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Science and technology parks and their heterogeneous effect on firm innovation

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ABSTRACT

Science and Technology Parks (STPs) have proliferated in many countries as a policy initiative to foster innovation. Previous studies have mostly analysed average effects on the innovation performance of tenant firms, leading to mixed results. This paper aims to explore whether there are heterogeneous STP effects. Creating a novel database of Spanish patents generated on- and off-park, merged with firm and STP characteristics, we find that younger and larger firms benefit more from being on-park and younger and older STPs have a stronger effect on tenants' patent quality, while STPs promoted by universities do not exhibit a differential effect.

1. Introduction

The role of innovation as a driver of economic development and its importance for economic growth is broadly recognised in policy and economic fora (Battiston et al., 2023; Box, 2009). Policy initiatives to foster business innovation are often mentioned as key priorities in the political agenda (OECD, 2011; UNIDO, 2021), but when designing and implementing them, it is often forgotten that the characteristics of firms and their interaction with policy instruments should be at the centre of the process (Crespo et al., 2016) as firms are extraordinarily heterogeneous (Bloom et al., 2014).

One of the most widely used innovation policy measures consists of co-locating firms to generate agglomeration effects (Bloom and Reenen, 2019). Within the broader set of policy instruments used by governments to foster the development of business clusters, science and technology parks (STPs) are one of the most widespread (Ng et al., 2019). STPs are non-spontaneous clusters, often the result of political decisions, aimed at promoting the creation and growth of knowledge and technology-based firms with a management team that pursues the objectives of the park (Vásquez-Urriago et al., 2016). They are widespread in both developed (Hobbs et al., 2017) and emerging countries (Ribeiro et al., 2021; Rodríguez-Pose and Hardy, 2014).

STPs have gained significant academic and political interest because of their potential to help firms deliver high-tech innovations and entrepreneurial activities that benefit regional economic development (Poonjan et al., 2022; Sandoval Hamón et al., 2022). The large public investment made to promote and establish STPs is proof of their importance to governments around the world. In Europe, cohesion funds have been requested to support STPs with the aim of fostering regional development (Battiston et al., 2023; Nauwelaers et al., 2014). STPs have also had a relevant role in Research and Innovation Strategies for Smart Specialisation (RIS3) in the European Union (Jacobsen et al., 2022; Nauwelaers et al., 2019). Remarkably, about 85 % of European STPs have received public funding,

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around €4.8 billion during the period 2000–2012 (Rowe, 2014).

The STP phenomenon is not only a policy steadily settled in Europe with over 360 STPs established (Rowe, 2014), but is also widespread across the world. In China, the number of STPs reached up to 176 STPs in 2017 (UNIDO, 2021). In the US and Canada, the figure exceeded 300 STPs established (Battelle Technology Partnership Practice, 2013). This relevance goes beyond the developed countries since even in emerging countries such as Turkey, with 72 active STPs (Ünlü et al., 2022), STPs are an extensive policy to encourage economic growth. Furthermore, a number of initiatives have been acquiring remarkable importance in Africa, Latin America, and Australia (Lecluyse et al., 2019).

The rationale behind STPs is rooted in theoretical models in which the notion of knowledge spillover takes an essential role in facilitating the transfer of knowledge (Marshall, 1890). Geographical proximity between workers and, in turn, agents such as firms, public research institutions, universities and so on, ease their interaction and the spread of knowledge spillovers which are paramount in innovation. Therefore, Marshall describes the agglomeration of firms as a source of innovation. Reinforcing this idea, Krugman (1991) within the New Economic Geography theory, states that the spatial concentration fosters the propensity to innovate that, in turn, leads to growth. In a similar manner, Porter (1990) argue that knowledge spillovers, that are geographically localised, stimulate growth. Indeed, Krugman (1991) points out that the concentration in geographic areas as "the most striking feature of the geography of economic activity" by benefitting from a smoother transfer of knowledge. In the same vein, Porter (1998) puts the emphasis on the cluster concept and outlines industrial clusters are drivers of innovation that account for the productivity growth.

The empirical literature has addressed the effects of STPs on tenants, mainly as regards economic performance, cooperation behaviour, and innovation performance (Albahari et al., 2023), leading to contrasting evidence. Most of these studies have considered only an average STP effect (Corrocher et al., 2019; Squicciarini, 2008; Yang et al., 2009) without taking into account that some parks may have a greater effect on tenants, and some tenants may benefit more than others from on-park location. Some scholars have indeed suggested that the effect of STPs on firms is far from homogeneous (Albahari et al., 2018; Huang et al., 2012; Ng et al., 2022; Squicciarini, 2009; Vásquez-Urriago et al., 2016).

The contrasting empirical evidence found may be due, to some extent, to the fact that the evaluation of this policy has focused mainly on average STP effects. Factors that may produce heterogeneous effects relate to the characteristics of both the tenants and the parks. The few studies on the heterogeneous effect of STPs reach no consensus on how heterogeneity influences the STP effect by considering either park characteristics (Albahari et al., 2018; Lamperti et al., 2017; Squicciarini, 2009; Teng et al., 2020) or tenant characteristics (Díez-Vial and Fernández-Olmos, 2017; Huang et al., 2012; Vásquez-Urriago et al., 2016), so more research is needed to evaluate the use of STPs as an innovation policy instrument from this point of view (Albahari et al., 2023; Lecluyse et al., 2019).

The main goal of this work is to develop new evidence of the heterogeneous effects of STPs on tenants' innovation performance. To this end, we focus on Spanish STPs, which are particularly suitable for our research as they exhibit remarkable heterogeneity (Albahari et al., 2013). We observe the existence of parks in different stages of development with STPs established since the mid-1980s and others established in the 2010s. Following the approval of special funds by the Spanish government in 2000 to promote the creation of STPs, their number and importance increased throughout the country. Remarkable is also the involvement of universities in STPs as the establishment of several parks has been promoted by universities. Therefore, we can find some STPs in which the university plays a key role in their promotion, while for other STPs the university is just another agent in their innovation ecosystem and in some cases, there is no relationship at all between the STP and universities. From the tenant's point of view, we find a wide range of firms, from large to small and from old to newly established. This seems to indicate the existence of heterogeneity in both the STPs themselves and the firms housed, which could support the idea that the 'average' park does not allow us to observe the STP effect accurately.

Patent count has often been recognised as one of the preferred innovation indicators in the innovation literature, mainly due to the increasing availability, accessibility, and richness of patent data (Higham et al., 2021; van Zeebroeck, 2011). Accordingly, most of the papers in the STP literature employ patent counts to estimate innovation performance. However, the patent literature raises many concerns about this indicator, as when considering the number of patents, the value of the patents themselves is not taken into account (Griliches, 1990; Scherer and Harhoff, 2000). Due to their inherent nature, the value of patents is highly skewed (Gambardella et al., 2008). Indeed, a recent study emphasises the need to consider the heterogeneous nature of innovation, and in particular, the fact that the value of patents is heterogeneously distributed (Higham et al., 2021). In this sense, previous research has questioned the appropriateness of using patent counts instead of other innovation indicators (Dang and Motohashi, 2015; Ünlü et al., 2022). Within STP literature, the recent paper by Anton-Tejon et al. (2024) adopt this approach by employing patent quality indicators to estimate the STP effect on tenants' innovation performance.

Within this framework, the patent quality concept is a reliable alternative to the biased patent count indicator. Patent quality is a multidimensional concept that embraces diverse components of patents such as technological importance and economic value. Using patent quality indicators enables us to deal with the heterogeneity of patents and following the patent literature (Higham et al., 2021), we use forward citations (Jaffe et al., 1993; Trajtenberg, 1990) and patent renewal (Griliches et al., 1987), which are two of the main indicators employed in patent literature to estimate patent quality.

Our results show that the effect of the park on the technological importance of patents is greater for younger firms, and the effect on the economic value of patents is greater for larger firms. As for the age of the park, we find that younger and older parks have the greatest effect on the quality of tenants' patents, while medium-aged parks do not show significant results. Finally, the presence of the university as a promoting entity of the STP does not seem to improve patent quality compared with patents in parks where the university is not a promoting entity.

The remainder of the paper is organised as follows: Section 2 presents a review of the literature; Section 3 presents the data and describes the variables used; Section 4 details the methodology used; Section 5 presents the empirical results; and Section 6 concludes, suggesting implications of the study and lines for further research.

2. STP heterogeneous effects

As pointed out by some recent literature reviews on STPs (Albahari et al., 2023; Lecluyse et al., 2019; Sandoval Hamón et al., 2022), quantitative papers that aim to assess the effects of STPs on firms mostly consider homogenous effects. That is, these papers estimate the 'average' STP effect on tenants. However, STPs and tenants are essentially heterogeneous (Albahari, 2019), and some characteristics of parks may increase their effect, just as some characteristics of tenants may contribute to their benefiting more than others from the on-park location.

In what follows, we review theoretical arguments and report empirical evidence that illustrates the moderating effects of firm and STP characteristics on the park effect on tenants. The literature usually provides opposite arguments on the influence of the different firms and STP characteristics. In the same vein, empirical evidence is often contradictory.

2.1. Firm characteristics

We consider two firm-level characteristics that may modify the effect of STPs on tenants: firm age and firm size. That is, we can ask whether on-park location is more beneficial for younger or older firms and for smaller or larger firms. This means that we consider, e.g. the comparison of a young firm located in the STP with the same young firm located outside the STP and, in turn, the comparison of an old firm located in the STP with the same old firm located outside the STP.

2.1.1. Firm age

Some well-established theoretical arguments suggest that younger firms benefit more than older firms from park location.

