KU LEUVEN
FACULTY OF ECONOMICS AND BUSINESS

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Science Parks as Catalyzers for Radical Inventions?

A Quantitative and Exhaustive Look at the United States of America

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Thesis submitted to obtain
the degree of

MASTER OF BUSINESS ENGINEERING (LEUVEN)
Major Technology and Entrepreneurship

Promoter: Dennis Verhoeven
Assistant: Dennis Verhoeven

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This thesis studies the relation between locating on a science park and innovative output. As past research regarding the effect of science parks is highly ambiguous, this thesis tries to contribute in four ways. First, quality-oriented innovation measures are adopted. Second, all science parks in the USA are quantitatively and exhaustively considered. Third, a longitudinal dataset covering more than 30 years is employed. Fourth, the methodology is based on a pooled OLS regression and two fixed effects frameworks that allow controlling for time-invariant unobservable traits on the level of inventors and firms. The results proof that including these fixed effects influences the results and they should thus be properly accounted for. Overall, the findings support that the number of patents is positively and novelty is negatively related to locating on a science park. Accordingly, the theory that recombination and spillover mechanisms enable science park firms to create more novel patents is not supported. The relation with citations and breakthrough appears to be explained by the effect of the individual inventors and firms. Furthermore, the fact that inventors with certain characteristics select themselves (or are selected) to work on a science park seems to have an important influence on the probability of novelty. In conclusion, three promising research avenues are proposed.

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1 Introduction

Universities typically conduct scientific research that is unattractive to firms due to the associated market failures (Arrow, 1962). Nevertheless, the knowledge resulting from scientific research is highly relevant for the development of novel technologies, and the development of novel technologies has been argued to increase the potential of scientific inquiry (e.g., Arthur, 2009; Arora, Belenzon & Patacconi, 2018). Based on such potential for cross-fertilization between science and technology, science parks have been proposed as policy instruments aimed at promoting research-based industrial and innovative activity (Löfsten & Lindelöf, 2002; Phillimore, 1999; Quintas, Wield & Massey, 1992; Westhead & Batstone, 1998). This motivates the need for a better understanding of when and why science parks might increase innovative performance, and as such inspire more effective policy intervention (Cheng, van Oort, Geertman & Hooimeijer, 2014; Phan, Siegel & Wright, 2005).

Many scholars and practitioners indicate that science parks are expected to generate a positive effect on various economic dimensions (Cheng, van Oort, Geertman & Hooimeijer, 2014; UKSPA, 2003). This expectation is based on multiple mechanisms. As science park firms are more likely to establish links with other firms and universities, they have a higher chance to increase their recombinatory set on which novel technologies are based (Löfsten & Lindelöf, 2002; Weitzman, 1998; Fleming, 2001, 2007; Arthur, 2009). Moreover, this recombination is enhanced by establishing communication networks in science parks. These networks promote knowledge spillovers and increase and diversify tenants' stock of knowledge (Quintas, Wield & Massey, 1992; Fleming, 2007; Rosenkopf & Nerkar, 2001). Additionally, hiring workers from (competing) firms, a practice that is not uncommon in science parks (Fallick, Fleischman & Rebitzer, 2006), seems to be a key means to access the network crucial for knowledge spillovers (Breschi & Lissoni, 2003). Furthermore, science parks assist their tenants in arranging practicalities (in terms of infrastructure), enabling their firm owners to focus entirely upon business activities (McAdam & McAdam, 2008). In conclusion, the incubation services provided by science parks support new ventures in finding capital in early stages (Rubin, Aas & Stead, 2015).

Past empirical results are highly ambiguous. On the one hand, many scholars and practitioners indicate that science parks are expected to generate a positive effect on various economic dimensions such as job creation, new product development, high-tech business development, profitability and survival (e.g., Autio & Klofsten, 1998; Vedovello, 1997; Link & Scott, 2003; Malecki, 1991; Hansson, Husted & Vestergaard, 2005; Phan, Siegel & Wright, 2005; Storey & Tether, 1998). On the other hand, not everyone is positive about the science park concept. A high number of (influential) papers have raised concerns about its actual performance, with some authors even describing science parks as high-tech fantasies (Macdonald, 1987; Bakouros, Mardas & Varsakelis, 2002; Quintas, Wield & Massey, 1992). For nearly all dimensions of (innovative) firm performance (e.g., firms' likelihood to patent, R&D intensity, R&D productivity, interaction between firms and universities, employment, sales growth, promoting regional growth, profitability), both positive and negative evidence can be found (e.g., Quintas, Wield & Massey, 1992; Bakouros, Mardas & Varsakelis, 2002; McAdam & McAdam, 2008; Lindelöf & Löfsten, 2002, 2003, 2004).

This inconclusiveness alone makes it worth to study science parks in more detail. Additionally, past empirical papers commonly encounter certain limitations. First, a large share of the previous literature based its results on momentary small-scale case studies. Second, previously used indicators of innovation are limited to R&D investments and patent counts, which investigate quantity rather than quality. Third, due to their cross-sectional econometric design, previous results may be explained by other factors such as unobserved individual or firm ability.

In this thesis, we contribute to the literature by addressing these methodological problems. First, we exhaustively take into account all science parks in the United States of America, the provenance of the science park concept. Second, we study the period between 1980 and 2010, covering 31 years. Third, we pay more attention to the quality of inventive output based on the technological impact and novelty measures as defined by Verhoeven, Bakker & Veugelers (2016). The novelty measure enables us to evaluate the quality of patents ex ante, which contrasts with universally used ex post measures of innovation. Fourth, the methodology will be based on a pooled OLS regression, an inventors fixed effects and an inventor-firm fixed effects framework. Estimating the pooled OLS coefficients enables us to get an idea about the importance of alternative explanations by comparing them with the fixed effects frameworks. These frameworks allow controlling for time-invariant unobservable traits on the level of inventors and/or firms. Accordingly, we can specifically identify the effect attributable to resp. science parks, inventors and firms, and judge whether methodological choices made by previous research have influenced the results. The evidence in this thesis proofs that including individual inventors and firms fixed effects indeed influences the results.

Our results reveal a number of interesting patterns. First, when controlling for time-invariant unobservable traits on the level of inventors and firms, the number of patents is positively and the probability of novelty is negatively related to locating on a science park. Second, science parks seem to have a different relation with indicators of impact (i.e., citations and breakthrough) compared with novelty. The apparent relation with impact however appears to be explained by the individual inventors and firms. Third, the fact that inventors with certain characteristics select themselves (or are selected) to work on a science park seems to have an important influence on the results regarding novelty.

The rest of this thesis is structured as follows. In the theoretical background of Section 2, the reader will be introduced to science parks and the mixed empirical results regarding the concept. This section concludes with how this thesis tries to complement the existing literature. Section 3 explains how the data was gathered and which innovation measures are used. This section also formulates the different econometric designs, and provides a first look on the data. Section 4 describes the results, while Section 5 interprets these and links back to the theory. Section 5 concludes with the limitations of this study and the corresponding further research avenues. Section 6 concludes this thesis.

2 Theoretical Background

2.1 An Introduction to Science Parks

2.1.1 The Origins of Science Parks

The science park phenomenon has its origins in the USA (1950s). According to UNESCO ("Science Parks around the World" 2017), the Stanford Research Park, better known as Silicon Valley, was the pioneer in the development of science parks back in the early 1950s. It was followed by Sophia Antipolis (France) in the 1960s and Tsukuba Science City (Japan) in the early 1970s. Inspired by the success of Silicon Valley and Route 128 in the US and recognizing the importance of knowledge-based industries as a new driving force of growth, many countries have adopted a strategy of establishing science parks to help develop high-tech industries and to promote technological capacity (Quintas, Wield & Massey, 1992; Bakouros, Mardas & Varsakelis, 2002; Colombo & Delmastro, 2002; Amirahmadi & Saff, 1993).

Today, UNESCO documents over 400 science parks worldwide and their number is still growing. The top three countries in terms of number of science parks includes the USA (over 150), Japan (around 110) and China (around 100). Europe currently houses around 230 science parks, with the UK (63), France (60) and Finland (24) as protagonists ("Science Parks in Europe" 2017; Storey & Tether, 1998). The success stories of US science parks have been successfully emulated in some developing countries, such as Taiwan (Jongwanich, Kohpaiboon & Yang, 2014).

2.1.2 Merging a Variety of Definitions

Surprisingly, given their long history in the United States as well as in other countries, there is no generally accepted definition of a science park (Link & Scott, 2003; Amirahmadi & Saff, 1993). Science parks have in fact spread worldwide taking each time a different form. Moreover, empirical research does not always clearly distinguish between science parks and incubators (Ratinho, 2010) or other related terms. It is therefore difficult to estimate whether the (perceived) benefits relate to a particular type of science park.

In an attempt to merge a variety of definitions, a science park:

- Is property-based (UKSPA, 1996). Many different definitions concur that the property dimension is a key factor (e.g., Phan, Siegel & Wright, 2005; Hansson, Husted & Vestergaard, 2005; Salvador & Rolfo, 2011). This enables them to provide innovative companies access to critical human and physical capital (Siegel, Westhead & Wright, 2003a; Storey & Tether, 1998) as well as providing facilities for fairs, exhibitions and market development ("Science Parks and Technology Business Incubators" 2017).
- Tries to bridge research and industry (Squicciarini, 2007; Fikirkoca & Saritas, 2012; Fukugawa, 2006) as it promotes spillovers through formal and operational links between firms (both small and large), universities (Yang, Motohashi & Chen, 2009), and other research institutions.
- Provides an environment that enables large companies to develop relationships with small, high-tech companies (UKSPA, 1996; Parry & Russell, 2000; Ferguson & Olofsson, 2004). The clustering of high-tech firms should serve to stimulate synergies (Castells & Hall, 1994),

networking activities (Salvador & Rolfo, 2011), technology transfer and the acquisition of key business skills (Siegel, Westhead & Wright, 2003a).
- Fosters the formation and growth of innovative new companies and their R&D activities (UKSPA, 1996; Phillips & Yeung, 2003) and supports incubation and spin-offs (OECD, 1997; Salvador & Rolfo, 2011; Fukugawa, 2006). Science parks enable academics at the local university to commercialise their research ideas in a convenient location (Storey & Tether, 1998).
- Houses a management that is actively engaged in, amongst others, the transfer of technology and business skills to the organisations on site (UKSPA, 1996; Squicciarini, 2007).

