_{i,t-1}$ is a vector of the explanatory variables for firm i at time t-1. ω_j and ψ_t represent a set of industry[6] and time dummies, controlling respectively for macroeconomic and time fluctuations. Transforming Equation (1), we obtain an alternative specification of Gibrat's Law as follows:

$$\begin{aligned} Growth_{i,t} &= \lambda_1 + \lambda_2 \ln\left(X_{i,t-1}\right) + \beta_1 KSTOCK_{i,t-1} + \\ &+ \beta_2 (GREEN_{i,t} \times KSTOCK_{i,t}) + \beta_3 AGE + \sum \psi_t + \varepsilon_{i,t} \end{aligned} \quad (5)$$

Equation (2) can be estimated using traditional panel data techniques implementing the fixed effects estimator by removing industry-specific effects, since by definition they are accounted for by firm-level fixed effects. The effects of generic innovation on firm growth are captured by the coefficient β_1, while β_2 allows us to appreciate the differential effects of eco-innovations on firm growth. When $GREEN_{i,t}$ = 1, β_2 adds β_1 and the effect of $KSTOCK_{i,t}$ is augmented accordingly.

However, as noted in section 3.2.1, the kernel density plot of the dependent variable reveals that its distribution is closer to a Laplacian than a Gaussian distribution. For this reason traditional linear estimators such as standard fixed effects may perform poorly.

To cope with this, a viable and increasingly used alternative consists of implementing LAD techniques, which are based on minimizing the absolute deviation from the median rather than the squares of the deviation from the mean. The equation to be estimated becomes:

$$\begin{aligned} Growth_{i,t} &= \lambda_1 + \lambda_2 \ln\left(X_{i,t-1}\right) + \beta_1 KSTOCK_{i,t-1} + \\ &+ \beta_2 (GREEN_{i,t} \times KSTOCK_{i,t}) + \\ &+ \beta_3 AGE + \sum \omega_i + \sum \mu_i + \sum \psi_t + \varepsilon_{i,t} \end{aligned} \quad (6)$$

[6] The industry context is important because innovation is 'industry context specific' (Dosi, 1988). Thus, we need to control for industry effects.

where we reintroduce industry dummies ω_j, and add country dummies μ_j. Following Coad (2010), we do not include individual dummies in the analysis. Since we are dealing with rates rather than levels of growth, in our view any firm-specific components have been mostly removed. We follow the large literature on the analysis of firm growth rates which states that the non-Gaussian nature of growth rate residuals is a more important econometric problem and deserving of careful attention.

4 Empirical results

The results of the fixed effects estimations of the relationship between eco-innovation and firm growth are reported in table 4. Columns (1) and (2) show the results obtained by running the estimations on the whole dataset. Column (1) includes only $KSTOCK_{t-1}$ as the focal regressor alongside the other controls. This allows our results to be positioned in relation to previous empirical work on the topic. The figures appear to be in line with other studies - the coefficient of $KSTOCK_{t-1}$ is positive and highly significant. The commitment of resources to innovation activities, proxied by the outcome variable represented by firm's patents stock, on average is associated with increasing growth rates.

>>> INSERT TABLE 4 ABOUT HERE <<<

Column (2) includes the interaction between $KSTOCK_{t-1}$ and $GREEN_{t-1}$, i.e. the dummy variable that takes the value 1 if the firm *i* has applied for at least one green patent at time *t*, and 0 otherwise. These coefficients provide information on the extent to which the impact of innovation activities on firm growth is augmented by the fact that some of the firm's patents are related to green technologies. The coefficient is positive and significant, supporting the idea that among innovating firms, those producing green technologies are likely to benefit from a higher impact of innovation activities on their performance. In other words, increasing firm sales are associated with innovation efforts but this link is amplified if the innovation activity involves eco-innovations. This result is in line with our main working hypothesis that firms generating green technologies are favored by increasing derived demand from downstream firms which respond creatively to increasingly stringent environmental regulatory frameworks. This raises the production costs for polluting firms such that the resources committed to the adoption of green technologies are offset by a reduction in production costs due to compliance with environmental regulations.

Next we turn our attention to the difference between HGFs and non-HGFs. There are various definitions of HGFs in the literature, and the OECD has proposed its own 'institutional' definition. In this paper, rather than following aprioristic definitions we try to align as closely as possible with the information conveyed by the data. Thus, we calculate each firm's average annual growth rate over the observed time span, and apply the label HGF if the average annual growth rate is in the uppermost decile of the distribution.