First, newly established firms suffer several obstacles more than older firms, for example, when developing new relationships with different agents or when raising resources (Baum et al., 2000). STPs may help young firms to overcome these obstacles by establishing relationships with several actors in regional innovation ecosystems, including universities, research centres, and venture capital funds (Albahari et al., 2019). Unlike young firms, older companies may not be interested in establishing relationships with local firms and agents as they are able to obtain knowledge and experience through their own networks (Diez-Vial and Fernández-Olmos, 2017).

Second, facing the challenge of earning a recognised reputation from customers, suppliers, investors or society in general, young companies benefit more from being co-located in the STP with established companies, research centres or universities because of the prestige that interacting with these organisations provides (Felsenstein, 1994; Ferguson and Olofsson, 2004; Lindelöf and Löfsten, 2005). In this sense, STPs are good 'brand names' for young firms (Salvador, 2011).

Third, STPs may be more beneficial for younger companies also because of their greater flexibility. On the one hand, STPs provide a proper environment in which firms at different stages of development can exchange knowledge (Löwegren, 2003). This need to acquire new knowledge and assimilate new ways of operating, pushes young firms to be more flexible. On the other hand, older firms may be more reluctant to change (Henderson, 1999) and less flexible when incorporating new knowledge because of organizational principles and routines already established (McCann and Folta, 2011).

These arguments do not imply that old firms do not benefit from STP location. They just highlight that the effect of being located in an STP (relative to being located elsewhere) is expected to be larger for younger firms than for older firms.

Despite the fact that theoretical arguments and the policy rationale for the creation of STPs clearly point to a greater benefit for young firms from on-park location, the scarce empirical evidence that exists is controversial (see Table 1). While Diez-Vial and Fernández-Olmos (2017) find that the park's effect on employment growth, sales growth and sales from new products declines with

Table 1
Empirical evidence of the effect of STPs on innovation performance.

Characteristics	Positive impact	Negative impact	Non-linear relation	Non-significant impact
Firm age		Díez-Vial and Fernández-Olmos, 2017		Liberati et al., 2016
Firm size		Huang et al., 2012 Liberati et al., 2016	Vásquez-Urriago et al., (2016)[3]	
STP age	Hobbs et al., 2017 Liberati et al., 2016 Link and Scott, 2005 Teng et al., 2020[1] Yang and Lee, 2021	Squicciarini, 2009 Teng et al., 2020[1]	Albahari et al., 2018[4]	Lamperti et al., 2017
University involvement	Albahari et al., 2017[2] Arauzo-Carod et al., 2018 Yang and Lee., 2021	Albahari et al., 2017[2] Squicciarini, 2009 Teng et al. 2020		Lamperti et al., 2017

[1]Teng et al. (2020) find that STP age positively influences the effect of STPs when considering patents and negatively when considering sales from new products.
[2]Albahari et al. (2017) find that a higher level of university involvement in STPs is related to a higher number of patents filed by tenants and lower sales from new products.
[3]Vásquez-Urriago et al., (2016) find a U-inverted-shaped relation between firm size and new-to-the market product sales, with smaller firms showing a better performance.
[4]Albahari et al. (2018) find a U-shaped relationship between park age with new-to-the-market product sales, with firms in younger and older parks outperforming firms in medium-aged parks.

firm age, Liberati et al. (2016) do not observe any heterogeneous effect of STPs on the number of patent applications of tenants according to firm age. Nonetheless, they find that the park's effect on tenant sales increases with firm age, in contrast with Diez-Vial and Fernández-Olmos (2017).

2.1.2. Firm size

There are theoretical arguments supporting the view that larger firms may benefit more from STP locations than smaller firms and also arguments to the contrary, i.e., that small companies benefit more from being located in an STP.

On the one hand, firm size has been widely seen as being positively related to innovation performance (Scherer, 1965). One of the reasons is larger firms' higher absorptive capacity, that is, the ability to recognise and assimilate knowledge (Cohen and Levinthal, 1990). The external knowledge provided by the park ecosystem (both tenants and off-park organisations) would be more easily accessed and used by large companies that, in this way, would benefit more than companies with smaller absorptive capacity (Claver-Cortés et al., 2018).

On the other hand, smaller firms suffer more barriers to generating internal R&D, and their lower internal R&D capabilities motivate them to access external knowledge (Barge-Gil, 2010; Shaver and Flyer, 2000). As knowledge spillovers are often geographically localised (Feldman and Kogler, 2010), such firms should benefit from location in an STP. Thus, smaller firms may obtain needed resources and knowledge by locating in STPs (Huang et al., 2012). Furthermore, small firms are able to be more flexible and adapt their structures when identifying a new opportunity (Rogers, 2004).

Again, the empirical evidence is quite limited. To our knowledge, the three papers which assess the park's effect, explicitly taking into consideration firm size, are Huang et al. (2012), Liberati et al. (2016) and Vásquez-Urriago et al. (2016). Although they analyse the park's effect on different outcomes (number of patents, sales and sales from new-to-the-market products, respectively), they agree that the park's effect decreases with company size. It is worth noting that Vásquez-Urriago et al. (2016) show a non-linear effect of firm size on the park effect.

2.2. STP characteristics

The characteristics we consider as sources of park heterogeneity are park age and the participation of universities as promoters of the park. We ask whether companies perform better in younger or older parks and whether their performance is affected by the relationship between universities and the park.

2.2.1. Park age

Park age has often been indicated as one of the major sources of heterogeneity of STPs. There are theoretical arguments for both a positive and a negative effect of park age.

On the one hand, one of the main benefits of being located in an agglomeration is being able to establish ties with other organisations more easily. These ties produce better results with time because of a better understanding of mutual needs, closer relationships, and increased mutual trust (Barge-Gil and Modrego-Rico, 2011; Izushi, 2003). Over time, organisations accumulate knowledge that they can apply to achieve better performance (Decarolis and Deeds, 1999; Peters et al., 2004). Thus, the stock of available knowledge within STP organisations increases over time, and this enhances the possibility of knowledge spillovers (Beaudry and Breschi, 2003). In addition, as a park management team gains experience, it increases its understanding of tenants' needs and is able to provide better business support (Albahari et al., 2018).

On the other hand, younger parks may perform better because firms may decide to locate in parks because of the prestige and visibility that these sites provide (Salvador, 2011). This reputational effect may fade over time (Albahari et al., 2018). In addition, like other organisations, STPs can be less effective over time because of the bureaucratisation of management routines, non-learning processes, blindness, and conservatism (Durand and Coeurderoy, 2001). This greater rigidity would also affect the quality of business support provided to tenants.

Several studies have empirically dealt with the influence of park age on the effect of STPs on tenants. The evidence is not conclusive. On the one hand, some authors find a positive effect of park age on the park effect on sales (Liberati et al., 2016), the number of spin-offs created (Hobbs et al., 2017; Link and Scott, 2005), the number of patents (Teng et al., 2020), and R&D efficiency (Yang and Lee, 2021).

On the other hand, there is also evidence of a negative effect of the age of the park on the number of patents obtained by tenants (Squicciarini, 2009). In addition, some studies find non-statistically significant differences in different outputs according to park age. This is the case of Teng et al. (2020) on sales from new-to-the-market products and Lamperti et al. (2017) on the number of patents and on the propensity to invest in R&D.

Albahari et al. (2018) reconcile these two contrasting views, finding a U-shaped relationship, with firms from younger and older STPs performing better than firms from medium-aged STPs in terms of new-to-the-market product sales.

2.2.2. University role

Another important source of park heterogeneity is the role played by universities in the park. Again, there are theoretical arguments for and against a positive effect of the presence of universities in the park.

On the one hand, parks with a greater presence of universities may perform better for a variety of reasons. First, the importance of universities in firm innovation is widely recognised (Bercovitz and Feldman, 2007; Bozeman, 2000; Salter and Martin, 2001) as being fundamental to the development and diffusion of knowledge, and to the role of science–industry links as a booster of firm innovation

(Perkmann and Walsh, 2007) and a source of valuable information for firms in the process of transforming knowledge into innovations (Jaffe et al., 1993; Verspagen and Schoenmakers, 2000). Companies in parks with a greater university presence may take advantage of this knowledge. Second, universities provide a highly skilled workforce (Uyarra, 2008) that is of fundamental importance in R&D projects (Yang and Lee, 2021). Third, greater proximity to universities allows firms to benefit from knowledge spillovers, which are geographically localised in their surroundings (Fischer and Varga, 2003; Jaffe et al., 1993; Maurseth and Verspagen, 2002; Sonn and Storper, 2008). Fourth, the creation and promotion of STPs is one of the policies adopted to foster the relationship between universities and firms (Albahari et al., 2017; Malairaja and Zawdie, 2008; Martin, 2016; Vedovello, 1997), and we may expect this collaboration to be greater in parks with a higher university presence.

On the other hand, a greater university presence may also have negative effects on firms. The presence of a university may lead the lines of research of the firms located in the parks too much towards basic research (Squicciarini, 2009). This would imply that the innovations developed would not be as market-oriented as expected (Mansfield and Lee, 1996). Ünlü et al. (2022) point to the orientation of the university as a key factor in influencing the innovation ecosystem of the STP where the firms are embedded. Furthermore, universities and industry follow a different logic (Foray and Lissoni, 2010; Tomelin et al., 2018), and the management of joint research between universities and industry is often challenging (Bercovitz and Feldman, 2006).

Empirical evidence of the effect of a greater university presence is not conclusive. We find contrasting evidence in many dimensions of the park effect. For instance, where the number of patents is analysed, Albahari et al. (2017) find a positive effect, while Teng et al. (2020) and Squicciarini (2009) show a negative effect. Regarding innovation sales, Albahari et al. (2017) and Teng et al. (2020) find a negative effect, while Arauzo-Carod et al. (2018) show a positive effect. Where R&D activities are analysed, Lamperti et al. (2017) did not find a conclusive result for the role of the university in the effect of STPs on R&D investment, while Yang and Lee (2021) find a positive influence on the effect of STPs on R&D efficiency.