2.1.3 Related Terms

Several related terms exist to describe similar initiatives in the value chain of support activities, such as Research Park, Technology Park, Business Park, Innovation Centre, etc. (Monck, 1988). After reading through the most prominent literature from the last thirty years around science parks, it was noticed that whereas science parks predominantly include physical property, incubation services and vicinity to a higher education institution, incubators and commercial/industrial parks only accommodate fragments of these (Fukugawa, 2006; Salvador & Rolfo, 2011). To clarify the relation between science parks and incubators, Ratinho & Henriques (2010) depict business incubators as potential tenant-feeders to science parks.

In research parks, the majority of tenants are heavily engaged in research; in technology/innovation parks in applied research and development; while commercial/industrial parks are more production-oriented (Link & Scott, 2003; Cheng, van Oort, Geertman & Hooimeijer, 2014). Business parks provide premises but little else (Guy, 1996; Spithoven & Knockaert, 2011). Hansson, Husted & Vestergaard (2005) define a technology centre as a combination of the technological level of a science park with the managerial support of an incubator. Many parks include a combination of several categories however, making it difficult to sustain a distinction in practice (Amirahmadi & Saff, 1993).

In this work, the term ‘science park’ will be used, differentiated from related terms as defined above. Hence, the literature review will be focused on science parks. However, Diez-Vial & Montoro-Sanchez (2017) explain that time has mixed up the research between similar terms like parks and incubators. Therefore, the review will be complemented with literature on incubators, research parks, etc. when gauged appropriate. Also during the data collection, only data on parks that sufficiently comply with the definition established in Section 2.1.2 is included (for more detail, see Section 3.1 and Appendix 1).

2.2 A Promising Concept with Mixed Empirical Results

2.2.1 Science Parks: a Promising Concept

Many scholars and practitioners indicate that science parks are expected to generate a positive effect on various economic dimensions (Cheng, van Oort, Geertman & Hooimeijer, 2014; UKSPA, 2003). More specifically they are argued to spur reindustrialization and regional development through the creation of jobs and regional technological capacity (Jongwanich, Kohpaiboon & Yang, 2014; Autio & Klofsten, 1998; Castells & Hall, 1994; Appold, 1991; Vedovello, 1997; Malecki, 1991; Shefer & Bar-El, 1993; Link & Scott, 2003), help commercialization of publicly financed research (Nowotny et al., 2001), facilitate innovation and new product development, decrease unemployment (Hansson, Husted & Vestergaard, 2005; Amirahmadi & Saff, 1993; Phan, Siegel & Wright, 2005; Westhead, 1997; Westhead & Cowling, 1995; Squicciarini, 2008, 2009) and promote the development of new high-tech business (Storey & Tether, 1998; Link & Scott, 2003). Finally, some authors claim that science parks encourage wealth creation and business profitability (Geroski, Machin & Van Reenen, 1993; Harris & Trainor, 1995) and survival (Westhead & Storey, 1995; Ferguson & Olofsson, 2004; Van Tilburg & Vorstman, 1994; Bower, 1993) because acquiring technological knowledge positively relates to the innovativeness of products/services developed by entrepreneurs (Sullivan & Marvel, 2011).

But why exactly do we expect science parks to positively influence the inventiveness of their tenants? The rest of this section reviews the different mechanisms by which science parks are deemed to increase inventive performance.

2.2.1.1 Recombinant Growth

In order to develop novel technologies, inventors recombine already existing technological components in a novel manner (Weitzman, 1998; Fleming, 2001; Fleming & Sorenson, 2004; Arthur, 2009). However, the number of potential components and combinations that an inventor can simultaneously consider is limited (Fleming, 2001). Enhancing this recombinatory set can increase innovative output (Ahuja, Lampert & Tandon, 2008, p. 65). This can be achieved by establishing links with other firms, universities and research centers (Fleming, 2007). Many studies have indeed regarded universities as a critical source of external knowledge (Chen, Chen & Vanhaverbeke, 2011; Fabrizio, 2009; Fontana, Geuna & Matt, 2006; Grimpe & Sofka, 2009; Köhler, Sofka & Grimpe, 2012; Laursen & Salter, 2004; Sofka & Grimpe, 2010). Universities provide scientific knowledge elements whose recombination seems to be particularly beneficial in the development of radical innovations (Ahuja & Katila, 2004; Fabrizio, 2009; Köhler, Sofka & Grimpe, 2012). Science park firms are more likely to establish links with other firms, universities and research institutes than off-park firms (Löfsten & Lindelöf, 2002; Fukugawa, 2006; Colombo & Delmastro, 2002; Vedovello, 1997). Thanks to this enhanced receptiveness to recombination, science park inventors can be expected to create more highly novel inventions and help select good out of all possible solutions.

2.2.1.2 Knowledge Spillovers

An important finding of Jaffe (1989), Acs, Audretsch & Feldman (1992, 1994) and Feldman (1994a, b) is that investment in R&D by private corporations and universities spills over for third-party firms to exploit (see also Audretsch & Feldman, 1996). Using patent citations, Jaffe, Trajtenberg & Henderson (1993) conclude that knowledge spillovers are geographically localized. Remark however that the actual interaction between firms and hence formation of networks is crucial, as geography is not a sufficient condition for accessing a local pool of knowledge. It requires active participation in a network of knowledge exchanges (Breschi & Lissoni, 2003). Science parks aim to promote inter-firm links and social interaction by establishing these communication networks (Quintas, Wield & Massey, 1992). Ultimately, this should facilitate knowledge spillovers (Quintas, Wield & Massey, 1992; Fleming, 2007), allowing firms to increase and diversify their stock of knowledge (Ahuja & Lampert, 2001; Rosenkopf & Nerkar, 2001; Fleming, 2007).

2.2.1.3 Human Capital

Even as old reasons for clustering have diminished in importance with globalization, new influences of clusters on competition have taken on growing importance (Porter, 2000). Next to the mentioned knowledge spillovers, other possible advantages of spatial clustering have been identified in the research literature such as the build-up of a skilled labour force (Malmberg & Maskell, 2002). Silicon Valley's computer cluster has even become famous for its job hopping (i.e., the rapid movement of skilled employees between competing firms; Fallick, Fleischman & Rebitzer, 2006). Moreover, hiring workers from competitors and other firms seems to be a key means to access a network crucial for knowledge spillovers (Breschi & Lissoni, 2003). The set of organizations found on a park could enable individuals to pick up a lot of new (complementary) skills, which in turn facilitates invention through recombination.

2.2.1.4 Physical Capital

Moreover, one of the objectives of establishing a science park in most countries is to provide the infrastructure that a young firm needs in the process of struggling to gain a foothold in a competitive market (Guy, 1996). Malmberg & Maskell (2002) recognized shared costs for infrastructure as one of the advantages of clustering. In the same line, Rogers & Larsen (1988) identified the availability of pre-existing infrastructure as a critical factor of the success of Silicon Valley. More generally, hard infrastructure has been recognized as a critical factor of a successful science park policy (Jongwanich, Kohpaiboon & Yang, 2014). In conclusion, because science parks assist their tenants in arranging practicalities, they enable firm owners to focus entirely upon business activities during the early stages of growth (McAdam & McAdam, 2008).

2.2.1.5 Increases in Investment

Another factor of success in Silicon Valley as identified by Rogers & Larsen (1988) includes the availability of venture capital. Motohashi (2013) confirms that Silicon Valley actively exchanges information about venture capital. The literature suggests that small new ventures tend to fail because they lack the ability to raise capital in an early stage. Incubators are expected to overcome these obstacles by offering enhanced access to capital at a firm's early stage (Rubin, Aas & Stead, 2015). Venture capital firms are in this way relevant market actors that provide not only financial resources, but also market credibility (Fernandez-Alles, Camelo-Ordaz & Franco-Leal, 2015). Although clear differences exist between science parks and incubators (see Sections 2.1.2 and 2.1.3), science parks often offer similar services, or simply house an incubator.

2.2.2 Empirical Results are Ambiguous[1]

In spite of their potential, science parks did not prove to be the panacea for development that many policymakers and developers made or still make it out to be (Amirahmadi & Saff, 1993; Hansson, Husted & Vestergaard, 2005; Macdonald, 1987; Colombo & Delmastro, 2002). The science park as a catalyst in urban and regional growth is not a well-trodden path and, despite public policy rhetoric to the contrary, few examples exist of science park-led local economic

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[1] In this section, the work by Albahari, Pérez-Canto and Landoni (2010) has been a helpful complement for the literature review on the impact of science (and technology) parks.

development (Quintas, Wield & Massey, 1992; Fikirkoca & Saritas, 2012; Salvador & Rolfo, 2011). Some authors even describe science parks as high-tech fantasies (Macdonald, 1987; Bakouros, Mardas & Varsakelis, 2002; Quintas, Wield & Massey, 1992). Independently of the type of analysis carried out (unit of analysis, measure of performance or specific econometric tool used), evidence is mixed with respect to the park's effectiveness (Squicciarini, 2007).