Columns (3) and (4) provide the results of the estimations carried out on the subset of HGFs identified using the procedure just described. The results are in line with previous estimations. The coefficient of $KSTOCK_{t-1}$ remains positive and highly significant in both models. Moreover, the coefficient of the interaction is positive and significant. Again, innovation is associated with higher growth rates even for HGFs, and the relationship is stronger if the firm's technological activity involves the generation of green technologies. Columns (5) and (6) provide the estimation results for the subsample of non-HGFs. The differences with HGFs are evident.

Neither $KSTOCK_{t-1}$ nor the interaction variable has a significant coefficient, although positive. This implies that the results for the whole sample are driven by HGFs.

In order to get a more comprehensive understanding of the effects of eco-innovation we implement another set of estimations including the dummy variable $GREEN_{t-1}$ on its own rather than interacting it with $KSTOCK_{t-1}$. The results are presented in Table 5.

>>>INERT TABLE 5 ABOUT HERE <<<

Interpretation of the coefficient of the dummy is straightforward; it implies a change in the intercept of the regression line, which explains its shift. The first column in Table 5 reports the results of the estimation carried out on the full sample. Consistent with the other regressions, the coefficient of $KSTOCK_{t-1}$ is positive and statistically significant. The dummy $GREEN_{t-1}$ is also characterized by a positive and significant coefficient which denotes an upwards shift in the regression line. This means that innovation is related to higher firm growth rates, and that for each level of innovative activity, those firms that produce green technologies show higher growth rates on average. This further qualifies our argument that eco-innovation not only enhances the link between innovative activities and firm growth, it also provides eco-innovative firms with some kind of comparative advantage which enables higher growth rates compared to innovative firms not involved in the generation of green technologies.

Column (2) presents the results of the estimation carried out on the subset of HGFs. Again, the results are fairly consistent with our findings so far. The coefficients of $KSTOCK_{t-1}$ and $GREEN_{t-1}$ are positive and significant. Table 5 column (3) reports the results of the regressions for non-HGFs; we observe that the coefficients of both $KSTOCK_{t-1}$ and $GREEN_{t-1}$ are not significant. Taken together, the results in columns (2) and (3) suggest that the results of the overall estimations are driven by HGF dynamics. Therefore, in response to the question in the title of this paper - 'Do green gazelles run faster'? the answer is yes. The generic result that the generation of green technologies i) enhances the effects of innovation on firm growth, and ii) provides comparative advantage which translates into higher firm growth rates (on average), would seem to hold for HGFs but not for other firms.

Table 6 provides the results for a subset of econometric estimations obtained by implementing the LAD estimator with boostrapped standard errors to act as a robustness check. This step is required since as observed in section 3, the dependent variable is more similar to a Laplacian than a Gaussian distribution.

>>> INSERT TABLE 6 ABOUT HERE <<<

The first set of results in table 6 is for the HGF subsample. Column (1a) reports the coefficients in the baseline model, i.e. the model including only $KSTOCK_{t-1}$. In this step we do not include firm-level dummies since most individual effects are removed by taking the normalized log-difference of sales as the dependent variable. However, we include time and country and industry dummies (these last calculated on the basis of the 2 digit NACE rev. 2 classification). The results seem to be robust to a change of estimator since the coefficient of $KSTOCK_{t-1}$ is still positive and significant. Column (1b) reports the model that includes the interaction between $KSTOCK_{t-1}$ and $GREEN_{t-1}$. The coefficient of the interaction variable, and the coefficient of $KSTOCK_{t-1}$ on its own remain positive and significant. Finally column (1c) includes the dummy variable $GREEN_{t-1}$ instead of the interaction variable. Again the results are in line with the previous estimations. Thus, we can conclude that eco-innovation contributes to the growth process of HGFs in such a way that 'green gazelles' "run faster" than other HGFs.