Table 1 summarises empirical evidence of the influence of firm and park characteristics considered in this paper on the effect of STPs on tenants' patent quality.

3. Data and variables used

We build a database which includes information on all European Patent Office (EPO) patent applications filed by Spanish firms between 2004 and 2012. This amounts to 6885 company patents for which we can retrieve firms' and patent quality information. Of these, 1102 (16.0 %) are from companies located in an STP. The sample is limited to patents with an application date between 2004 and 2012 to allow a 7-year time window for properly observing forward citations.

The database has been built from different sources, as specified in what follows.

First, the January 2020 version of the REGPAT database from the OECD (Organisation for Economic Co-operation and Development) is the main source of patent information for our dataset as it provides information on patents since 1977 (priority date). The information contained in REGPAT, including the full addresses of applicants and inventors of patents, allows us to geographically locate the patents (Maraut et al., 2008) based on the methodology described below. REGPAT contains information on patent applications from the EPO.

Second, the July 2021 version of the OECD Patent Quality Indicators Database provides several indicators related to the importance and value of EPO patents (Squicciarini et al., 2013).

Third, the Iberian Balance Sheet Analysis System (SABI) database, a product of Bureau Van Dijk, accessed in August 2020, gives information on the balance sheets and other financial data of more than 2.7 million Spanish companies. The database provides historical information on the financial accounts of companies since 1990 and allows searches by company name and fiscal ID.

Fourth, the annual APTE (Association of Science and Technology Parks of Spain) directories of companies from 2004 to 2012 provide information on the firms located in STPs. They allow us to identify whether a patent applicant is located in an STP based on the methodology described below. It is worth noting that all Spanish STPs are associated with the APTE. The 2012 annual directory[1] of the APTE shows that, at that time, 47 STPs belonged to the association and hosted more than 6200 firms with almost 144,000 employees, 29,000 of whom were involved in R&D activities (APTE, 2013). Furthermore, APTE directories allow us to collect the park characteristics for each STP in our sample.

Our dataset is the result of a thorough process of matching and disambiguation of STP tenant names with patent applicant names, alongside a process of discernment between on- and off-park patents. The process can be divided into three different matching processes. The first one consists of matching the REGPAT database with the SABI database, which allows us to link the patent applicant information (firm size, firm age, firm sales) to each patent application correspondingly. Then, we match the REGPAT database with the APTE directories. Finally, we added patent quality indicators calculated by the OECD based on PATSTAT version spring 2021 (Squicciarini et al. 2013). Thus, we ended up with a dataset which includes patent applications, patent applicant information, the location or not in an STP, and patent quality indicators.

The matching process entails the well-known *'Names game'* (Trajtenberg et al., 2006). Taking into account the aim of our study, the matching process is based on patent applicant names, in our case, firm names. To address this challenging task, we have performed a

[1] Currently, 50 STPs belong to the association, hosting 5780 firms with more than 150,620 employees, 34,190 of whom are involved in R&D activities (APTE, 2023).

matching process made up of the following steps: standardisation of names, simple match, largest common sequence algorithm match, and Soundex algorithm match.[2] This procedure is first carried out including the postcode of the applicant in the matching process in order to reduce the rate of false positives. Likewise, after this first procedure, the same steps are followed without including the postcode to increase recall by manual review.

Having precisely matched the patent applications with their corresponding firms and their location in an STP during the period observed, we tackle the challenge of ascertaining whether patent applications may be considered on-park or off-park patents. To this end, we have followed the procedure and assumptions detailed in Appendix 2.

It should be noted that our unit of analysis is the patent, and that the final database includes: (i) information on patent quality, used as a proxy to estimate the innovation performance of tenants (forward citations and renewals) obtained from the OECD Patent Quality Indicators Database (version January 2020), (ii) information on patent characteristics (year of application and technological field), (iii) STP location (by combining information on inventors and applicants from the OECD REGPAT and from the APTE), (iv) firm characteristics (such as age, size, region or industry), which are extracted from the SABI and the OECD REGPAT and (v) STP characteristics, which are extracted from the APTE.

3.1. Dependent variables

We use patent quality to estimate the innovation performance of tenants. One of the main characteristics of this indicator is that it encompasses different dimensions of a patent (Higham et al., 2021; Nagaoka et al., 2010; Squicciarini et al., 2013). Gambardella et al. (2008) and Scherer and Harhoff (2000) showed that patents differ greatly in terms of value, and only a small portion of all patents may be considered high-value patents most are in fact low-value patents. In line with recent studies, there is a need to take into consideration the importance and quality of innovations (Higham et al., 2021). Because of the multidimensionality of this concept, we rely on two indicators to measure patent quality and use forward citations and patent renewal as indicators of technological importance and patent value, respectively. Both indicators are used widely in patent quality studies (Higham et al., 2021; van Zeebroeck, 2011).

Forward citations *(fwd_cits7)* are the number of citations received by a patent application up to seven years after its filing date. In the patent quality literature, this indicator has been associated mainly with the technological importance of the patent (Griliches, 1990; Harhoff et al., 2003). Therefore, we may consider that the greater the number of citations, the greater the impact the patent has in its technological field. We have selected this indicator because it provides a longer time window to observe citations received by patent applications.

Patent renewal *(renewal)* is the number of years a patent is kept in force. This indicator is highly associated with the economic value of a patent (Bessen, 2008; Pakes and Schankerman, 1984). This is because the more years a patent is renewed, the more investment is required from the applicant and the higher the economic return the applicant may expect from the patent. EPO patents are renewed annually as of the third year after the application.

3.2. Treatment variable

We use the variable *Park* to differentiate between patents filed by firms located inside STPs or outside their boundaries. This variable takes the value 1 if we consider the patent an on-park patent and 0 otherwise.

3.3. Explanatory variables

3.3.1. Firm characteristics variables

We consider two firm characteristics: firm age and firm size. *Firm_age* is defined as the number of years between the creation of the firm and the patent application year. As for firm size, we use two different proxies: *lfirm_emp* is the number of employees in the year of application (in logs), and *lfirm_sales* is the amount of sales in the year of application (in logs). These proxies have been widely used in the literature and have been shown to be related to the innovative behaviour and output of firms (Díez-Vial and Fernández-Olmos, 2017; Huang et al., 2012; Liberati et al., 2016; Vásquez-Urriago et al., 2016).

3.3.2. STP characteristics variables

We consider two STP characteristics: park age and university involvement.

First, we define three dummy variables to proxy for the age of the park: *old_park,* which takes the value of 1 for parks older than 12 years and 0 otherwise, *mid_park*, which takes the value of 1 for parks between 9 and 12 years old (both included) and 0 otherwise, and *young_park*, which takes the value of 1 for parks younger than 9 years and 0 otherwise. These thresholds have been chosen to have groups of similar sample size.

Second, we define two complementary dummy variables to indicate whether the university was one of the promoters of the STP: *uni_park,* which takes the value of 1 if the university was a promoter and 0 otherwise, and *non_uni_park,* which takes the value of 1 if the university was not a promoter and 0 otherwise.

[2] For further information about techniques followed in this study, see Miguélez and Gómez-Miguélez (2012), Pezzoni et al. (2014), and Raffo and Lhuillery (2009).

3.4. Control variables

Some studies have addressed the variation of patent quality by economic sectors and technology fields. First, there are sectors in which patents receive more citations than others, and their patents are kept in force longer because of higher expectations to earn economic profits, such as in the pharmaceutical sector (van Zeebroeck, 2011). Second, citation patterns may differ across technology fields and specific inventions (Youtie et al., 2008), and the economic value of patents is also different across technological fields (Schankerman, 1998). Accordingly, we include a set of dummies for the technological field of the patent (*Tech_field*) and a set of dummies for the applicant's economic sector of activity (*NACE_code*) as control variables. In addition to these two control variables, we also include regional and year fixed effects in every specification.

4. Empirical specification

First, taking into consideration firm characteristics as a source of heterogeneity, to measure the heterogeneous effect of STPs on tenants' innovation performance, we estimate the following equation:

$$PQI = \alpha + \beta\ Park + \gamma Park{*}FC + \delta FC + \varepsilon FirmControls + \theta PatentControls + \mu \quad (1)$$

where *PQI* is the dependent variable, i.e., forward citations or patent renewal. *Park* is a dummy variable which takes the value 1 if the patent arose in an STP. *FC* is the firm characteristic, our main explanatory variable, whose interaction with the park we want to estimate. We include the demeaned *FC* so that β estimates the park effect for a patent with average value in the firm characteristic. We have two different sets of control variables: FirmControls, which includes *NACE_code* and the rest of the firm characteristics which do not interact with *Park*, and PatentControls, which includes *reg_code*, *tech_field* and *app_year*; μ is the error term.

Second, to measure innovation performance of tenants depending on the park characteristics considered in our study, we estimate the following equation:

$$PQI = \alpha + \beta\ PC + \varepsilon FirmControls + \theta PatentControls + \mu \quad (2)$$

where *PQI* is the dependent variable, either forward citations or patent renewals. *PC* is a set of dummy variables that represent the park characteristics, so that the reference category are patents developed outside STPs. As in Eq. (1), we use two different sets of control variables: FirmControls, which includes *NACE_code* and, in this case, the three firm characteristics detailed above, *lfirm_age*, *lfirm_emp* and *lfirm_sales*, and PatentControls, which includes *reg_code*, *tech_field* and *app_year*; μ is the error term.

In what follows, we will provide the OLS results for simplicity of exposition. These results are similar when using a Poisson regression.[3]

5. Results

5.1. By firm characteristics

We begin our analysis by studying the relationship between the *Park* variable and the characteristics of individual firms; that is, we estimate the influence of tenant characteristics on the park effect.