When assessing the impact of science and technology parks on the **innovative output** of firms, Squicciarini (2008 and 2009) and Jongwanich, Kohpaiboon & Yang (2014) find that parks seem able to enhance the tenants' likelihood to patent. Verhoeven, Rabijns & Bakker (2017) confirm that firms' science park affiliates are more likely to create highly novel inventions compared to the same firm's off-park affiliates. Others showed no statistically significant differences between on- and off-park firms with regard to innovation measures like patents/products launched and copyrights (Lindelöf & Löfsten, 2002, 2003; Colombo & Delmastro, 2002; Siegel, Westhead & Wright, 2003a; Westhead & Storey, 1994). According to Felsenstein (1994), science park location has only a weak and indirect relationship with innovation level. He adds that the seedbed effects[2], as indicated by the level of interaction with a local university and the entrepreneur's educational background, are not necessarily related to the firm's innovative level.

In terms of **R&D intensity**, Fukugawa (2006), Lindelöf & Löfsten (2002) and Leyden (2008) present positive effects while Westhead (1997), Colombo & Delmastro (2002) and Siegel, Westhead & Wright (2003a) do not find a positive correlation with on-park location. Also in **R&D productivity** opinions are divided: Link & Scott (2006) and Jongwanich, Kohpaiboon & Yang (2014) offer a suggestive argument that park formations do increase R&D efficiency. Yang, Motohashi & Chen (2009) argue that on-park firms invest more efficiently. On the other hand, Westhead (1997) and Siegel, Westhead & Wright (2003a) are more skeptical.

Many authors find a positive park effect on the **interaction** between **firms and universities/research centers**[3] (Felsenstein, 1994; Vedovello, 1997; Löfsten & Lindelöf, 2002, 2003; Colombo & Delmastro, 2002; Westhead & Storey, 1995; Link & Scott, 2003; Marques, Caraca & Diz, 2006; Fukugawa, 2006). Bower (1993) for example finds that a substantial proportion of science park firms are exploiting academic inventions. Others, however, do not find any effect or even a negative one (Quintas, Wield & Massey, 1992; Malairaja & Zawdie, 2008; Radosevic & Myrzakhmet, 2009, Bakouros, Mardas & Varsakelis, 2002; Mønsted, 2003). Lindelöf & Löfsten (2003) even question the basis for the science park strategy as a means to achieve linkage.

Vedovello (1997) presents strong results indicating that science parks facilitate the establishment of informal and human resources **links**. However, Radosevic & Myrzakhmet (2009) and Chan, Oerlemans & Pretorius (2010) find that on-park firms are more likely to collaborate with off-park firms than with other firms inside the park. According to Malairaja & Zawdie (2008), the difference in the number of cooperative relations maintained by

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[2] Implicit in the 'seedbed' metaphor is the notion of a nurturing process that eventually creates an environment for growth. The science park as a 'seedbed' therefore refers to the conditions created to promote innovation (Felsenstein, 1994).

[3] The form of linkages between firms and higher education institutes can include the transfer of people and knowledge, sponsoring research, access to facilities but also less formal interchange of information (Monck, 1988). Löfsten & Lindelöf (2005) clarify that most accessing of academic resources relates to low-level contacts based on recruiting university graduates or informal contacts.

organisations located on-park and those located off is not significant (also see Van Dierdonck, Debackere & Rappa, 1991).

Moreover, the positive effect of the good **public image** of science parks on technology tenants is minimal and only seems to be a good selling point for tenants as they can take advantage of this reputation to make deals (Chan & Lau, 2005). Felsenstein (1994) adds that the choice of a science park location is due as much to the status and prestige effect as it is to the perceived benefits in terms of innovative edge (see also Monck, 1988; Westhead & Storey, 1994; Joseph, 1989; Luger, 1991; Macdonald, 1987; Amirahmadi & Saff, 1993).

In terms of **economic measures** such as employment and sales growth again positive (e.g., Lindelöf & Löfsten, 2002, 2003, 2004; Löfsten & Lindelöf, 2001, 2002 and 2003; Colombo & Delmastro, 2002; Ratinho & Henriques, 2010; Westhead & Storey, 1994) and insignificant or negative (Ferguson, 2004; Ferguson & Olofsson, 2004; Shearmur & Doloreux, 2000; Siegel, Westhead & Wright, 2003a; Westhead & Cowling, 1995) effects are found. Additionally, no clear evidence has been found of better performance of on-park firms when profitability is concerned (Lindelöf & Löfsten, 2002; Löfsten & Lindelöf, 2001, 2002 and 2005). Löfsten & Lindelöf (2002) were even struck by how similar the profitability measures were between on- and off-park firms. Monck (1988) even finds lower levels of employment by a given age in science park firms than comparable firms located off-park. Further analysis indicated, however, that almost 20% of businesses in science parks were founded by (ex-)academics and it was those businesses which underperformed in terms of employment growth.

Westhead & Storey (1995) argue that science parks in the UK may have proved critical for the **survival** of small high-tech firms. Other scholars confirm these findings (Ferguson & Olofsson, 2004; Van Tilburg & Vorstman, 1994; Bower, 1993). Alternative studies do not find significant differences in the probability of survival between on- and off-park firms (Siegel, Westhead & Wright, 2003a; Westhead & Storey, 1994).

Lastly, several studies conclude that science parks tend to fail in attracting and developing high-tech companies (Hansson, Husted & Vestergaard, 2005) or **promoting regional growth** (Amirahmadi & Saff, 1993; Castells & Hall, 1994; Quintas, Wield & Massey, 1992).

2.3 Greater Detail in Research May Reveal a More Accurate Picture

As the former suggests, science parks have been researched extensively in the past. Nevertheless, the dynamic nature and critical conditions necessary for creating a successful science park in terms of the various dimensions of firm performance still form an open question that is well worth exploring (Yang, Motohashi & Chen, 2009; Ratinho & Henriques, 2010; Phan, Siegel & Wright, 2005).

Past empirical papers commonly encounter certain limitations. First, a large share of the previous literature bases its results on momentary small-scale case studies (e.g., Salvador & Rolfo, 2011; Bigliardi et al., 2006; Chan & Lau, 2005). This setup limits generalization both in time and geographically. Second, due to their cross-sectional econometric design, previous results may be explained by other factors such as unobserved individual or firm ability. Third, previously used indicators of innovation are limited to R&D investments and patent counts, which investigate the quantity of the output rather than the quality. Hence, they cannot distinguish between for example the types of innovation pursued, i.e., radical or incremental innovation.

In this thesis, we contribute to the literature by addressing these methodological problems. First, we exhaustively take into account all[4] science parks in the United States of America, the provenance of the science park concept. Second, this work studies the period between 1980 and 2010, covering 31 years. Third, this thesis tries to pay more attention to the quality of inventive output based on the technological impact and novelty measures as defined by Verhoeven, Bakker & Veugelers (2016). The novelty measure enables us to evaluate the quality of patents ex ante, which contrasts with universally used ex post measures of innovation. Fourth, the methodology will be based on a pooled OLS regression, an inventors fixed effects and an inventor-firm fixed effects framework. Estimating the pooled OLS coefficients enables us to get an idea about the importance of alternative explanations by comparing them with the fixed effects frameworks. These frameworks allow controlling for time-invariant unobservable traits on the level of inventors and/or firms. Accordingly, we can specifically identify the effect attributable to resp. science parks, inventors and firms, and judge whether methodological choices made by previous research have influenced the results.

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[4] More specifically, all US parks that match the definition (see Section 2.1.2) and on which sufficient data is available are included.

3 Data and Methodology

3.1 Data Collection

The sample has been constructed in multiple steps as follows. Initially, a list of science parks in the US was established by combining multiple sources. As described in full detail in Appendix 1, all parks that were mentioned by the sources were critically checked against the definition of Section 2.1.2. Hence, the website of each park was examined to verify whether the park (i) collaborates with a local university; (ii) fosters the formation and growth of innovative new companies; and (iii) is not restricted to incubation (i.e., does not only house start-ups). For the parks that were eventually included, all tenant firms were collected for the entire history of the park. In a next step, we linked these firms to all patents on which they were listed as an applicant. To include spelling variations of these firm names on patents, we applied an approximate string matching technique (the Jaro-Winkler score) to identify additional candidate patents[5]. After using this string-matching algorithm, we manually selected all correct matches from this group of potential matches. For all these applicants, we collected all patents they filed for the USPTO between 1980 and 2010. To derive inventor address information and disambiguate their names, we linked this dataset to the Li et al. (2014) database. This database holds comprehensive information on inventors listed on USPTO patents and uses address information on the patent to derive geographic coordinates for each inventor. Using this information and manually geo-coding the addresses of our list of science parks, we calculated the distance between the inventor and all science parks. To establish whether an inventor worked on a science park when applying for a certain patent, we demanded that the applicant on the science park was listed as tenant at that science park and that the inventor's address was within a distance of 30km from the science park. Verhoeven, Rabijns & Bakker (2017) report a distance of 30 km to perform best in terms of validity based on a sample of inventors located around Research Triangle Park in North Carolina, USA. As such, we obtained a variable indicating whether a person was working on a science park for a certain patent. In a final step, the patents were linked to the innovation measures as defined by Verhoeven, Bakker & Veugelers (2016).

3.2 Innovation Measures

The novelty and impact measures as defined by Verhoeven, Bakker & Veugelers (2016) were adopted in this thesis. More specifically, the analyses as described below have been executed using patent count, novelty, total citations (after five years) and breakthrough (2 standard deviations) as core dependent variables.