The second set of regressions provides evidence on the relationship between innovation, and eco-innovation, and the rates of growth of firms not included in the HGF subsample. Column (2a) shows the coefficients in the estimation of the baseline model. The main difference from the previous estimations is that the lagged value of *SALES* is not significant, while AGE_{t-1} is characterized by a negative and significant coefficient. The coefficient of $KSTOCK_{t-1}$ is positive and significant, suggesting that increasing growth rates are associated with higher levels of innovative activity. Column (2b) includes the interaction term between $KSTOCK_{t-1}$ and $GREEN_{t-1}$. While the results for the other regressors are substantially unchanged, the coefficient of the interaction term is not significant for the subsample of non-HGF firms. This result supports the findings from the linear fixed effects estimations in table 4. Firm growth is associated with higher levels of innovations which holds for both gazelles and non-HGFs. However, if we look at the differential effects of eco-innovation green-gazelles seem to grow more rapidly than their non-green counterparts, while eco-innovation does not have a significant effect on the relationship between innovation and growth rates for non-HGFs. Finally, column (2c) shows the results obtained by including the $GREEN_{t-1}$ dummy alone rather than interacted with $KSTOCK_{t-1}$. In this case, the results deviate from the results in the previous tables since the dummy has a positive and significant coefficient. This suggests that although the fact of producing eco-innovation does not affect the impact of innovations on firm growth in the case of HGFs, on average eco-innovation is associated with higher levels of firm growth.

5 Conclusions

There is growing attention at policy level to the importance of regulation as a means to induce firms to lower their polluting emissions while simultaneously improving the efficiency of their production processes. Building on the seminal contribution of Porter and van der Linde

(1995), numerous environmental policy measures have been aimed at coupling environmental and economic performance (particularly productivity) improvements. These benefits are supposed to emerge as a result of greater efforts by firms to adopt eco-innovations in their production processes. However, a rather less investigated aspect of this normative environment refers to the spread of the effects of inducement mechanisms along the value chain.

In this paper we hypothesized that the derived demand for eco-innovation by downstream firms is likely to positively affect the performances, and sales in particular, of upstream firms that produce and supply eco-innovations. We focused especially on a particular type of firm, i.e. HGFs or gazelles, because of their - mostly undisputed - contribution to the process of economic growth. Our econometric estimations of the determinants of firm growth provide support for the idea that eco-innovation positively affects the firm's growth processes. We showed also that this generic result is driven by HGFs rather than non-HGFs. This allows us to conclude that innovation plays a key role in the HGF growth process, and that 'green gazelles' or HGFs producing green technologies are i) much more affected by innovation, and ii) are characterized by higher growth rates on average.

Green gazelles run faster than other HGFs. This finding has important policy implications, and calls for more attention to the systemic character of technology and environmental policies (Crespi and Quatraro, 2013, 2015). It seems clear that the effects of environmental policies which push firms to adopt green technologies engender a bandwagon effect in the economy, which spreads along the value chain. At the same time, technology policies promoting the development of specific technological areas should be coordinated with environmental policies such that firms producing new technologies receive appropriate incentives to produce 'green technologies' in anticipation of increasing demand from their downstream firms. There would seem also to be a case for ‘competent’ public procurement of innovation. Public expenditure is key to the development of strategic technological fields, and its combination with technology and environmental policies may be crucial for achieving positive effects on the medium and long term environmental and economic performance of both firms and the whole economy.

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Table 1 - Country distribution of sampled firms

	Full Sample		Cleaned Sample	
Country	Freq.	Percent	Freq.	Percent
DE	223,301	23.87	83,31	18.26
ES	186,501	19.94	115,706	25.36
FR	129,815	13.88	122,205	26.79
UK	197,191	21.08	450	0.10
IT	141,949	15.17	132,538	29.05
SE	56,722	6.06	2,031	0.45
Total	935,479	100.00	456,240	100.00

Source: our elaboration on Bureau Van Dijk Orbis Data.