5.1.1. Firm Age

Table 4 shows the result for the analysis of the heterogeneous effect of STP location according to firm age.

First, we observe that the effect of STP location on forward citations significantly decreases with firm age. It should be noted that the coefficient for the interaction effect in Column 1 (Table 4) is large in magnitude. Fig. 1 plots the STP effect (and its confidence interval at 95 %) for the 10 deciles of firm age. While the 'base' STP effect (for a patent with an average firm age of 17) is 6 %, the effect for a firm in the first decile (3 years old) is 17.9 %. That is, the magnitude of the effect for a young firm is almost triple that of the 'average' firm. On the other hand, we do not find evidence of a statistical effect of STPs on forward citations for firms in the sixth decile or above (24 years or more).

Second, we find that the effect of STP location on renewals is very stable across different firm ages, with the STP effect for a firm of average age around 7 % and the coefficient for the interaction term non-significant and small in magnitude.

These findings support the results obtained by Diez-Vial and Fernández-Olmos (2017), who observed that the interaction between the age of the firm and the park had a negative linear relationship. Thus, young firms benefit more from being located in the park.

These results imply that STPs may play a relevant role for young firms by enhancing the diffusion of their innovations, either fostering relationships with other actors in the regional ecosystem (Baum et al., 2000; Hansson et al., 2005) or as a prestige endowment for these young companies that are not established in the market and may suffer from mistrust by society (Felsenstein, 1994; Ferguson and Olofsson, 2004; Lindelöf and Löfsten, 2005).

Finally, the relationship between firm age and patent quality is negative for firms not located in STPs. More precisely, a 1 % increase in age is related to a −0.04 % variation in forward citations and a −0.05 % variation in renewals. These results are in line with

[3] Results available upon request.

Table 2
Description of variables.

Characteristics	Label	Description
Dependent variables		
Forward citations	*Fwd_cits7*	Number of patent citations received up to seven years after publication
Renewal	*Renewal*	Number of years that the patent application has been renewed
Independent variables		
Patent generated on-park	*Park*	1 if for on-park patents, 0 otherwise
Firm characteristics		
Firm age	*Firm_age*[a]	Firm age in patent application year
Firm size	*Firm_emp*	Number of employees of the firm in patent application year
	Firm_sales	Firm sales in euros for patent application year
STP characteristics		
STP age	*Young_park Mid_park Old_park*	1 if park age lower than 9, 0 otherwise 1 if park age between 9 and 12, 0 otherwise 1 if park age higher than 12, 0 otherwise
University involvement	*Uni_park Non_uni_park*	1 for on uni_park patents, 0 otherwise 1 for on non-uni_park patents, 0 otherwise
Control variables		
Firm sector	*NACE_code*	Patent applicant National Classification of Economic Activities (NACE), 1–22 NACE codes
Firm location	*Reg_code*	Region of the applicant's address, 1–10 regions
Patent application year	*App_year*	Year of the EPO patent application, 1–9 years
Patent technology field	*Tech_field*	Technological field of the patent application

[a] The minimum value of firm_age is 0 as there are cases in which patents are applied for before the creation of the company itself. These are mainly startups whose promoters apply for the patent before founding the organisation. Therefore, the application is considered to be made in year 0 of the company.

Table 3
Descriptive statistics of variables.

	On-park (n=1102)				Off-park (n=5783)			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Dependent variables								
Fwd_cits7	1.32	2.18	0	20	0.93	2.06	0	36
Renewal	7.56	3.72	1	16	6.58	3.86	0	16
Firm characteristics								
Firm_age	16.60	23.13	0	115	28.29	24	0	166
Firm_emp	1259	1718	1	6522	631	1730	1	31,237
Firm_sales (thousands of euros)	360,151	541,436	1	2319,034	549,036	1623,290	1	8475,999
STP characteristics								
Young_park	0.35	0.48	0	1				
Mid_park	0.30	0.46	0	1				
Old_park	0.34	0.48	0	1				
Uni_park	0.30	0.46	0	1				
Non_uni_park	0.70	0.46	0	1				

Table 4
STP effect on patent quality (heterogeneous effect by firm age).

	(1) Fwd_cits7	(2) Renewal
Park	0.060** [0.025]	0.073*** [0.023]
Park*lfirm_age_dm	-0.068*** [0.019]	0.016 [0.017]
lfirm_age_dm	-0.037*** [0.011]	-0.047*** [0.010]
lfirm_emp	0.004 [0.009]	0.010 [0.008]
lfirm_sales	0.017*** [0.006]	0.008 [0.006]
Year dummies	YES	YES
Technology dummies	YES	YES
Industry dummies	YES	YES
Region dummies	YES	YES
N	6885	6885

Marginal effects; standard errors in brackets (d) for discrete change of dummy variable from 0 to 1. lfirm_age_dm stands for the demeaned value of lfirm_age, so the STP coefficient can be interpreted as the STP effect for a patent with average lfirm_age. The average firm age is 17.
*$p<$ 0.10, **$p<$ 0.05, ***$p<$ 0.01

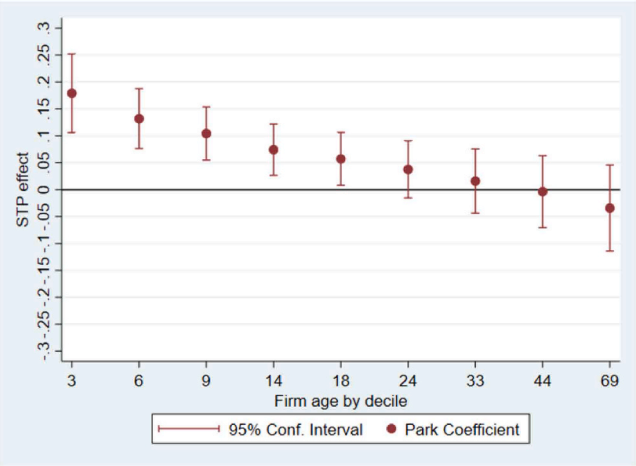

Fig. 1. Evolution of park effect on forward citations by firm age decile.

Balasubramanian and Lee (2008), who found that older firms obtain lower patents, and with Acs et al. (1994), who suggested that younger firms have a structure and culture that allowed them to be less rigid, which would be conducive to higher-quality innovations.

5.1.2. Firm Size

We consider two different indicators for firm size[4]: number of employees and amount of sales. The results are reported in Table 5 and Fig. 2 for employees and Table 6 and Fig. 3 for sales. Both indicators show a similar picture: STP effect on renewals increases with firm size, while STP effect on forward citations is stable across firm size.

It should be highlighted that the amount of heterogeneity in the STP effect according to firm size is smaller than it is according to age. Firms in the ninth decile for number of employees show an STP effect of 11.4 % (with an effect of 6.7 % for a firm with average employment), and firms in the ninth decile of sales show an STP effect of 13.3 % (with an effect of 8 % for a firm with average sales). It should also be highlighted that firms from decile 3 and above enjoy a statistically significant, positive STP effect on renewals.

These results suggest that larger firms enhance the economic value of their patents by accessing knowledge in the park ecosystem which they are capable of assimilating, probably because of a higher absorptive capacity (Cohen and Levinthal, 1990).

As can be seen in Tables 5 and 6, there is a positive relationship between firm size and patent quality also for firms not located in an STP. More precisely, a 1 % increase in the number of employees is related to a 0.016 % increase in renewals, while a 1 % increase in sales is related to a 0.012 % increase in renewals.

5.2. By STP characteristics

In addition to addressing the possible heterogeneity of the park effect due to the characteristics of the tenant firms, we study whether some characteristics of the parks may also be a source of heterogeneity for the park effect.

5.2.1. Park age

Table 7 shows the STP effect for the three groups of STPs, defined according to age.

Whether we use forward citations or renewals as a dependent variable, we find that young STPs have the stronger effects, followed by older STPs and being the middle-age STPs those with the lower effects. More precisely, patents from firms located in young STPs show 16.3 % more citations than patents from firms outside STPs and 15.4 % more renewals. Old STPs also show a significant effect on forward citations (8.2 %) and a positive, non-significant effect on renewals (3.3 %). Finally, middle-aged STPs show a positive, non-significant effect on both citations and renewals.

These results agree with those by Albahari et al. (2018), who also found that the STP effect was higher for young and old than for medium-aged STPs, but it contradicts the results by Squicciarini (2009), who found that the STP effect decreased with STP age.

There are two types of arguments that explain our results. On the one hand, firms in young STPs benefit from visibility and the prestige of STPs (Salvador, 2011), but this effect seems to diminish over time (Albahari et al., 2018). On the other hand, older parks benefit from the accumulation of experience of the management team (Decarolis and Deeds, 1999; Peters et al., 2004) as they could offer better services to tenants and a deeper understanding of tenants' needs, leading to an improvement in tenants' innovative performance (Yang and Lee, 2021).

[4] Vásquez-Urriago et al. (2016) found that the relationship between STP effect and firm size had a non-linear component, with small firms enjoying higher benefits. This is why we also tried a non-linear specification, but we did not find evidence of non-linear effects. Anyway, it should be clarified that we use patent quality as the output indicator, while they use sales from new-to-the market products.

Table 5
STP effect on patent quality (heterogeneous effect by firm employees).