A first measure, the scale of innovation, represents the total number of patents an inventor has filed for in a certain year. A second measure, novelty, has been constructed based on three ex-ante measures of novelty, i.e. novelty in recombination, novelty in technological knowledge and

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[5] We demanded a match of the first letter in addition to a score of ≥ 0.85.

novelty in scientific knowledge origins[6]. The novelty measure for a certain patent is constructed as a dummy equal to 1 if at least one of these three novelty measures is strictly greater than 0 (and is equal to 0 otherwise). A third measure, total citations after five years, measures the number of forward citations in the five years after the innovation was launched. A fourth measure, breakthrough, gives an indication of the breakthrough level of the patent. For more detailed information on these measures, see Verhoeven, Bakker & Veugelers (2016).

Regarding novelty, citations and breakthrough, the average is taken over the patents per year. Further, remark that these three measures as defined in this thesis are measures for fraction, not count, and are not dependent on the number of patents. In other terms, they are interpreted in the intensive margin, relative to the quantity of innovation. The main analyses have been repeated in the extensive margin as a robustness test (see Section 5.1).

To conclude, it must be mentioned that Verhoeven, Bakker & Veugelers (2016) define many more variants on the variables as described above. For example, to measure total citations, they do not only measure the number of citations after five years, but also after three, seven and ten years. Similarly, a breakthrough variable to measure outlier impact is defined for two, five and ten standard deviations. Yet another measure is similar to the previous, but considers five years. Hence, multiple alternative measures exist as compared to defined above. However, the analyses as defined below have been replicated for all these different variants as a robustness check. The results do not quantitatively change when using these alternative measures. Therefore, the results in the core text will only be described for the main innovation measures (i.e., number of patents, novelty, total citations after five years and breakthrough (2 standard deviations)), as defined in the beginning of this section[7]. The science park coefficients for all innovation measures can be consulted in Appendix 4.

3.3 Econometric Design

Three different econometric designs were constructed to test whether being located on a science park influences innovative output: a pooled OLS (ordinary least squares) regression, a fixed effects for inventors and a fixed effects for inventors and tenants model. As explained in Section 3.2, innovative output is measured using the number of patents, novelty, citations and breakthrough.

It is widely accepted that OLS regressions can potentially be biased if unobservable characteristics correlate with the dependent variable. Estimating pooled OLS coefficients however enables us to get an idea about the importance of alternative explanations by

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[6] Noicos & Verhoeven (2016) describe these dimensions in detail as follows: an invention is identified as having novelty in recombination if the combination of components and principles of working applied to serve its purpose are different from those embodied in previous technologies. An invention is identified as having novel technological knowledge origins if it draws technological knowledge from domains that were previously not used in the technological domain of the invention. An invention is identified as having novel scientific knowledge origins if it draws scientific knowledge from domains that were previously not used in the technological domain of the invention.

[7] When simply referred to ‘citations’ or ‘breakthrough’ in the remainder of this text, this will concern resp. total citations after five years and breakthrough (2 standard deviations).

comparing them with other designs. Hence, including the pooled OLS regressions (models 1-4) contributes to the notion that methodological choices impact the science park coefficients[8].

Moreover, it could be argued that inventors and firms that operate on-park differ from inventors, resp. firms that have never been on a science park. The decision to locate on a park is likely to be affected by unobservable characteristics that also correlate with inventive output (such as firm strategy, ambition, researcher's ability…). Therefore, a fixed effects model for inventors (models 5-8) and for inventors and firms jointly (models 9-11[9]) seems to be justified. These frameworks allow controlling for time-invariant unobservable traits on the level of inventors and firms. Hence, they estimate the effect of locating on a park given all time-invariant unobserved characteristics on the level of inventors, resp. inventors and firms.

Note that when estimating the inventors fixed effects model, only those inventors that moved in the analysis period from or to a science park show variation. Therefore, the sample is remarkably smaller for models 5-8.

These OLS and fixed effects designs have each been executed four times, every time adding different control variables. Firstly, only the dependent variable science park was estimated (models 1, 5 and 9). Secondly, the application year and technology field in which a patent has been filed were added as control variables (models 2, 6 and 10). The third model will not be reported[10]. Fourthly, also tenant dummies were included as additional control variables (models 4 and 8).

3.4 Descriptive Statistics

In total, data on 159,166 inventors was collected spread over 513 firms. This resulted in 591,622 US patents of which 20,589 (i.e., around 3%) were filed by on-park inventors and thus 571,033 (i.e., around 97%) by off-park inventors. As shown in Figure 1, these on-park patents originate mainly in the pharma, computer, measurement, biotech and semiconductors industry, which together constitute around half of the on-park patents. The last quarter of industries is

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[8] In a first step, two pooled OLS regressions were executed with first inventor–patent family and second inventor-year as unit of observation. Comparing the estimates for the science park variable in both OLS models however reveals that these are very similar. Hence, only the results of the pooled OLS on the inventor-year level will be reported (models 1-4) as on the inventor-year level also the number of patents per inventor per year can be used as a dependent variable. This is not the case on the inventor-patent level.

[9] Remark that for this fixed effects framework only three models are estimated because the only difference between the third and the fourth model is that the fourth additionally controls for tenants. These are however already incorporated as fixed effects in this case. Due to collinearity, the variable would have to be dropped and after dropping tenants, model four equals model three (see last paragraph of Section 3.3).

[10] In the third model, the size of the patent family (patent family size), the number of inventors (team size) and number of applicants (number of applicants), the number of combinations in technology origins, recombination and scientific origins (resp. count NTO combinations, count NR combinations and count NSO combinations) and a variable indicating whether the patent created a new International Patent Classification class (new IPC class) were added on top of the previous control variables. The results for the third type of model consistently lie very close to the results of the second design, however. Therefore, these models will be hidden in the output (i.e., models 3, 7 and 11).

aggregated in Figure 1 and contains the remainder of patents, whose technology fields each represent 2% or less[11].

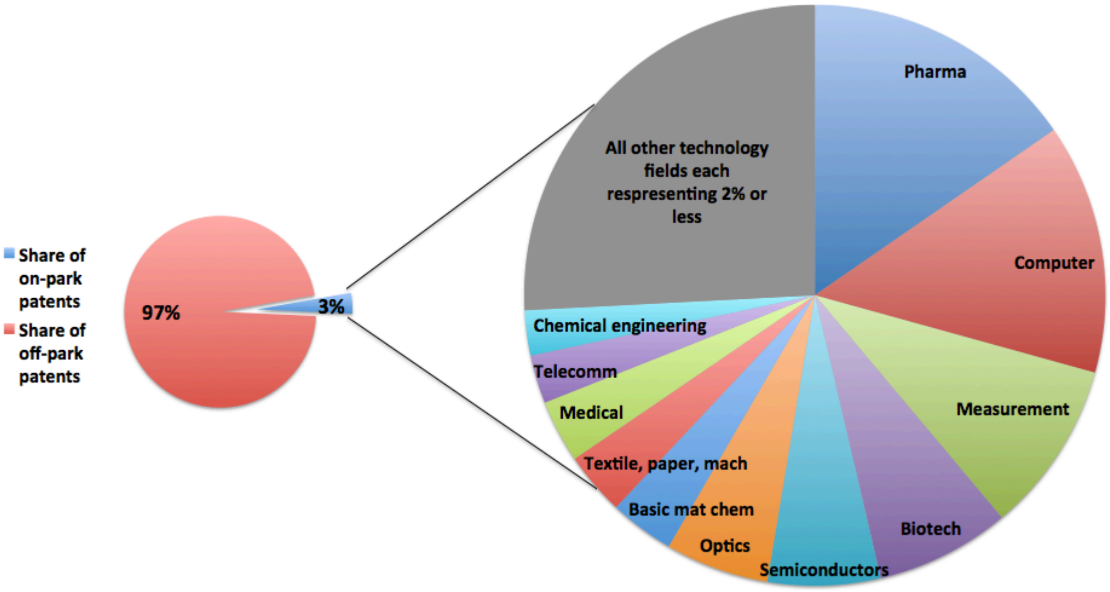

Figure 1: 3% of patents come from on-park inventors, of which around half originate in the pharma, computer, measurement, biotech and semiconductors industry.

Taking a closer look at the trends over time (see Figure 2), it can be observed that the number of filed patents initially increases, resulting in a peak around 2003. Afterwards, the number of patents decrease sharply[12]. When contrasting on- and off-park patents, we see that the share of on-park patents rises, probably because the number of science parks increases as well.

Additionally, an analysis resembling difference-in-difference estimation was conducted both on firm and inventor level. The analysis looks within a 10-year window – starting 10 years before a move to a science park until 10 years after it. In Figure 3, the on-park line shows the number of patents a firm (Figure 3a) or inventor (Figure 3b) filed before and after moving to a science park. Note that the year 0 indicates the moment of the move to a science park. The off-park line displays the average change over time of the number of filed patents for firms/inventors that never went to a park, where each year is weighted by the relative number of on-park patents in that year.

Figure 3a shows that off-park firms gradually patent more over time. Companies that make a move to a science park, however, demonstrate substantially higher growth in number of filed patents after their move. Also for inventors (see Figure 3b), the number of filed patents seems to increase after a move to a science park. Nevertheless, due to a notable drop during the years before the move, this does overall not lead to considerably more patents than before the move.

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[11] These fields consist of anal. biol. mater., audio visual, basic comm. proc., civil engineering, control, digital comm., elect. mach. app. ener., engines, pumps and turbines, environmental, food chem., furniture and games, handling, IT meth. management, machine tools, macromol chem. polym., materials metallurgy, mech. elements, micro nano, organ fine chem., other consumer goods, other spec. mach., surface coating, thermal proc. app. and transport.