Table 2 - Sector Distribution of Sampled Firms

Nace rev. 2	Definition	Full Sample		Cleaned Sample	
		Freq.	Percent	Freq.	Percent
10	Manufacture of food products	109,052	11.66	55,598	12.19
11	Manufacture of beverages	14,144	1.51	7,237	1.59
12	Manufacture of tobacco products	311	0.03	106	0.02
13	Manufacture of textiles	30,29	3.24	13,859	3.04
14	Manufacture of wearing apparel	33,809	3.61	17,493	3.83
15	Manufacture of leather and related products	16,362	1.75	10,202	2.24
16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	47,887	5.12	20,351	4.46
17	Manufacture of paper and paper products	12,227	1.31	6,173	1.35
18	Printing and reproduction of recorded media	63,827	6.82	29,288	6.42
19	Manufacture of coke and refined petroleum products	1,394	0.15	539	0.12
20	Manufacture of chemicals and chemical products	24,279	2.60	11,647	2.55
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	4,977	0.53	2,137	0.47
22	Manufacture of rubber and plastic products	34,298	3.67	18,465	4.05
23	Manufacture of other non-metallic mineral products	44,431	4.75	23,576	5.17
24	Manufacture of basic metals	13,659	1.46	7,116	1.56
25	Manufacture of fabricated metal products, except machinery and equipment	156,227	16.70	83,907	18.39
26	Manufacture of computer, electronic and optical products	39,06	4.18	16,488	3.61
27	Manufacture of electrical equipment	29,244	3.13	13,883	3.04
28	Manufacture of machinery and equipment n.e.c.	75,857	8.11	38,673	8.48
29	Manufacture of motor vehicles, trailers and semi-trailers	14,062	1.50	6,563	1.44
30	Manufacture of other transport equipment	12,552	1.34	4,814	1.06
31	Manufacture of furniture	44,028	4.71	21,224	4.65
32	Other manufacturing	64,119	6.85	21,623	4.74
33	Repair and installation of machinery and equipment	49,383	5.28	25,278	5.54
Total		935,479	100.00	456,240	100.00

Source: our elaboration on Bureau Van Dijk Orbis Data.

Table 3 – Variables definition and descriptive statistics

Variables	Definition	N	Max	Min	Mean	St. Dev.
$S_{i,t}$	Normalized firms' growth rates	2030552	9.091	-11.252	0.021	0.221
$SALES_{i,t-1}$	Logarithm of firms' sales level	2366794	10.424	-3.542	0.042	1.090
$AGE_{i,t-1}$	Logarithm of firms' age	2429568	5.974	0.000	3.212	0.459
$KSTOCK_{i,t-1}$	Firms' knowledge capital stock (PIM on patent applications)	2045318	11.331	0.000	0.064	0.443
$GREEN_{i,t-1}$	Dummy variable = 1 if the firm has applied At least one green patent at time t	2431033	1.000	0.000	0.003	0.057

Table 4 – Econometric results (I), fixed effects estimations

	Overall		HGFs		Non-HGFs	
	$S_{i,t}$	$S_{i,t}$	$S_{i,t}$	$S_{i,t}$	$S_{i,t}$	$S_{i,t}$
***SALES**$_{i,t-1}$*	-0.4821***	-0.4821***	-0.6513***	-0.6513***	-0.4866***	-0.4866***
	(0.0006)	(0.0006)	(0.0020)	(0.0020)	(0.0007)	(0.0007)
***AGE**$_{i,t-1}$*	0.1169***	0.1170***	-0.1006***	-0.0998***	0.0988***	0.0988***
	(0.0039)	(0.0039)	(0.0209)	(0.0209)	(0.0035)	(0.0035)
***KSTOCK**$_{i,t-1}$*	0.0183***	0.0179***	0.0125***	0.0111***	0.0014	0.0015
	(0.0011)	(0.0012)	(0.0042)	(0.0042)	(0.0011)	(0.0011)
***GREEN**$_{i,t-1}$* × ***KSTOCK**$_{i,t-1}$*		0.0025*		0.0081*		-0.0004
		(0.0013)		(0.0047)		(0.0013)
Time dummies	YES	YES	YES	YES	YES	YES
Cons	-0.3374***	-0.3377***	0.5447***	0.5424***	-0.3145***	-0.3145***
	(0.0118)	(0.0118)	(0.0598)	(0.0598)	(0.0108)	(0.0108)
N	1981248	1981248	192243	192243	1789005	1789005
AIC	-1.4739e+06	-1.4739e+06	68133.1226	68131.4696	-1.8749e+06	-1.8749e+06
BIC	-1.4738e+06	-1.4738e+06	68244.9543	68253.4678	-1.8747e+06	-1.8747e+06

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5 – Econometric results (II), fixed effects estimations