	(1) Cits7	(2) Renewal
Park	0.089*** [0.064]	0.068*** [0.059]
Park*lfirm_emp_dm	-0.000 [0.011]	0.017* [0.010]
lfirm_emp_dm	0.026*** [0.005]	0.016*** [0.005]
lfirm_age	-0.045*** [0.010]	-0.039*** [0.009]
Year dummies	YES	YES
Technology dummies	YES	YES
Industry dummies	YES	YES
Region dummies	YES	YES
N	6885	6885

Marginal effects; standard errors in brackets (d) for discrete change of dummy variable from 0 to 1.
lfirm_emp_dm stands for the demeaned value of lfirm_emp, so the STP coefficient can be interpreted as the STP effect for a patent with average lfirm_emp. Average firm employment is equal to 1259.
*$p<$ 0.10, **$p<$ 0.05, ***$p<$ 0.01

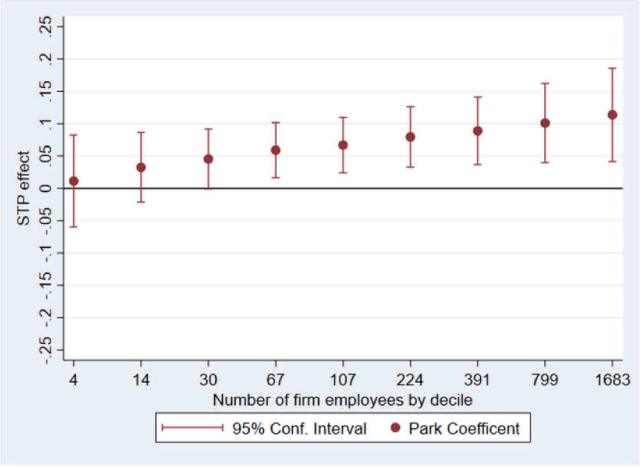

Fig. 2. Evolution of park effect on patent renewal by firm employees decile.

Table 6
STP effect on patent quality (heterogeneous effect by firm sales).

	(1) Cits7	(2) Renewal
Park	0.095*** [0.025]	0.080*** [0.037]
Park*lfirm_sales_dm	0.000 [0.007]	0.015** [0.007]
lfirm_sales_dm	0.021*** [0.004]	0.012*** [0.004]
lfirm_age	-0.052*** [0.010]	-0.041*** [0.009]
Year dummies	YES	YES
Technology dummies	YES	YES
Industry dummies	YES	YES
Region dummies	YES	YES
N	6885	6885

Marginal effects; standard errors in brackets (d) for discrete change of dummy variable from 0 to 1.
lfirm_sales_dm stands for the demeaned value of lfirm_sales, so the STP coefficient can be interpreted as the STP effect for a patent with average lfirm_sales. Average firm sales are equal to 360151.
*$p<$ 0.10, **$p<$ 0.05, ***$p<$ 0.01

5.2.2. University Parks

Table 8 and Figs. 6 and 7 show the differentiated effect of university and non-university STPs on forward citations and renewals.

Both types of STPs improve forward citations when compared with patents from firms not located in STPs. However, the STP effect is 7.4 % for university STPs and 10.4 % for non-university STPs.

As for renewals, the coefficients are positive for both types of STPs, but for university STPs, the coefficient is not statistically

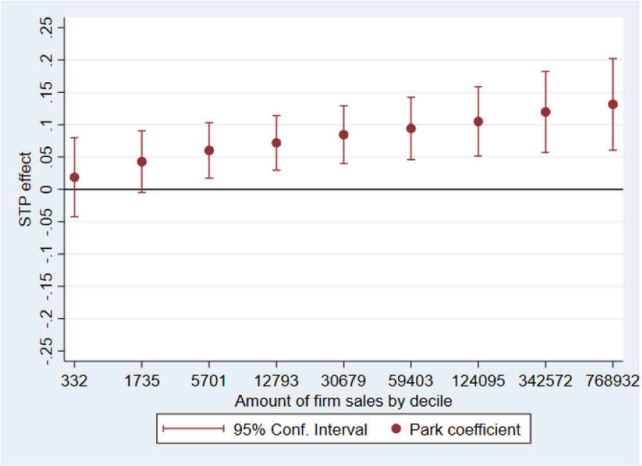

Fig. 3. Evolution of park effect on patent renewal by firm sales decile.

Table 7
STP effect on patent quality (heterogeneous effect by STP age group).

	(1) Cits7	(2) Renewal
old_park	0.082*** [0.032]	0.033 [0.029]
young_park	0.163*** [0.042]	0.154*** [0.034]
mid_park	0.027 [0.039]	0.018 [0.032]
lfirm_age	-0.050*** [0.010]	-0.041*** [0.009]
lfirm_emp	0.006 [0.009]	0.010 [0.008]
lfirm_sales	0.017*** [0.006]	0.007 [0.005]
Year dummies	YES	YES
Technology dummies	YES	YES
Industry dummies	YES	YES
Region dummies	YES	YES
N	6885	6885

Marginal effects; standard errors in brackets (d) for discrete change of dummy variable from 0 to 1.
*$p<0.10$, **$p<0.05$, ***$p<0.01$
old_park takes the value 1 in patents with STP age>12
mid_park takes the value 1 in patents with 8<STP age<=12
young_park takes the value 1 in patents with STP <=8

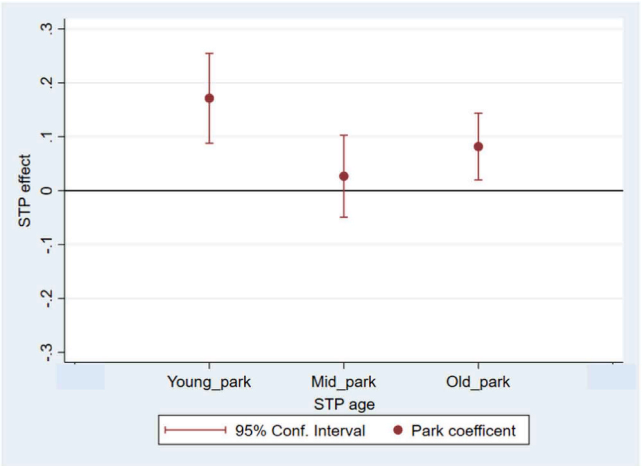

Fig. 4. Park effect on forward citations by STP age group.

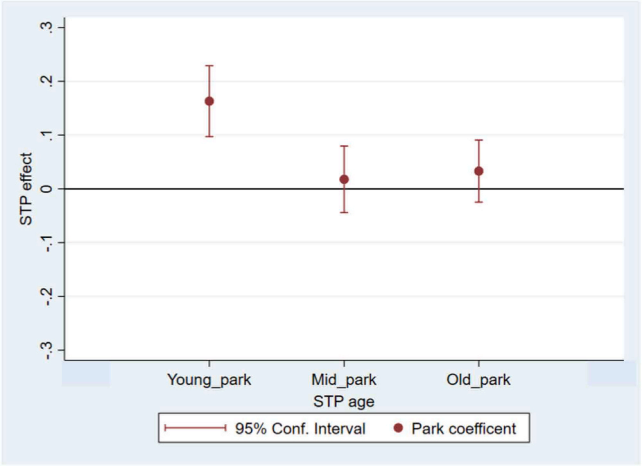

Fig. 5. Park effect on patent renewal by STP age group.

Table 8
STP effect on patent quality (heterogeneous effect by university involvement).

	(1) Cits7	(2) Renewal
uni_park	0.074* [0.038]	0.035 [0.031]
non_uni_park	0.104*** [0.029]	0.085*** [0.026]
lfirm_age	-0.052*** [0.010]	-0.043*** [0.009]
lfirm_emp	0.006 [0.009]	0.010 [0.008]
lfirm_sales	0.018*** [0.006]	0.008 [0.005]
Year dummies	YES	YES
Technology dummies	YES	YES
Industry dummies	YES	YES
Region dummies	YES	YES
N	6885	6885

Marginal effects; standard errors in brackets (d) for discrete change of dummy variable from 0 to 1.
*$p<$ 0.10, **$p<$ 0.05, ***$p<$ 0.01

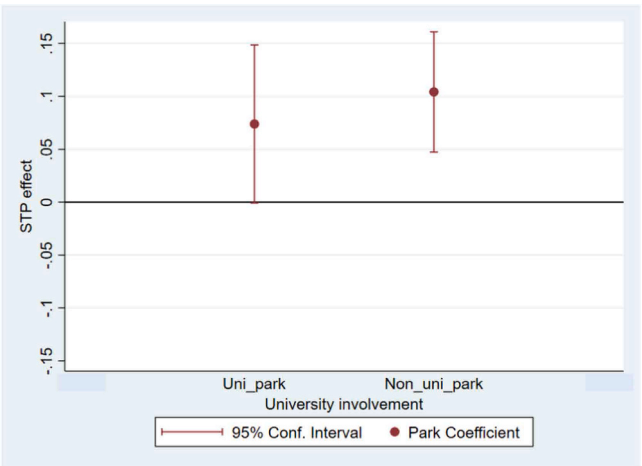

Fig. 6. Park effect on forward citations by university role in STPs.

significant (magnitude 3.5 %), while the effect for non-university STPs is 8.5 % and statistically significant.

Our results agree with those from previous studies by Squicciarini (2009) and Teng et al. (2020), who found that a stronger university presence did not translate to better performance on the number of patent applications. It is possible that greater university specialisation in basic science leads to innovations that take longer to reach the market (Squicciarini, 2009), giving a more relevant

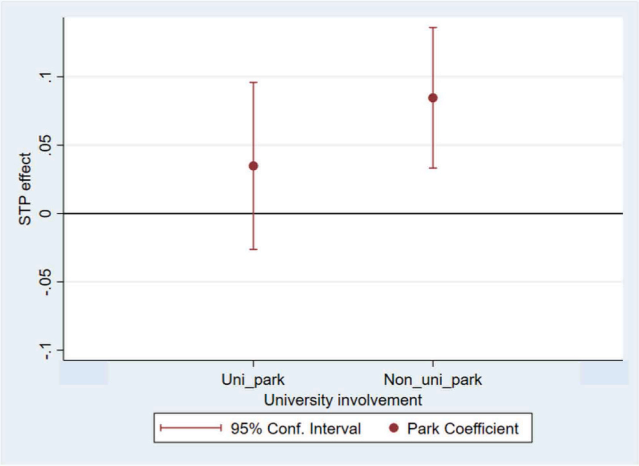

Fig. 7. Park effect on patent renewal by university role in STPs.

role to creating and disseminating knowledge for society and delaying profit-making (Mansfield and Lee, 1996).