[12] Remark that Figure 2 is truncated because we used PATSTAT 2011, which only exhibits patent documents filed before October 2010. This has been dealt with by integrating year-dummies in the econometric design (see Section 3.3).

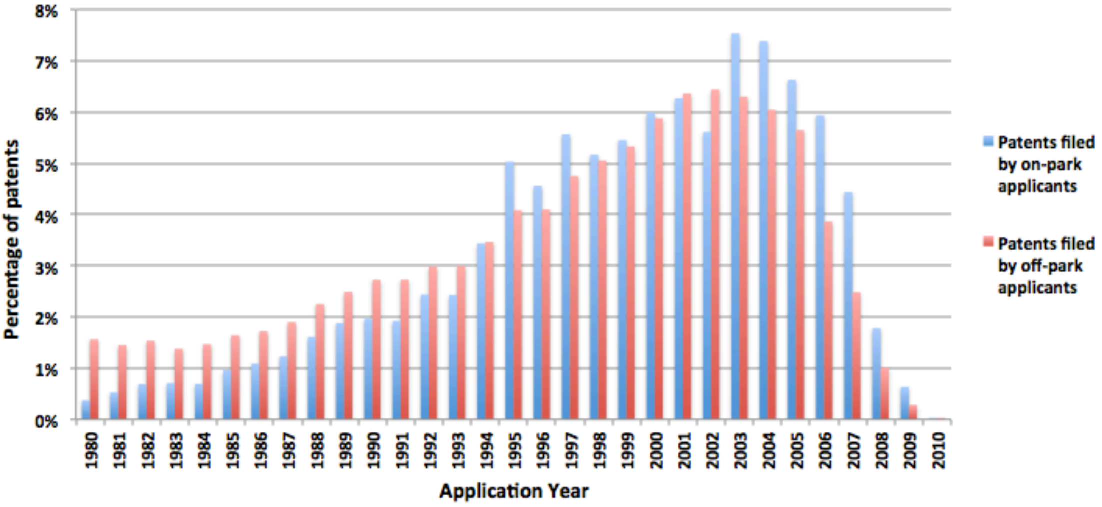

Figure 2: The share of on-park patents rises with a peak around 2003 for both on- and off-park patents.

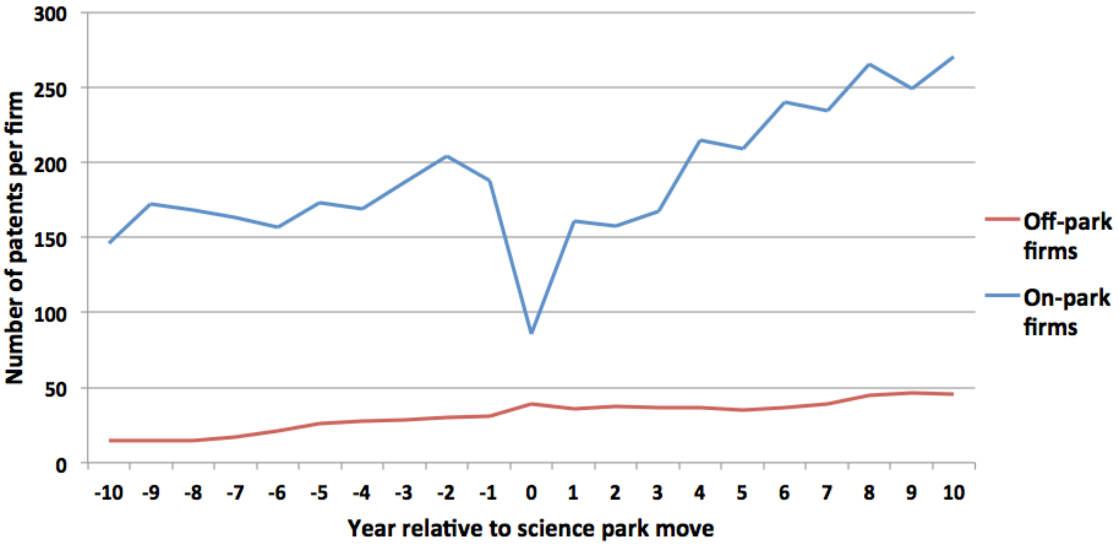

Figure 3a: The scale of innovation seems to increase during the years after a firm moves on-park.

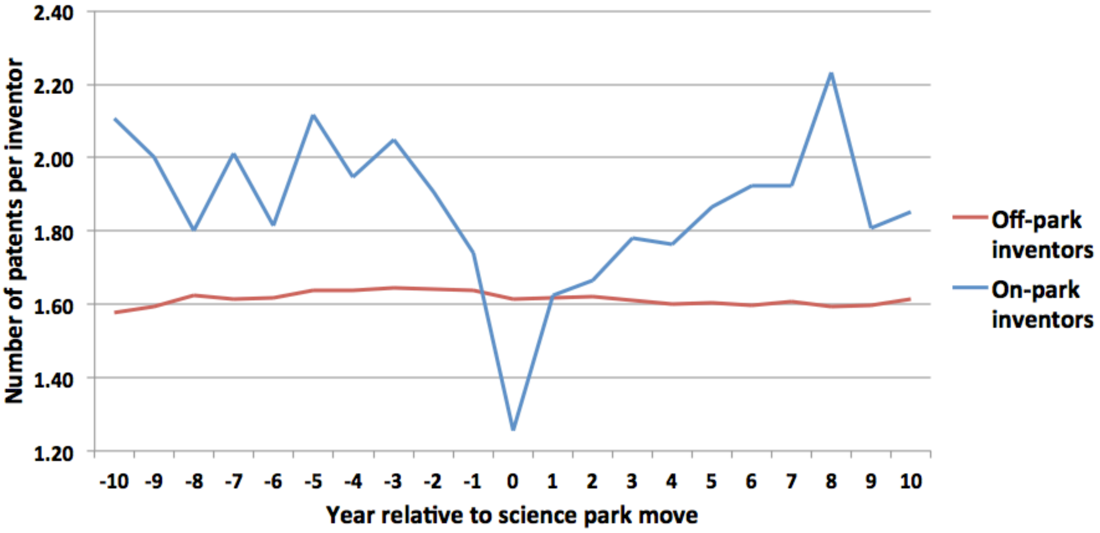

Figure 3b: The scale of innovation seems to increase after an inventor moves on-park. However, due to a pronounced drop during the years right before the move, this only leads to a return to previous output levels.

The same analysis has been carried out for both number of citations and novelty. The figures illustrating these analyses can be found in Appendices 2 and 3. In short, the number of citations does not seem to be influenced by being on a park (see Appendix 2). Neither on firm nor inventor level do on-park applicants show higher growth in citations after moving to a park, though showing more variation. The novelty of the patents even seems to be reduced by moving on-park (see Appendix 3).

To conclude this section, two-sample t tests were conducted on the individual patent level. The results are presented in Table 1. As can be seen, on-park patents are significantly less novel, but the difference is relatively small. Both total citations and probability of breakthrough are significantly higher on-park and amount to almost double of the off-park patents.

Table 1: Two-sample t tests with equal variances demonstrate that on-park patents are significantly more cited and breakthrough yet slightly less novel.

	Observations	Novelty	Total citations (after 5 years)	Breakthrough (2 std. dev.)
Mean On-park	20,589	0.2602	9.7580	0.1268
Mean Off-park	571,033	0.2996	5.7490	0.0666
Pr(|T| > |t|) for Ha: difference ≠ 0		0.0000	0.0000	0.0000

3.5 Reported Output

A high number of models and variables have been defined in the econometric design. Not all models are equally important, and thus not all output will be shown in the text. Note that the variables controlling for technology field, application year, and tenant have been hided in Section 4 to avoid overcomplicating the output. Furthermore, the results for the second and third group of control variables are very similar (for more detail, see Section 3.3). Hence, only the second group is reported (i.e., models 2, 6 and 10). In conclusion, many variants for the innovation measures used in this thesis exist (as explained in Section 3.2). The science park coefficients for all variants can be found in Appendix 4. The results do not turn out to differ substantially from the original innovation measures.

4 Results

4.1 The Scale of Innovation

The pooled OLS regressions show both significantly negative and significantly positive estimates. Without any control variables, inventors are on average expected to file 0.119 fewer patents per year when locating on-park. This estimate rises when controlling for technology domain and application year, and even more when additionally controlling for firms (up to 0.0488 patents on average more per inventor per year when located on-park). The inventors fixed effects framework only displays a significant science park estimate in the model with all control variables. In this model, on-park inventors are expected to file on average 0.461 more patents per year. The inventor-firm fixed effects framework estimates on-park inventors to file 0.193 more patents per year without and 0.178 more patents per year with control variables for domain and year (see Table 2).

Table 2: The estimates for the scale of innovation.