	(Overall)	(HGF)	(Non-HGF)
	$S_{i,t}$	$S_{i,t}$	$S_{i,t}$
***SALES**$_{i,t-1}$*	-0.4821***	-0.6514***	-0.4866***
	(0.0006)	(0.0020)	(0.0007)
***AGE**$_{i,t-1}$*	0.1170***	-0.0997***	0.0988***
	(0.0039)	(0.0209)	(0.0035)
***KSTOCK**$_{i,t-1}$*	0.0177***	0.0106**	0.0013
	(0.0012)	(0.0042)	(0.0011)
***GREEN**$_{i,t-1}$*	0.0192***	0.0530***	0.0049
	(0.0043)	(0.0151)	(0.0043)
Time Dummies	YES	YES	YES
Cons	-0.3378***	0.5421***	-0.3146***
	(0.0118)	(0.0598)	(0.0108)
N	1981248	192243	1789005
AIC	-1.4739e+06	68119.8644	-1.8749e+06
BIC	-1.4738e+06	68241.8626	-1.8747e+06

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6 – Econometric results (III), LAD estimations

	HGF			NON-HGF		
	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)
	$S_{i,t}$	$S_{i,t}$	$S_{i,t}$	$S_{i,t}$	$S_{i,t}$	$S_{i,t}$
***SALES**$_{i,t-1}$*	-0.0195***	-0.0195***	-0.0194***	0.0002	0.0002	0.0002
	(0.0005)	(0.0006)	(0.0005)	(0.0001)	(0.0002)	(0.0002)
***AGE**$_{i,t-1}$*	-0.0270***	-0.0271***	-0.0271***	-0.0089***	-0.0089***	-0.0089***
	(0.0012)	(0.0014)	(0.0013)	(0.0002)	(0.0002)	(0.0002)
***KSTOCK**$_{i,t-1}$*	0.0117***	0.0108***	0.0109***	0.0039***	0.0039***	0.0036***
	(0.0008)	(0.0010)	(0.0008)	(0.0003)	(0.0004)	(0.0004)
***GREEN**$_{i,t-1}$* × ***KSTOCK**$_{i,t-1}$*		0.0028*			0.0004	
		(0.0018)			(0.0009)	
***GREEN**$_{i,t-1}$*			0.0108***			0.0063**
			(0.007)			(0.0031)
Country dummies	YES	YES	YES	YES	YES	YES
Industry dummies	YES	YES	YES	YES	YES	YES
Time dummies	YES	YES	YES	YES	YES	YES
Cons	0.2789***	0.2787***	0.2784***	0.0700***	0.0699***	0.0699***
	(0.0309)	(0.0263)	(0.0267)	(0.0027)	(0.0015)	(0.0014)
N	192243	192243	192243	1789005	1789005	1789005

Bootstrapped Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure 1 – Kernel Distribution, Firms' Normalized Growth Rates