6. Discussion and implications

STPs are a very common innovation policy instrument in most countries. Their aim is to exploit agglomeration effects by facilitating the co-location of innovative firms. The rationale behind STPs is rooted in the theoretical models developed by Marshall (1890), Porter (1998, 1990), and Krugman (1991), according to which the geographical proximity that characterised firms agglomerations provides an appropriate environment to facilitate innovation. However, the empirical literature on STP effects on tenants is somewhat inconclusive.

The limited consideration of the importance of heterogeneity in agglomeration firms benefits has been recognised in the literature (McCann and Folta, 2008). We contribute to the STP literature by evaluating the effect of parks taking into account how certain characteristics of the parks and tenants impact the quality of the tenants' patents.

In relation to tenants' characteristics, our results indicate that the effect of STP location on citations to patents filed by tenants significantly decreases with firm age: the magnitude of the effect is almost three times higher for a firm in the first age decile than for a firm of average age. This finding supports the result obtained by Diez-Vial and Fernández-Olmos (2017), who affirm that being located in a park is relatively more advantageous for young firms. STPs provide younger firms a proper ecosystem in which they can establish relationships (Albahari et al., 2019), which allows them to enhance the visibility of their patents because of the knowledge transferred from local agents such as other tenants, universities or public organisations, the use of their patents in subsequent inventions and the impact on their stakeholders (Lindelöf and Löfsten, 2005).

In contrast, the effect of STP location on patent renewal increases with firm size, measured in terms of both number of employees and turnover. Holding firm age constant, the effect of STP location is higher for larger firms than for smaller firms. This is in line with previous results that show that firms with low absorptive capacity find it more difficult to benefit from STP location (Vásquez-Urriago et al., 2016). It should, however, be noted that the heterogenous effect of STP location is less strong for firm size than for firm age.

Policy implications of these results must be made with caution. The fact that parks are more beneficial for a certain type of firm than for another does not automatically suggest that only those firm that receive more benefit should be admitted to the park. It may be the case, in fact, that the park effect is due, at least in part, to the co-location of enterprises with different characteristics. For instance, smaller firms might benefit from co-location with larger firms because of the anchor effect (Huang et al., 2012; Squicciarini, 2009) provided by larger companies and larger stock of on-site knowledge that larger firms provide.Concerning park characteristics, the age of the park seems to influence the extent to which the park impacts the quality of tenants' patents. We find that younger and older parks outperform medium-aged parks. On the one hand, younger parks are shown to have the greatest effect on both patent quality indicators, namely, patent citations and patent renewal. Firms located in younger parks may benefit from their location because of reputational effects (Salvador, 2011). In an early stage, this gain of reputation due to location in the STP may affect the patent quality performance of its tenants. Notwithstanding, this first reputational effect may vanish over time. On the other hand, older parks show a positive and significant effect on patent citations. Over the years, the STP's management accumulate knowledge that facilitates the provision of a better service to their tenants. The latter reflection is closely related to the concept of "patient capital". Mazzucato (2015) suggests the need to be patient when investing in innovation. The trend in long-term commitment finance is growing, even more, when the finance comes from public capital and is focused on flourishing long-run innovation (Mazzucato, 2013). Thus, our findings support the results obtained by Albahari et al. (2018), who find that younger and older parks have stronger effects than medium-aged parks.

The presence of universities as a promoting entity does not show significant statistical differences in the effect of the park on patent quality. Both types of STPs, with or without university promoters, improve forward citations when compared with patents from firms

not located in STPs. In contrast, non-university STPs increase patent renewal, while university STPs do not show a statistically significant effect on patent renewal when compared with patents from off-park firms. The presence of universities in STPs may affect the quality of tenants' patents since the innovations developed are shown to be less market-oriented (Mansfield and Lee, 1996). This is probably because universities have an influence by leading tenants towards more basic research (Squicciarini, 2009). Moreover, considering the idiosyncrasy of university-industry collaboration, the difference in orientation must be contemplated since universities have traditionally prioritized dissemination of knowledge through publications, whereas firms tend to protect innovation and place more importance in obtaining economic returns rather than on supporting disclosure (Fabrizio, 2007; Simeth and Raffo, 2013). Our findings coincide with previous studies that highlight that the involvement of a university in the park does not translate into better innovation performance by the tenants compared with non-university parks (Squicciarini, 2009; Teng et al., 2020).

Our findings imply several practical implications that engage with a set of stakeholders. For firm managers, our results provide helpful information when deciding on the possible on-park location. Considering the types of firms that benefit the most from being located in an STP, they can evaluate whether location in an STP would benefit them. For instance, firms created or in the early stages of development in STPs face the situation of having to leave the park. The decision of leaving the STP might derive from either the company or even park policies which compel it to continue to grow elsewhere after surviving its early stages of evolution (Diez-Vial and Fernández-Olmos, 2017). STPs may facilitate access to financial, technological, and high-skilled human resources. However, our findings show that as firms increase in size, they benefit from the park's positive effect on the economic value of their patents. In this sense, large companies might benefit from the pool of high-skilled workers aroused in the STP ecosystem due to their potential in attracting talent (Bessen et al., 2023). Thus, both younger and developing firms benefit from being located in the park. To sum up, our results suggest that before deciding to locate in an STP, firm managers should thoroughly contemplate the benefits provided by the on-park location along with their own internal characteristics (Capasso and Morrison, 2013; Rodríguez-Gulías et al., 2021) and needs in order to leverage all resources and externalities that STP location offers.

From an STP manager's point of view, our work provides information on STP characteristics which enhance tenants' innovation performance. The result we found on the effect of the involvement of a university deserves attention, especially if we consider that universities see STPs as facilitators to commercialise the outcomes of their research (Link and Scott, 2007) and transfer their knowledge (Steruska et al., 2019). Universities can influence the development of business innovations by transferring more scientific and analytical knowledge to tenants (Albahari et al., 2017), resulting in more basic-research-oriented innovation, which is more difficult to transform into marketable products. Therefore, it is important to be aware of these barriers in order to maximise the park effect. Thus, STP managers should explore whether the collaboration university-tenants is obtaining the expected results. Moreover, in the light of our findings, we argue that after the short-term effect, the knowledge and experience accumulated over the years provide STPs with enough know-how to foster and develop a proper service alongside an environment that facilitates the enhancement of innovation amongst tenants. In this sense, Amoroso and Hervas Soriano (2019) stress that STPs must have the capacity to adapt their services and environments to the evolving context in which they operate.

The public money invested in establishing and developing STPs (Rowe, 2014), urges policymakers to understand how to design and implement these types of policies. Our work supports the need to move away from one-size-fits-all innovation policy instruments (see, for example, Barca et al., 2012) as policies are often designed and implemented without taking into account the circumstances in which they are to be applied (Ganau and Grandinetti, 2021; Todtling and Trippl, 2005; Veugelers and Schweiger, 2016). Studies such as Crespo et al. (2016) and Segarra-blasco et al. (2008) also stress the need to design and implement place-based policies that consider the barriers and opportunities that arise in each case. Given this framework, the implementation of STPs deserves to be taken into consideration within the set of smart specialisation policies encouraged by the European Commission (Smart Specialisation Strategies – S3) (Jacobsen et al., 2022). Our research intends to strengthen the need to adapt the policy by drawing on internal and external factors that might influence the correct implementation of the policy (Camagni and Capello, 2017) in order to meet the objectives previously planned by policymakers. We advocate for shaping the implementation of the STP by tailoring the policy to the context as a fundamental step to comply with the policy purpose (Nischalke and Schöllmann, 2005). As regards the development of the parks themselves, it is noted that, although younger parks are shown to produce a greater effect on tenants' patent quality, older parks also generate a positive effect, mainly on the technological impact of patents. Hence, when implementing this innovation policy, we must be aware of the need to enable time for the park's own development (Liberati et al., 2016). The public funds used to establish and develop STPs should be protected from the effects of political cycles (Albahari et al., 2018). Thus, our results suggest that policymakers should be patient with the development of STPs given their long-run effect on innovation, emphasising that this is not only a short-term performance policy, but also their effects extend over the long-term.

7. Conclusions

Our research provides a better understanding of how park and tenants heterogeneity affects tenants' patent quality. We contribute to the literature by presenting novel empirical evidence on the effect of the interaction between on-park location and certain characteristics of the parks and tenant firms on patent quality in Spain. The sources of heterogeneity considered in our study are firm age and size on a firm level, and STP age and university involvement with parks on the STP level.

Our results show that the STP effect on their tenants is generally positive in terms of patent quality indicators. Nevertheless, when putting the focus on heterogenous effects, we observe that firm age is a source of heterogeneity since the older the firm is, the lower the STP effect is in terms of forward citations. Thus, younger firms are more benefitted from locating inside an STP. On the other hand, when considering firm size, the STP effect on patent renewal increases along with size, being larger firms more benefitted by the on-park location.

We also provide empirical evidence on STP characteristics impact on the quality of tenants' patents. Specifically, STP age shows a U-shaped effect on forward citations. Whereas the positive impact on patent renewal comes mainly from young STPs. This means that younger and older STPs impact positively on patent quality. Where the university role as promoting entity of the STP is concerned, we find that both types of STPs – promoted or not by a university – have a positive impact on patent quality and the presence of the university does not have statistically significant effects.