PATENT COUNT								
	Pooled OLS			Inventor fixed effects			Inventor-firm fixed effects	
	(1)	(2)	(4)	(5)	(6)	(8)	(9)	(10)
Science park	**-0.119*****	**-0.0855*****	**0.0488*****	**-0.0169**	**0.0663**	**0.461*****	**0.193*****	**0.178*****
	(0.0116)	(0.0121)	(0.0134)	(0.0691)	(0.0691)	(0.0858)	(0.0522)	(0.0528)
Family size			**0.00276*****			**-0.000722**		
			(0.000553)			(0.00631)		
Team size			**0.00959*****			**0.0140**		
			(0.00169)			(0.0231)		
Nr of applicants			**0.000888**			**0.00467**		
			(0.00181)			(0.0165)		
Nr of NTO combinations			**0.000299*****			**-0.000793**		
			(0.0000436)			(0.000924)		
Nr of NR combinations			**-0.000231***			**-0.000254**		
			(0.0000979)			(0.000932)		
Nr of NSO combinations			**-0.000914***			**0.00397**		
			(0.000382)			(0.00620)		
New IPC			**-0.0547***			**-0.0335**		
			(0.0229)			(0.272)		
Domain fixed effects	NO	YES	YES	NO	YES	YES	NO	YES
Year fixed effects	NO	YES	YES	NO	YES	YES	NO	YES
Firm fixed effects	NO	NO	YES	NO	NO	YES	NO	NO
Inventor fixed effects	NO	NO	NO	YES	YES	YES	NO	NO
Inventor-firm fixed effects	NO	NO	NO	NO	NO	NO	YES	YES
Constant	**1.617*****	**1.492*****	**-0.943*****	**2.067*****	**1.569*****	**1.150***	**1.592*****	**1.546*****
	(0.00305)	(0.0184)	(0.0659)	(0.0335)	(0.255)	(0.467)	(0.00208)	(0.0375)

N	366890	366890	366890	6357	6357	6357	369840	369840
R-squared	0.000169	0.0188	0.0521	0.0000100	0.0340	0.0544	0.0000279	0.0108

Standard errors in parentheses

$^{+} p < 0.10$, $^{*} p < 0.05$, $^{**} p < 0.01$, $^{***} p < 0.001$

4.2 Novelty

As displayed in Table 3, the probability of novelty of inventors' patents is overall significantly and negatively related to locating on-park. The pooled OLS estimates are very close to zero and appear inconclusive. In contrast, nearly all science park coefficients are significantly negative for all fixed effects models. Additionally, they change little when adding control variables within the fixed effects frameworks. All estimates are larger in absolute terms for the inventor-firm fixed effects, but they remain relatively small.

It is important to mention that primarily the coefficients change after the extra controls. The standard errors do not differ substantially between the pooled OLS and inventors or firms fixed effects models. This is an important confirmation that including individual inventors/firms fixed effects influences the results. These should thus be properly accounted for.

Table 3: The estimates for novelty.

	NOVELTY							
	Pooled OLS			Inventor fixed effects			Inventor-firm fixed effects	
	(1)	(2)	(4)	(5)	(6)	(8)	(9)	(10)
Science park	**-0.0440*****	**0.00489**	**0.00484**	**-0.0182+**	**-0.0213***	**-0.0282***	**-0.0405***	**-0.0392***
	(0.00352)	(0.00322)	(0.00405)	(0.0109)	(0.0104)	(0.0128)	(0.0161)	(0.0154)
Family size			**0.00901*****			**0.0106*****		
			(0.000200)			(0.00200)		
Team size			**0.00213*****			**0.00232**		
			(0.000296)			(0.00308)		
Nr of applicants			**-0.00389*****			**-0.00759**		
			(0.000408)			(0.00480)		
Nr of NTO combinations			**0.000741*****			**0.000607*****		
			(0.0000109)			(0.0000660)		
Nr of NR combinations			**-0.000961*****			**-0.00126*****		
			(0.0000598)			(0.000260)		
Nr of NSO combinations			**-0.000590*****			**0.000103**		
			(0.0000627)			(0.000407)		
New IPC			**0.102*****			**0.176****		
			(0.00950)			(0.0590)		
Domain fixed effects	NO	YES	YES	NO	YES	YES	NO	YES
Year fixed effects	NO	YES	YES	NO	YES	YES	NO	YES
Firm fixed effects	NO	NO	YES	NO	NO	YES	NO	NO

Inventor fixed effects	NO	NO	NO	YES	YES	YES	NO	NO
Inventor-firm fixed effects	NO	NO	NO	NO	NO	NO	YES	YES
Constant	**0.306*****	**0.132*****	**0.106*****	**0.262*****	**0.120**	**0.0521**	**0.306*****	**0.200*****
	(0.000723)	(0.00574)	(0.00770)	(0.00527)	(0.0953)	(0.150)	(0.000642)	(0.00830)
N	366890	366890	366890	6357	6357	6357	369840	369840
R-squared	0.000403	0.153	0.218	0.000696	0.113	0.224	0.0000321	0.0790

Standard errors in parentheses

$^{+}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

4.3 The Number of Citations

The Pooled OLS regressions estimate science park inventors to receive more citations after five years (see Table 4). On average, inventors are expected to receive 3.583 more citations per year. This number drops when controlling for domain and application year and even more when additionally controlling for firms, but remains significantly positive. In the fixed effects models, we notice that the initial science park effects seem to be overestimations as the coefficients drop the more control variables are added. Models 8 to 10 show that after controlling for the variation caused by inventors and firms, inventors are not expected to receive more citations for their patents when they locate on a science park.

Table 4: The estimates for impact.

CITATIONS								
	Pooled OLS			Inventor fixed effects			Inventor-firm fixed effects	
	(1)	(2)	(4)	(5)	(6)	(8)	(9)	(10)
Science park	**3.583*****	**2.965*****	**1.078*****	**2.993*****	**1.419****	**0.152**	**-0.328**	**-0.0959**
	(0.121)	(0.112)	(0.134)	(0.542)	(0.479)	(0.443)	(0.576)	(0.543)
Family size			**0.319*****			**0.580*****		
			(0.00525)			(0.115)		
Team size			**0.382*****			**0.582*****		
			(0.00823)			(0.134)		
Nr of applicants			**-0.0458*****			**-0.112**		
			(0.0112)			(0.150)		
Nr of NTO combinations			**0.00630*****			**0.00231**		
			(0.000199)			(0.00235)		
Nr of NR combinations			**-0.00182+**			**0.0233**		
			(0.00109)			(0.0155)		
Nr of NSO combinations			**0.00621*****			**0.0278+**		
			(0.00140)			(0.0162)		
New IPC			**0.648***			**-1.916**		
			(0.292)			(1.997)		
Domain fixed effects	NO	YES	YES	NO	YES	YES	NO	YES
Year fixed effects	NO	YES	YES	NO	YES	YES	NO	YES

Firm fixed effects	NO	NO	YES	NO	NO	YES	NO	NO
Inventor fixed effects	NO	NO	NO	YES	YES	YES	NO	NO
Inventor-firm fixed effects	NO	NO	NO	NO	NO	NO	YES	YES
Constant	**5.610*****	**2.747*****	**1.834*****	**8.840*****	**7.364*****	**9.827****	**5.785*****	**5.082*****
	(0.0144)	(0.0622)	(0.177)	(0.263)	(1.704)	(3.671)	(0.0230)	(0.105)
N	366890	366890	366890	6357	6357	6357	369840	369840
R-squared	0.00619	0.0935	0.211	0.0118	0.131	0.289	0.00000617	0.0515

Standard errors in parentheses

$^{+}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

4.4 Breakthrough

A very similar picture is shown in Table 5 for breakthrough (2 standard deviations). Again, the pooled OLS estimations seem to overestimate the science park effect as adding any control variable considerably decreases the science park variable. All pooled OLS models expect on-park inventors to have a significantly higher chance of high impact. This significance reduces however when controlling jointly for domain, application year and inventor (i.e., model 6). It fully disappears when also adding firms (i.e., model 8). The inventor-firm fixed effects framework never estimates a significant science park effect for breakthrough whatsoever.

Table 5: The estimates for the probability of high impact.

	BREAKTHROUGH							
	Pooled OLS			Inventor fixed effects			Inventor-firm fixed effects	
	(1)	(2)	(4)	(5)	(6)	(8)	(9)	(10)
Science park	**0.0507*****	**0.0460*****	**0.0125*****	**0.0355*****	**0.0233***	**0.00757**	**0.00390**	**0.00688**
	(0.00251)	(0.00247)	(0.00301)	(0.00929)	(0.00932)	(0.0104)	(0.0135)	(0.0134)
Family size			**0.00953*****			**0.0145*****		
			(0.000148)			(0.00234)		
Team size			**0.00792*****			**0.0111*****		
			(0.000205)			(0.00285)		
Nr of applicants			**0.000239**			**0.00120**		
			(0.000313)			(0.00388)		
Nr of NTO combinations			**0.000188*****			**0.000102+**		
			(0.00000703)			(0.0000611)		
Nr of NR combinations			**0.000162*****			**0.000233**		
			(0.0000401)			(0.000290)		
Nr of NSO combinations			**0.000242*****			**0.000197**		
			(0.0000418)			(0.000337)		
New IPC			**0.0145+**			**-0.0261**		
			(0.00760)			(0.0460)		
Domain fixed effects	NO	YES	YES	NO	YES	YES	NO	YES

Year fixed effects	NO	YES	YES	NO	YES	YES	NO	YES
Firm fixed effects	NO	NO	YES	NO	NO	YES	NO	NO
Inventor fixed effects	NO	NO	NO	YES	YES	YES	NO	NO
Inventor-firm fixed effects	NO	NO	NO	NO	NO	NO	YES	YES
Constant	**0.0670*****	**-0.00112**	**-0.0278*****	**0.115*****	**0.0734**	**0.158**	**0.0689*****	**0.0427*****
	(0.000391)	(0.00290)	(0.00441)	(0.00450)	(0.102)	(0.105)	(0.000539)	(0.00443)
N	366890	366890	366890	6357	6357	6357	369840	369840
R-squared	0.00177	0.0370	0.138	0.00408	0.0658	0.216	0.000000940	0.0222

Standard errors in parentheses

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

5 Discussion

5.1 Interpretation of the Results

In general, it can be observed that science parks seem to have a different relation with indicators of impact as compared with novelty. Across the three models, the overall patterns seem rather negative for novelty while positive for impact. When controlling for a bare minimum of variables (i.e., application year and domain), on-park patents have a higher impact and a higher probability of exceptional impact (remark the significantly positive science park estimates of the 'naïve' pooled OLS model in Tables 4 and 5). This effect however diminishes plainly when controlling for firms fixed effects. It also decreases when controlling for inventors fixed effects, and even more when controlling for both firms and inventors[13]. In this last case, no single significantly positive effect is reported (see both fixed effects models in Tables 4 and 5). In conclusion, this means that the initial relation between science parks and both citations and breakthrough seems to be explained instead by the average impact of the inventors and firms. More specifically, when only using the variation *within* an inventors' output given the average output and controlling for firms (i.e., model 8), no significant science park effect regarding citations or breakthrough is uncovered.