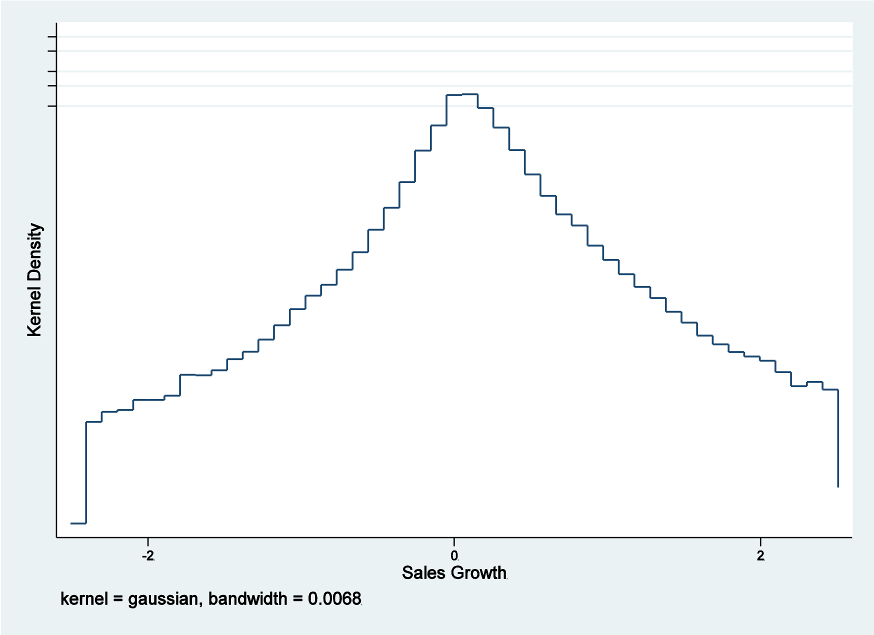

Table A1 – WIPO IPC Green Inventory

TOPIC	IPC
ALTERNATIVE ENERGY PRODUCTION	
Bio-fuels	
Solid fuels	C10L 5/00, 5/40-5/48
Torrefaction of biomass	C10B 53/02
	C10L 5/40, 9/00
Liquid fuels	C10L 1/00, 1/02, 1/14
Vegetable oils	C10L 1/02, 1/19
Biodiesel	C07C 67/00, 69/00
	C10G
	C10L 1/02, 1/19
	C11C 3/10
	C12P 7/64
Bioethanol	C10L 1/02, 1/182
	C12N 9/24
	C12P 7/06-7/14
Biogas	C02F 3/28, 11/04
	C10L 3/00
	C12M 1/107
	C12P 5/02
From genetically engineered organisms	C12N 1/13, 1/15, 1/21, 5/10, 15/00 A01H
Integrated gasification combined cycle (IGCC)	C10L 3/00
	F02C 3/28
Fuelcells	H01M 4/86-4/98, 8/00-8/24, 12/00-12/08
Electrodes	H01M 4/86-4/98
Inert electrodes with catalytic activity	H01M 4/86-4/98
Non-activeparts	H01M 2/00-2/04 , 8/00-8/24
Within hybridcells	H01M 12/00-12/08
Pyrolysis or gasification of biomass	
	C10B 53/00
	C10J
Harnessing energy from manmade waste	
Agricultural waste	C10L 5/00
Fuel from animal waste and crop residues	C10L 5/42, 5/44
Incinerators for field, garden or wood waste	F23G 7/00, 7/10
Gasification	C10J 3/02, 3/46
	F23B 90/00
	F23G 5/027
Chemicalwaste	B09B 3/00
	F23G 7/00
Industrial waste	C10L 5/48
	F23G 5/00, 7/00
Using top gas in blast furnaces to power pig-iron production	C21B 5/06
Pulp liquors	D21C 11/00
Anaerobic digestion of industrial waste	A62D 3/02
	C02F 11/04, 11/14
Industrial wood waste	F23G 7/00, 7/10
Hospital waste	B09B 3/00
	F23G 5/00
Landfill gas	B09B
Separation of components	B01D 53/02, 53/04, 53/047, 53/14, 53/22, 53/24
Municipal waste	C10L 5/46
	F23G 5/00
Hydroenergy	
Water-power plants	E02B 9/00-9/06
Tide or wave power plants	E02B 9/08
Machines or engines for liquids	F03B
	F03C
Using wave or tide energy	F03B 13/12-13/26
Regulating, controlling or safety means of machines or engines	F03B 15/00-15/22
Propulsion of marine vessels using energy derived from water movement	B63H 19/02, 19/04
Ocean thermal energy conversion (OTEC)	F03G 7/05
Wind energy	F03D
Structural association of electric generator with mechanical driving motor	H02K 7/18
Structural aspects of wind turbines	B63B 35/00
	E04H 12/00
	F03D 11/04
Propulsion of vehicles using wind power	B60K 16/00
Electric propulsion of vehicles using wind power	B60L 8/00
Propulsion of marine vessels by wind-powered motors	B63H 13/00
Solar energy	
Photovoltaics (PV)	
Devices adapted for the conversion of radiation energy into electrical energy	H01L 27/142, 31/00-31/078 H01G 9/20
	H02N 6/00

TOPIC	IPC
Using organic materials as the active part	H01L 27/30, 51/42-51/48
Assemblies of a plurality of solar cells	H01L 25/00, 25/03, 25/16, 25/18, 31/042
Silicon; single-crystal growth	C01B 33/02
	C23C 14/14, 16/24
	C30B 29/06
Regulating to the maximum power available from solar cells	G05F 1/67
Electric lighting devices with, or rechargeable with, solar cells	F21L 4/00
	F21S 9/03
Charging batteries	H02J 7/35
Dye-sensitised solar cells (DSSC)	H01G 9/20
	H01M 14/00
Use of solar heat	F24J 2/00-2/54
For domestic hot water systems	F24D 17/00
For space heating	F24D 3/00, 5/00, 11/00, 19/00
For swimming pools	F24J 2/42
Solar updraft towers	F03D 1/04, 9/00, 11/04
	F03G 6/00
For treatment of water, waste water or sludge	C02F 1/14
Gas turbine power plants using solar heat source	F02C 1/05
Hybrid solar thermal-PV systems	H01L 31/058
Propulsion of vehicles using solar power	B60K 16/00
Electric propulsion of vehicles using solar power	B60L 8/00
Producing mechanical power from solar energy	F03G 6/00-6/06
Roof covering aspects of energy collecting devices	E04D 13/00, 13/18
Steam generation using solar heat	F22B 1/00
	F24J 1/00
Refrigeration or heat pump systems using solar energy	F25B 27/00
Use of solar energy for drying materials or objects	F26B 3/00, 3/28
Solar concentrators	F24J 2/06
	G02B 7/183
Solar ponds	F24J 2/04
Geothermal energy	
Use of geothermal heat	F01K
	F24F 5/00
	F24J 3/08
	H02N 10/00
	F25B 30/06
Production of mechanical power from geothermal energy	F03G 4/00-4/06, 7/04