Our findings reflect implications of interest to several stakeholders of STPs. Policymakers, STP managers, and firm managers may find helpful insights for the decision-making process when designing and implementing this policy, managing the STP, and locating in an STP, respectively. Our work contributes to the discussion on STP effectiveness, providing empirical evidence on the existence of heterogeneous effects of STPs, supporting the idea of moving away from one-size-fits-all policies.

This study is not without limitations; especially, those related to the existence of factors other than those analysed here that might lead to further heterogeneity in the effect of the park. These may include the amount of R&D expenditure or subsidies received by the tenants, and any other services they may receive to boost their innovation performance inside and outside the park. Additionally, external factors might unveil other potential heterogeneity sources beyond the internal factors typically contemplated in the literature. In other words, contextual factors might be regulating the STP effect. These may include regional factors such as technological development, economic conditions, educational system, industrial setting, and trends, or social conditions. Considering these and other potential sources of heterogeneity is an avenue for future research that would help to account for the STP phenomenon and shape better policies.

The aim of many governments when implementing this innovation policy is to encourage innovation and economic growth of the region where the policy is applied, with the purpose of boosting regional development. Thus far, the effectiveness of STP policy in terms of impact on tenants has been the prevailing strand in the STP literature. Thereby, little research has been conducted to evaluate the effects of this policy in the region where they are established. Only a few studies have investigated their regional impact, following primarily a qualitative approach. As Lecluyse et al. (2019) advocate for, a broader and deeper quantitative analysis of how STPs contribute to regional development is needed to provide policymakers with empirical evidence and, in turn, bridge the gap in the literature.

On the other hand, as Amoroso and Hervas Soriano (2019) outline the relevance of government policies in shaping the creation and development of STPs through detecting the local competencies that enable STPs to meet their function of regional development boosters is still an unexplored land. Then, a wider understanding on how these policies interplay may lead to contributing to the design and implementation of STPs.

Another strand of research that deserves a deeper exploration is the role and influence of STPs with regard to economic shocks, such as the one COVID-19 produced. Following the idea suggested by a recent paper (Lee et al., 2023), the ecosystem generated inside and around the STPs alongside the strong interest in developing these areas by policymakers should generate an impact on how tenants may tackle and response to the shocks that might take place. On the other hand, COVID-19 has brought as a consequence a new landscape for STPs due to the boost of remote working across firms (Kniffin et al., 2021). Considering the idiosyncrasy of STPs, whose rationality is based on the physical proximity of the various actors, the growing trend of remote working could change the added value of location within a STP for companies and value creation mechanisms.

Finally, we use data on the Spanish STP system. Although Albahari et al. (2023), in their meta-analysis on STPs literature, find no significant differences in the average effect of the park on tenants in different countries, further studies using data from other countries would be very useful to build robust empirical evidence on the heterogeneous effects of parks

CRediT authorship contribution statement

Catalina Martinez: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. **Andres Barge-Gil:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. **Marcos Anton-Tejon:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Alberto Albahari:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing.

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Appendix 1. Descriptive statistics by heterogeneity factors

Table A1.1
Descriptive statistics by firm characteristics

			On-park			Off-park		
	N	Percentage	Fwd_cits7	Renewal	N	Percentage	Fwd_cits7	Renewal
Firm age								
0–2	156	14.16 %	2.51	8.12	393	6.80 %	0.98	7.11
3–5	224	20.33 %	1.42	7.61	499	8.63 %	0.71	6.61
6–8	236	21.42 %	1.34	7.24	446	7.71 %	0.82	6.61
9–13	160	14.52 %	0.93	7.29	587	10.15 %	1.40	7.06
14–17	57	5.17 %	0.69	8.81	600	10.38 %	1.18	6.26
18–23	63	5.71 %	0.87	7.91	628	10.86 %	0.68	6.87
24–32	58	5.26 %	1.02	6.91	664	11.48 %	0.70	6.60
33–43	40	3.63 %	0.70	7.40	655	11.33 %	0.76	6.88
44–68	17	1.54 %	0.88	7.71	689	11.91 %	0.80	6.90
+69	91	8.26 %	0.68	7.20	622	10.76 %	1.30	5.08
Firm emp								
1–3	51	4.63 %	1.02	6.14	523	9.04 %	0.80	6.31
4–13	160	14.52 %	1.20	6.19	602	10.41 %	0.65	6.39
14–29	83	7.53 %	1.87	7.77	607	10.50 %	0.81	6.50
30–66	96	8.71 %	0.58	7.02	621	10.74 %	0.75	6.60
67–106	54	4.90 %	1.33	7.19	631	10.91 %	1.69	6.57
107–223	74	6.72 %	1.35	7.04	619	10.70 %	0.75	6.76
224–390	68	6.17 %	1.60	9.68	622	10.76 %	0.75	7.92
391–798	77	6.99 %	1.95	7.27	614	10.62 %	0.78	6.60
799–1682	116	10.53 %	2.37	8.62	569	9.84 %	1.38	5.61
+1683	323	29.31 %	0.96	7.99	375	6.49 %	0.96	6.30
By firm sales (thousands of euros)								
<332	131	11.89 %	1.06	6.13	539	9.32 %	0.76	6.18
332–1734	129	11.71 %	1.26	6.39	562	9.72 %	0.80	6.63
1735–5700	100	9.07 %	1.50	8.06	592	10.24 %	0.60	6.37
5701–12,792	38	3.44 %	0.58	6.42	652	11.28 %	1.66	6.27
12,793–30,678	76	6.90 %	1.08	7.34	614	10.62 %	0.74	7.13
30,679–59,402	64	5.81 %	1.00	8.95	613	10.60 %	0.72	6.97
59,403–124,094	19	1.72 %	1.00	7.84	684	11.83 %	0.77	7.55
124,095–342,571	183	16.61 %	1.96	7.63	505	8.73 %	0.91	7.20
342,572–768,391	170	15.43 %	1.37	8.63	503	8.70 %	1.59	5.22
>768,392	192	17.42 %	1.19	7.86	519	8.98 %	0.78	5.92

Table A1.2
Descriptive statistics by STP characteristics

	On-park			
	N	Percentage	Fwd_cits7	Renewal
STP age				
Young park	388	5.66 %	1.84	8.89
Medium-aged park	335	4.87 %	1.03	6.73
Old park	379	5.51 %	1.05	6.92
Off-park	5783	83.99 %	0.93	6.58
STP university				
University	334	4.81 %	1.36	6.72
Non-university	768	11.16 %	1.31	7.93
Off-park	5783	83.99 %	0.93	6.58

Appendix 2. Patent classification

We use two pieces of information that can serve to classify a patent as on-park or off-park: the address of the applicant (the firm) and the address of the inventors[5](see Figure A2.1).

First, if the address of at least one of the applicants is on-park and the address of at least one of the inventors[6] is on-park or nearby, i.

[5] Each patent application has, on average, three inventors with an associated postal address for each.

[6] When there is no information on the address of the inventors but at least one applicant is on-park, we define that patent application as on-park.

e., located in the same region as the applicant, the patent is considered on-park (887 patent applications).

Second, if the address of at least one of the applicants is on-park but no inventor has an address in the park's region, the patent is considered an off-park patent despite having at least one on-park applicant. This is because the headquarters of a company may be located on-park and may be in charge of the administrative tasks related to patent filing, but if the research team that generated the patent is located off-park, the patent would be considered off-park according to our definition[7] (14 patent applications).

Third, if none of the applicants' addresses belong to an STP but at least one address of the inventors belongs to a park, the patent would be considered on-park. This is done to take into account cases in which a patent is generated on-park but the company files it from an off-park office (154 patent applications).

Fourth, if none of the applicants' addresses belong to any STP and none of the inventors' addresses are on-park, the patent would be considered off-park except in one situation: if the applicant has their headquarters located in an STP in the same province reported in the patent application. If so, the patent is considered on-park. This would correspond to a case where a company has offices in the same province on- and off-park, and even though the patent is filed from the off-park office, it is very likely that the park played a role in achieving the patent (61 patent applications).