This result proofs that including these fixed effects influences the results and they should thus be properly accounted for. For example, after reading the summary statistics, one would expect science parks to be positively related to citations and breakthrough (recall Table 1). After controlling for inventors and firms fixed effects however, it becomes clear that this relation is mainly due to the individual inventors and firms, not to science parks.

Zooming in on the model with the highest number of controlling conditions, only patent count (positively) and novelty (negatively) show significant results. This result seems to be of most interest, as evidence for the cross-fertilization capacity of science parks and the mechanisms regarding recombination and spillovers can only be accredited if it is established when controlling for the underlying characteristics of inventors and firms. This is not the case here. Remark that the recombination and spillover mechanisms would primarily predict a science park effect for novelty as this measure is most associated with these mechanisms. The results, however, are undoubtedly negative for the novelty measure. Because it is highly opposed to past research, this is an important result!

This negative relation between science parks and novelty is noteworthy. Remark that a drop in on-park novelty can be caused by both a drop in novelty when moving to a park, or a rise when moving away from a park. A rise in the novelty of an inventor's patents after moving away from a park could still conceal a (partial) science park effect (also see Section 5.4.2.3). Therefore, the models for novelty were executed once more, now controlling for inventors that previously moved away from a science park[14]. When controlling for this move away from a park, the

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[13] Remark that this drop in significance is mainly due to a drop in the actual coefficients and not by a consistent and sizable rise of the standard errors.

[14] More specifically, a dummy variable was created equalling 1 for each off-park patent of an inventor that was preceded by an on-park patent.

relation between science parks and novelty stays significantly negative. This means that off-park movers do not considerably influence the relation between science parks and novelty.

Remember from Section 2.2.1 that science parks could assist in selecting promising solutions based primarily on the recombination and spillover mechanisms. If this reasoning is valid, we should find a higher probability of (high) impact, *given* novelty. In other words, science parks should provide 'better' impact. The previously defined fixed effects frameworks have therefore been estimated again, now conditioning on novelty and only estimating impact measures. Again, no significant results have come to light (see Table 6). Both the coefficients and the standard errors remain very close to the ones obtained in Sections 4.3 and 4.4, i.e., without controlling for novelty.

Table 6: The results for (the probability of high) impact do not change considerably when additionally controlling for novelty.

(HIGH) IMPACT GIVEN NOVELTY				
	Citations		Breakthrough	
	Inventor fixed effects	Inventor-firm fixed effects	Inventor fixed effects	Inventor-firm fixed effects
Science park	**0.157**	**-0.0140**	**0.00906**	**0.00979**
	(0.441)	(0.522)	(0.0104)	(0.0129)

Standard errors in parentheses

$^{+}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Moreover, it is striking that the science park coefficient for novelty drops significantly when adding inventors fixed effects (compared to the pooled OLS). Hence, the fact that inventors with certain characteristics select themselves (or are selected) to work on a science park seems to have an important influence on the results regarding novelty.

In conclusion, the main analyses are executed in the intensive margin, i.e., relative to the quantity of innovation. This analysis was repeated in the extensive margin, i.e., summing the variables instead of looking relatively. In the latter case, coefficients for novelty, citations and breakthrough mostly stay negative or indifferent from zero. Only in the inventor-firm fixed effects model, the coefficients become positive. This difference between total and average novelty can be explained by one of the main findings of this thesis: on science parks, more patents are filed and there is more novelty/impact altogether, but the average novelty/impact is not higher compared to off-park patents.

5.2 Theoretical Implications

Independently of the type of analysis carried out (unit of analysis, measure of performance or specific econometric tool used), evidence is mixed with respect to the park's effectiveness (Squicciarini, 2007). Hence, the results of this thesis support a certain part of the literature, while diverging from other papers.

One of the main findings of this thesis is that on-park inventors patent more. This is in line with the body of literature that finds that parks enhance their tenants' likelihood to patent (Squicciarini, 2008, 2009; Jongwanich, Kohpaiboon & Yang, 2014) and, to a lesser extent, facilitate innovation and new product development (Hansson, Husted & Vestergaard, 2005; Amirahmadi & Saff, 1993; Phan, Siegel & Wright, 2005; Westhead, 1997; Westhead & Cowling, 1995; Squicciarini, 2008, 2009). Accordingly, the evidence in this thesis disagrees with those articles that do not find statistically significant differences between on- and off-park firms with regard to the number of patents (Lindelöf & Löfsten, 2002, 2003; Colombo & Delmastro, 2002; Siegel, Westhead & Wright, 2003a; Westhead & Storey, 1994).

One of the reasons of the increased number of filed patents in science parks may be the clustering of a skilled labour force. When on-park inventors are immersed in an environment that is generally intended to raise inventiveness and are surrounded by creative individuals, they may be more inclined to take the step to actually file a patent. Moreover, the increased scale of innovation in science parks could stem from the available physical capital and investments in science parks. Both factors have the potential to broaden the opportunities open to explore, as it is not unthinkable that improper infrastructure and/or lack of investment may turn out to be a barrier in many firms when exploring interesting avenues.

The other main finding of this thesis is that science parks are negatively related to the probability of novelty of inventors' patents. This contrasts for example with Verhoeven, Rabijns & Bakker (2017) who find that firms' science park affiliates are more likely to create highly novel inventions compared to the same firm's off-park affiliates.

It is difficult to argue why science parks are related negatively with their patents' novelty while the expected relation would rather be positive. However, novelty can be expected to arise, amongst others, from a tight relationship with other tenants and/or with the neighboring research institute. This relationship could indeed enable an inventor to tap into a wider variety of technological and scientific sources, and to recombine elements that he/she would not be able to put together without this interaction. Nonetheless, the assumption that science park firms are well informed about the research in the higher education institution does not seem valid: the degree of interaction between universities and firms has been overestimated by policymakers (e.g. see Joseph, 1989; Van Dierdonck, Debackere & Rappa, 1991). Furthermore, a lot of evidence exists stating that also the synergies and R&D interaction between on-park companies are limited (e.g. see Bakouros, Mardas & Varsakelis, 2002; Joseph, 1989; MacDonald, 1987; Currie, 1985; Van Dierdonck, Debackere & Rappa, 1991).

In conclusion, the adopted innovation measures have allowed estimating that although the quantity of on-park patents is higher, the impact and novelty is not. Skeptics can eagerly use this to argue that science parks do not prove to be the panacea for development that many policymakers and developers made or still make it out to be (Amirahmadi & Saff, 1993; Hansson, Husted & Vestergaard, 2005; Macdonald, 1987; Colombo & Delmastro, 2002). However, as will be discussed in full detail in Section 5.4.2, considerable heterogeneity exists between science parks. Therefore, another explanation of these results may be that the practical realization of science parks (i.e., an active managed, strong university-industry and interfirm links…) is flawed, instead of the concept itself.

5.3 Limitations

A number of limitations regarding this thesis must be mentioned. First, the econometric designs do not aim to uncover causal relationships[15]. One possible alternative explanation that remains open is that science parks, due to their prestige, attract more radical projects, which have a higher chance to result in the filing of a patent whatsoever. Hence, it cannot be concluded that science parks help inventors to be more prolific. Second, although a first step has been taken towards more general applicability of the results, only science parks in the USA have been considered. The multitude of definitions in the literature already revealed that science parks do not constitute a single, well-aligned phenomenon. Therefore, the results may not be applicable outside the USA. Third, the database used in this thesis considers patents up to 2010. It is not unthinkable that technological changes have greatly facilitated interaction between on-park parties in the meanwhile. Fourth, the use of patent data may result in the exclusion of potentially important, yet unpatented inventions. Patents however disclose valuable information and seem to be an uncontested instrument to study innovation.

5.4 Further Research

5.4.1 Do The Mechanisms Apply Generally?

As described in Section 5.2, the increased scale of innovation in science parks can have origins in different mechanisms. More research is however needed to study whether these mechanisms are generally applicable. Indeed, the increased number of patents could also be due to preselection of the more inventive employees in science parks (as was also raised in Section 5.1). More specifically, it is possible that firms with multiple premises redirect their more promising and/or radical projects to their science park affiliates, hence reallocating their inventors most apt to patent to science parks. Furthermore, it still forms an open question whether significant differences in inventive activity exist among off- and on-park firms due to physical capital and investment differences.

5.4.2 Further Distinction Between Science Parks

The results seem to point to the conviction that the influence of science parks on their patents' novelty and (high) impact is rather small. One possible conclusion would therefore be that science parks are not worth to be investigated further. A justified objection to this reasoning would however remain: why do firms on well-known parks such as the Stanford Research Park (better known as Silicon Valley) or the Research Triangle Park in North Carolina seem to outpace others (as also confirmed by our data; see further this section)? It has been mentioned before in the theoretical background that no two science parks are alike. Consequently, it may be that underlying differences between parks govern the ultimate inventive performance of their tenants. Examples of these underlying differences are described below, mainly based on elements that have been highlighted in the literature as not been taken into account in past research or simplified too much.