TOPIC	IPC
Other production or use of heat, not derived from combustion, e.g. natural heat	F24J 1/00, 3/00, 3/06
Heat pumps in central heating systems using heat accumulated in storage masses	F24D 11/02
Heat pumps in other domestic- or space-heating systems	F24D 15/04
Heat pumps in domestic hot-water supply systems	F24D 17/02
Air or water heaters using heat pumps	F24H 4/00
Heat pumps	F25B 30/00
Using waste heat	
To produce mechanical energy	F01K 27/00
Of combustion engines	F01K 23/06-23/10
	F01N 5/00
	F02G 5/00-5/04
	F25B 27/02
Of steam engine plants	F01K 17/00, 23/04
Of gas-turbine plants	F02C 6/18
As source of energy for refrigeration plants	F25B 27/02
For treatment of water, waste water or sewage	C02F 1/16
Recovery of waste heat in paper production	D21F 5/20
For steam generation by exploitation of the heat content of hot heat carriers	F22B 1/02
Recuperation of heat energy from waste incineration	F23G 5/46
Energy recovery in air conditioning	F24F 12/00
Arrangements for using waste heat from furnaces, kilns, ovens or retorts	F27D 17/00
Regenerative heat-exchange apparatus	F28D 17/00-20/00
Of gasification plants	C10J 3/86
Devices for producing mechanical power from muscle energy	F03G 5/00-5/08
TRANSPORTATION	
Vehicles in general	
Hybrid vehicles, e.g Hybrid Electric Vehicles (HEVs)	B60K 6/00, 6/20
Control systems	B60W 20/00
Gearingstherefor	F16H 3/00-3/78, 48/00-48/30
Brushless motors	H02K 29/08
Electromagnetic clutches	H02K 49/10
Regenerative braking systems	B60L 7/10-7/22
Electric propulsion with power supply from force of nature, e.g. sun, wind	B60L 8/00
Electric propulsion with power supply external to vehicle	B60L 9/00
With power supply from fuel cells, e.g for hydrogen vehicles	B60L 11/18
Combustion engines operating on gaseous fuels, e.g hydrogen	F02B 43/00
	F02M 21/02, 27/02

TOPIC	IPC
Power supply from force of nature, e.g. sun, wind	B60K 16/00
Charging stations for electric vehicles	H02J 7/00
Vehicles other than rail vehicles	
Drag reduction	
	B62D 35/00, 35/02
	B63B 1/34-1/40
Human-powered vehicle	B62K
	B62M 1/00, 3/00, 5/00, 6/00
Rail vehicles	B61
Drag reduction	B61D 17/02
Marine vessel propulsion	
Propulsive devices directly acted on by wind	B63H 9/00
Propulsion by wind-powered motors	B63H 13/00
Propulsion using energy derived from water movement	B63H 19/02, 19/04
Propulsion by muscle power	B63H 16/00
Propulsion derived from nuclear energy	B63H 21/18
Cosmonautic vehicles using solar energy	B64G 1/44
ENERGY CONSERVATION	
Storage of electrical energy	B60K 6/28
	B60W 10/26
	H01M 10/44-10/46
	H01G 9/155
	H02J 3/28, 7/00, 15/00
Power supply circuitry	H02J
With power saving modes	H02J 9/00
Measurement of electricity consumption	B60L 3/00
	G01R
Storage of thermal energy	C09K 5/00
	F24H 7/00
	F28D 20/00, 20/02
Low energy lighting	
Electroluminescent light sources (e.g. LEDs, OLEDs, PLEDs)	F21K 99/00
	F21L 4/02
	H01L 33/00-33/64, 51/50
	H05B 33/00
Thermal building insulation, in general	E04B 1/62, 1/74-1/80, 1/88, 1/90
Insulating building elements	E04C 1/40, 1/41, 2/284-2/296
For door or window openings	E06B 3/263
For walls	E04B 2/00