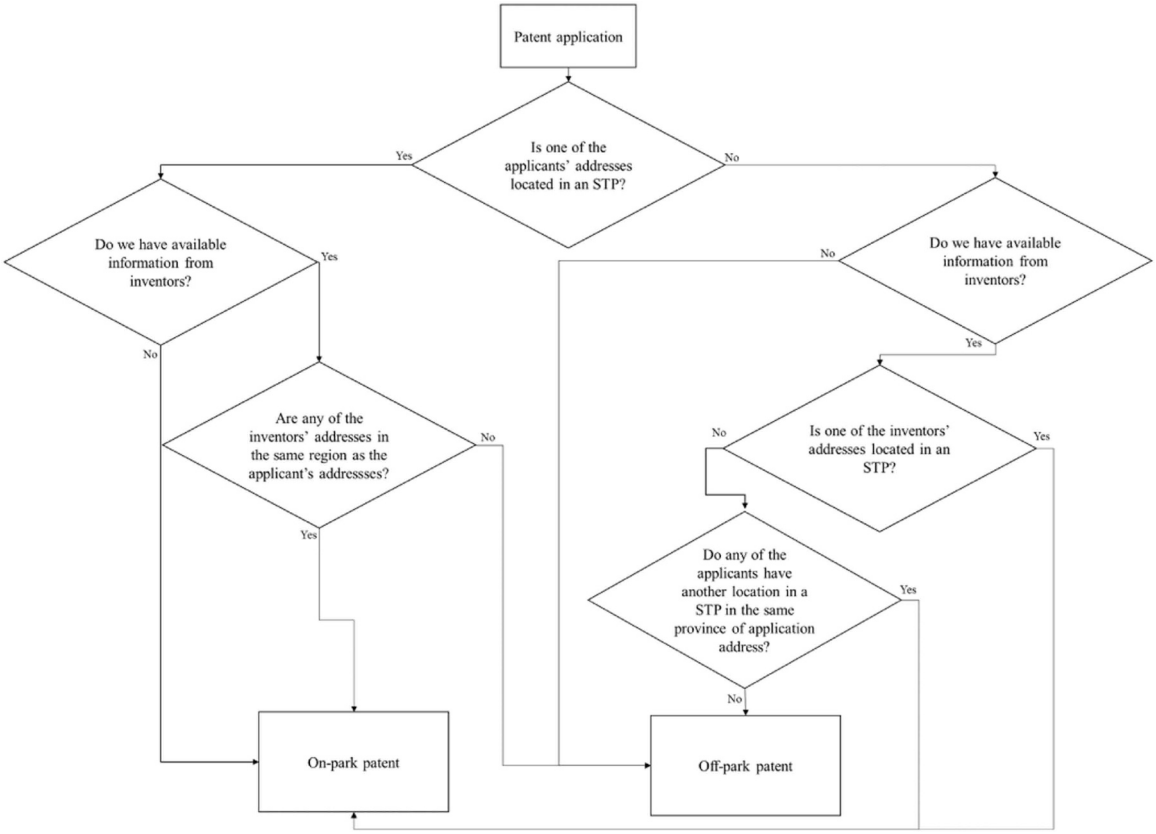

Figure A2.1. Flowchart of patent classification.

Appendix 3. Robustness checks

Table A3.1
STP heterogeneous effect on patent quality by selection criteria (STP–firm age interaction)

	OLS regression			
	(1)	(2)	(3)	(4)
	Fwd_cits7	Renewal	Fwd_cits7	Renewal

(*continued on next page*)

[7] In Appendix 3, we perform a robustness check in which we expand our definition to consider a patent application with these characteristics an on-park patent.

Table A3.1 (*continued*)

	OLS regression			
	(1)	(2)	(3)	(4)
Park_app	0.040 [0.025]	0.068*** [0.024]		
Park_app*lfirm_age_dm	-0.048** [0.021]	0.011 [0.018]		
Park_all			0.086*** [0.020]	0.041** [0.018]
Park_all*lfirm_age_dm			-0.004 [0.016]	-0.069*** [0.013]
lfirm_age_dm	-0.046*** [0.011]	-0.046*** [0.010]	-0.052*** [0.011]	-0.020* [0.011]
lfirm_emp	0.006 [0.009]	0.010 [0.008]	0.004 [0.009]	0.008 [0.008]
lfirm_sales	0.017*** [0.006]	0.008 [0.006]	0.017*** [0.006]	0.006 [0.006]
Year dummies	YES	YES	YES	YES
Technology dummies	YES	YES	YES	YES
Industry dummies	YES	YES	YES	YES
Region dummies	YES	YES	YES	YES
N	6885	6885	6885	6885

Marginal effects; standard errors in brackets (d) for discrete change of dummy variable from 0 to 1. lfirm_age_dm stands for the demeaned value of lfirm_age, so the STP coefficient can be interpreted as the STP effect for a patent with average lfirm_age.
Columns (1) and (2) show the results of the OLS regression model for criteria selection only with applicants' addresses. Columns (3) and (4) show the results of the OLS regression model for criteria selection which considers any patent of firms with on-park patents an on-park patent.
*$p<$ 0.10, **$p<$ 0.05, ***$p<$ 0.01

Table A3.2
STP heterogeneous effect on patent quality by selection criteria (STP–firm employees interaction)

	OLS regression			
	(1) Fwd_cits7	(2) Renewal	(3) Fwd_cits7	(4) Renewal
Park_app	0.061** [0.024]	0.061*** [0.021]		
Park_app*lfirm_emp_dm	-0.007 [0.011]	0.011 [0.009]		
Park_all			0.084*** [0.020]	0.047*** [0.018]
Park_all*lfirm_emp_dm			0.009 [0.009]	-0.027*** [0.008]
lfirm_emp_dm	0.028*** [0.005]	0.017*** [0.005]	0.021*** [0.005]	0.025*** [0.005]
lfirm_age	-0.048*** [0.010]	-0.039*** [0.009]	-0.046*** [0.010]	-0.043*** [0.009]
Year dummies	YES	YES	YES	YES
Technology dummies	YES	YES	YES	YES
Industry dummies	YES	YES	YES	YES
Region dummies	YES	YES	YES	YES
N	6885	6885	6885	6885

Marginal effects; standard errors in brackets (d) for discrete change of dummy variable from 0 to 1. lfirm_age_dm stands for the demeaned value of lfirm_age, so the STP coefficient can be interpreted as the STP effect for a patent with average lfirm_age.
Columns (1) and (2) show the results of the OLS regression model for criteria selection only with applicants' addresses. Columns (3) and (4) show the results of the OLS regression model for criteria selection which considers any patent of firms with on-park patents an on-park patent.
*$p<$ 0.10, **$p<$ 0.05, ***$p<$ 0.01

Table A3.3
STP heterogeneous effect on patent quality by selection criteria (STP–firm sales interaction)

	OLS regression			
	(1) Fwd_cits7	(2) Renewal	(3) Fwd_cits7	(4) Renewal
Park_app	0.064*** [0.024]	0.072*** [0.022]		
Park_app*lfirm_sales_dm	-0.007 [0.007]	0.012* [0.007]		
Park_all			0.086*** [0.019]	0.047*** [0.017]
Park_all*lfirm_sales_dm			0.008 [0.006]	-0.015*** [0.006]
lfirm_sales_dm	0.023*** [0.004]	0.018*** [0.004]	0.018*** [0.004]	0.017*** [0.004]
lfirm_age	-0.055*** [0.010]	-0.053*** [0.010]	-0.053*** [0.010]	-0.045*** [0.009]
Year dummies	YES	YES	YES	YES
Technology dummies	YES	YES	YES	YES
Industry dummies	YES	YES	YES	YES
Region dummies	YES	YES	YES	YES
N	6885	6885	6885	6885

Marginal effects; standard errors in brackets (d) for discrete change of dummy variable from 0 to 1. lfirm_age_dm stands for the demeaned value of lfirm_age, so the STP coefficient can be interpreted as the STP effect for a patent with average lfirm_age.
Columns (1) and (2) show the results of the OLS regression model for criteria selection only with applicants' addresses. Columns (3) and (4) show the

results of the OLS regression model for criteria selection which considers any patent of firms with on-park patents an on-park patent.
*$p<$ 0.10, **$p<$ 0.05, ***$p<$ 0.01

Table A3.4
STP heterogeneous effect on patent quality by selection criteria (STP age heterogeneity)

	OLS regression			
	(1) Cits7	(2) Renewal	(3) Cits7	(4) Renewal
old_park	0.062* [0.032]	0.023 [0.030]	0.090*** [0.032]	0.035 [0.030]
young_park	0.124*** [0.043]	0.169*** [0.034]	0.099*** [0.023]	0.054*** [0.020]
mid_park	0.003 [0.040]	0.012 [0.032]	0.016 [0.038]	-0.010 [0.031]
lfirm_age	-0.054*** [0.010]	-0.042*** [0.009]	-0.054*** [0.010]	-0.046*** [0.009]
lfirm_emp	0.008 [0.009]	0.010 [0.008]	0.005 [0.009]	0.011 [0.008]
lfirm_sales	0.017*** [0.006]	0.008 [0.005]	0.017*** [0.006]	0.007 [0.005]
Year dummies	YES	YES	YES	YES
Technology dummies	YES	YES	YES	YES
Industry dummies	YES	YES	YES	YES
Region dummies	YES	YES	YES	YES
N	6885	6885	6885	6885

Marginal effects; standard errors in brackets (d) for discrete change of dummy variable from 0 to 1.
Columns (1) and (2) show the results of the OLS regression model for criteria selection only with applicants' addresses. Columns (3) and (4) show the results of the OLS regression model for criteria selection which considers any patent of firms with on-park patents an on-park patent.
*$p<$ 0.10, **$p<$ 0.05, ***$p<$ 0.01
old_park takes the value 1 in patents with STP age>12
mid_park takes the value 1 in patents with 8<STP age<=12
young_park takes the value 1 in patents with STP <=8

Table A3.5
STP heterogeneous effect on patent quality by selection criteria (University role heterogeneity)

	OLS regression			
	(1) Cits7	(2) Renewal	(3) Cits7	(4) Renewal
uni_park	0.058 [0.039]	0.030 [0.032]	0.087** [0.038]	0.035 [0.032]
non_uni_park	0.068** [0.029]	0.080*** [0.026]	0.085*** [0.021]	0.043** [0.019]
lfirm_age	-0.054*** [0.010]	-0.043*** [0.009]	-0.054*** [0.010]	-0.046*** [0.009]
lfirm_emp	0.007 [0.009]	0.010 [0.008]	0.004 [0.009]	0.010 [0.008]
lfirm_sales	0.018*** [0.006]	0.008 [0.005]	0.017*** [0.006]	0.007 [0.005]
Year dummies	YES	YES	YES	YES
Technology dummies	YES	YES	YES	YES
Industry dummies	YES	YES	YES	YES
Region dummies	YES	YES	YES	YES
N	6885	6885	6885	6885

Marginal effects; standard errors in brackets (d) for discrete change of dummy variable from 0 to 1.
Columns (1) and (2) show the results of the OLS regression model for criteria selection only with applicants' addresses. Columns (3) and (4) show the results of the OLS regression model for criteria selection which considers any patent of firms with on-park patents an on-park patent.
*$p<$ 0.10, **$p<$ 0.05, ***$p<$ 0.01

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