TOPIC	IPC
	E04F 13/08
For floors	E04B 5/00
	E04F 15/18
For roofs	E04B 7/00
	E04D 1/28, 3/35, 13/16
For ceilings	E04B 9/00
	E04F 13/08
Recovering mechanical energy	F03G 7/08
Chargeable mechanical accumulators in vehicles	B60K 6/10, 6/30
	B60L 11/16
WASTE MANAGEMENT	
Waste disposal	B09B
	B65F
Treatment of waste	
Disinfection or sterilisation	A61L 11/00
Treatment of hazardous or toxic waste	A62D 3/00, 101/00
Treating radioactively contaminated material; decontamination arrangements therefor	G21F 9/00
Refuse separation	B03B 9/06
Reclamation of contaminated soil	B09C
Mechanical treatment of waste paper	D21B 1/08, 1/32
Consuming waste by combustion	F23G
Reuse of waste materials	
Use of rubber waste in footwear	A43B 1/12, 21/14
Manufacture of articles from waste metal particles	B22F 8/00
Production of hydraulic cements from waste materials	C04B 7/24-7/30
Use of waste materials as fillers for mortars, concrete	C04B 18/04-18/10
Production of fertilisers from waste or refuse	C05F
Recovery or working-up of waste materials	C08J 11/00-11/28
	C09K 11/01
	C11B 11/00, 13/00-13/04
	C14C 3/32
	C21B 3/04
	C25C 1/00
	D01F 13/00-13/04
Pollution control	
Carbon capture and storage	B01D 53/14, 53/22, 53/62
	B65G 5/00
	C01B 31/20
	E21B 41/00, 43/16

TOPIC	IPC
	E21F 17/16
	F25J 3/02
Air quality management	
Treatment of waste gases	B01D 53/00-53/96
Exhaust apparatus for combustion engines with means for treating exhaust	F01N 3/00-3/38
Rendering exhaust gases innocuous	B01D 53/92
	F02B 75/10
Removal of waste gases or dust in steel production	C21C 5/38
Combustion apparatus using recirculation of flue gases	C10B 21/18
	F23B 80/02
	F23C 9/00
Combustion of waste gases or noxious gases	F23G 7/06
Electrical control of exhaust gas treating apparatus	F01N 9/00
Separating dispersed particles from gases or vapours	B01D 45/00-51/00
	B03C 3/00
Dust removal from furnaces	C21B 7/22
	C21C 5/38
	F27B 1/18
	F27B 15/12
Use of additives in fuels or fires to reduce smoke or facilitate soot removal	C10L 10/02, 10/06
	F23J 7/00
Arrangements of devices for treating smoke or fumes from combustion apparatus	F23J 15/00
Dust-laying or dust-absorbing materials	C09K 3/22
Pollution alarms	G08B 21/12
Control of water pollution	
Treating waste-water or sewage	B63J 4/00
	C02F
To produce fertilisers	C05F 7/00
Materials for treating liquid pollutants	C09K 3/32
Removing pollutants from open water	B63B 35/32
	E02B 15/04
Plumbing installations for waste water	E03C 1/12
Management of sewage	C02F 1/00, 3/00, 9/00
	E03F
Means for preventing radioactive contamination in the event of reactor leakage	G21C 13/10
AGRICULTURE / FORESTRY	
Forestry techniques	A01G 23/00

TOPIC	IPC
Alternative irrigation techniques	A01G 25/00
Pesticide alternatives	A01N 25/00-65/00
Soil improvement	C09K 17/00
	E02D 3/00
Organic fertilisers derived from waste	C05F
ADMINISTRATIVE, REGULATORY OR DESIGN ASPECTS	
Commuting, e.g., HOV, teleworking, etc.	G06Q
	G08G
Carbon/emissions trading, e.g pollution credits	G06Q
Static structure design	E04H 1/00

NUCLEAR POWER GENERATION

Nuclear engineering	G21
Fusion reactors	G21B
Nuclear (fission) reactors	G21C
Nuclear power plant	G21D
Gas turbine power plants using heat source of nuclear origin	F02C 1/05