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[15] The ability of fixed effects models to adjust for unobserved time-invariant confounders comes at the expense of dynamic causal relationships, which it thus fails to account for (Bjerk, 2009; Imai & Kim).

5.4.2.1 Managed vs. non-managed parks

Only occasionally, a distinction is made between managed and non-managed parks (Siegel, Westhead & Wright, 2003a; Siegel, Westhead & Wright, 2003b; Westhead, 1997; Lindelöf & Löfsten, 2003; Westhead & Batstone, 1998; Westhead & Storey, 1995; Phillips & Yeung, 2003). Although science parks are advantageous in promoting university-industry collaboration from a physical perspective, some organizational effort and commitment of time and resources by all concerned is required to get them connected effectively (Fukugawa, 2006; Saxenian, 1994). No single university will provide the full range of skills required by the park's new technology-based firms (Lindelöf & Löfsten, 2003) and the management of a science park should compensate for this (Mian, Lamine & Fayolle 2016). Moreover, the deliberate process of aligning company business models with an ecosystem's business model is of critical importance to creating a sustained competitive advantage. Ecosystem managers have to deliberately facilitate exit routes for companies that no longer fit the ecosystem in order to enhance and reinforce its business model (van der Borgh, Cloodt & Romme, 2012). Westhead & Batstone (1998) found their respondents to be aware of the potential for property 'mismatch' and would appreciate that a science park manager could deal with this potential hurdle to business development.

5.4.2.2 The connection strength between the research facility and tenants

Additionally, the assumption that science park firms are well informed about the research in the higher education institution does not seem valid. Therefore, the role of some kind of liaison officer needs to be strengthened (Westhead & Storey, 1995). This could be a science park manager, but Malairaja & Zawdie (2008) even suggest that university staff should take the initiative and explain the type of research and facilities available to tenant firms. As a consequence, it would be interesting to examine the relation between the productivity differential among science parks and the "closeness" of the relationship between science park firms and the local university. For this, a direct measure of contact between these companies and academics and graduate students is needed (Siegel, Westhead & Wright, 2003b; Link & Scott, 2006; Phillimore, 1999; Vedovello, 1997; Castells & Hall, 1994).

5.4.2.3 The period after leaving the science park

As raised before, it is often the case that only one point in time is considered instead of a longitudinal dataset. In order to fully take into account the positive effect of location on a science park, it seems that firms should be compared only after the 'catalytic incubator environment' needed to transform basic science into commercially viable innovations (Westhead, 1997) has had the chance to finish its process, i.e. after firms have left the science park. The findings of Ferguson (2004) show that firms experiencing higher growth moved off of a science park prior to exhibiting high-growth performance. At a certain moment in time, high technology firms are ready to move beyond the science park (McAdam & McAdam, 2008). This suggests that we need to look beyond firms' on-park location to study the effects of a science park location (Ferguson, 2004).

5.4.2.4 The location of the science park

Possibly, important differences exist between urban and rural science parks (Ratinho & Henriques, 2010). Dense urban areas contain a complex synergy of factors that smaller, more remote places cannot attain when influencing the innovativeness and competitiveness of places (Malecki, 1991; Castells & Hall, 1994). This suggests that in most cases, existing urban agglomerations are more efficient and cost-effective locations for the establishment of science parks than remote and peripheral areas (Amirahmadi & Saff, 1993).

5.4.2.5 Other characteristics

Furthermore, it is seldom taken into account that science parks can differ in terms of other characteristics. More specifically, no distinction is made in the literature between different levels of expertise of the park or the adjacent university's faculty (Link & Scott, 2006), different levels of integration of the tenant firms (Philips & Yeung, 2003; van der Borgh, Cloodt & Romme, 2012), different levels of motivation of the firms (Massey, Quintas & Wield, 1992; Storey & Tether, 1998) or types of institutional restrictions and politics (Jongwanich, Kohpaiboon & Yang, 2014; Castells & Hall, 1994). Neither, a distinction is made between types of entrepreneur that locate on the park (Phan, Siegel & Wright, 2005; Siegel, Westhead & Wright, 2003a; Monck, 1988). The attitude and motivation of the founders and managers are key factors in the ability to raise funds and achieve high growth and profitability. Those firms with dynamic leadership seeking strong growth are much more likely to be successful. This contrasts with founders who are less aggressive and may have development opportunities open (including the potential value offered by a science park) but prefer a more relaxed lifestyle (Monck, 1988).

The positive effect of a science park on its tenants could be enhanced when the park scores better on these mechanisms or more precisely, when enterprises select the science park to match their strengths and compensate for their weaknesses (Lai & Shyu, 2005). Treating all science parks equally may result in diluting the effect of the well-managed parks, as might have been the case in this thesis. As mentioned explicitly and repeatedly in the literature and confirmed in this work, taking (some of) these mechanisms into account has the potential to enhance the quality of further research around science parks.

More specifically, the following categorization may assist in detecting which of the aforementioned mechanisms ultimately distinguish between science parks, or which additional mechanisms exist. The categorization is based on a two-sample t test which tests for each science park individually whether the patents generated on the park are significantly more novel, cited or breakthrough than all off-park patents in the dataset. Parks are allocated to category 1 if they turn out to be significantly better (at 10% significance) at at least one of the innovation measures novelty, citations or breakthrough. In category 2, the on-park patents thus do not significantly perform better than off-park patents. In Tables 7 and 8, resp. the best and worst performing science parks (given the data used in this work) are shown, along with their mean value regarding novelty, citations and breakthrough. In the bottom row, the results for the off-park patents are reported. The significance in Tables 7 and 8 indicates whether the novelty/citations/breakthrough of the patents on the science park is significantly *higher* than for the off-park patents.

Table 7: A list of the best performing science parks in the US (category 1), the ranking of their adjacent university and the mean value regarding novelty, citations and breakthrough of their patents. The average university of category 1 science parks is ranked 64th.

Science Park	Ranking	Mean novelty	Mean citations	Mean breakthrough
Stanford Research Park	5	**0.2329506** (0.0042242)	**11.35167***** (0.166834)	**0.1242137***** (0.0032959)
Research Triangle Park North Carolina	9 30	**0.3036566** (0.0129699)	**10.66932***** (0.4518232)	**0.1669316***** (0.0105182)

	81			
Science & Technology Park at Johns Hopkins	11	**1.0000*** (0.0000)	**0.0000** (0.0000)	**0.0000** (0.0000)
California Institute for Quantitative Biosciences	21	**1.0000*** (0.0000)	**0 .0000** (0.0000)	**0.0000** (0.0000)
NASA Research Park	25	**0.1702128** (0.0100121)	**7.385106***** (0.5037926)	**0.0907801***** (0.0076538)
University of Virginia Research Park	25	**0.5714286*** (0.1372527)	**1.928571** (0.4253542)	**0.0000** (0.0000)
BioSquare at Boston University	37	**0.320995**** (0.008035)	**10.5342***** (0.2733413)	**0.2007699***** (0.0068942)
Rensselaer Technology Park	42	**0.3064516** (0.0590275)	**14.27419***** (2.913904)	**0.1935484***** (0.0505847)
University Research Park Wisconsin-Madison	46	**0.1942446** (0.0336772)	**8.928058***** (0.8937182)	**0.0647482** (0.0209478)
Purdue Research Park of West Lafayette	56	**0.362069**$^{+}$ (0.0448161)	**14.78448***** (2.315543)	**0.25***** (0.0403786)
Virginia Tech Corporate Research Centre	69	**0.3425926** (0.045879)	**5.111111** (0.6196189)	**0.1481481***** (0.034343)
BioVentures Center (University of Iowa)	78	**0.5185185**** (0.0979908)	**3.592593** (0.5901839)	**0.3333333***** (0.09245)
Oakdale Research Park	78	**0.5833333*** (0.1486471)	**3.583333** (0.7533595)	**0.25**** (0.1305582)
Delaware Technology Park	81	**0.2419355** (0.0548325)	**7.532258**$^{+}$ (0.7885074)	**0.0000** (0.0000)
University Corporate Research Park	81	**0.377894***** (0.0132553)	**4.114264** (0.1505848)	**0.0612397** (0.0065549)
University of Colorado Research Park	90	**0.1292135** (0.0252129)	**6.983146*** (0.614499)	**0.0786517** (0.0202339)
University of Utah Research Park	110	**0.3725869***** (0.021264)	**6.048263** (0.3791865)	**0.1023166***** (0.0133287)
UMBC Research and Technology Center	159	**0.6666667**** (0.1259882)	**6.8** (2.356753)	**0.2*** (0.1069045)
Cummings Research Park	216	**0.1850716** (0.0124246)	**8.865031***** (0.3531386)	**0.093047***** (0.0092939)
High Technology Development Corporation	/	**0.3076923** (0.1332347)	**14.30769***** (5.471821)	**0.0000** (0.0000)
Mililani Technology Park	/	**0.2** (0.2)	**14.4*** (4.445222)	**0.0000** (0.0000)
Sandia Science and Technology Park	/	**0.4705882*** (0.0868881)	**16.44118***** (5.950508)	**0.1470588*** (0.0616521)
Off-park patents		**0.2995886** (0.0006062)	**5.749043** (0.0118453)	**0.0665776** (0.0003299)

Standard errors in parentheses

$^{+} p < 0.10$, $^{*} p < 0.05$, $^{**} p < 0.01$, $^{***} p < 0.001$

Table 8: A list of the worst performing science parks in the US (category 2), the ranking of their adjacent university and the mean value regarding novelty, citations and breakthrough of their patents. The average university of category 2 science parks is ranked 123th.

Science Park	Ranking	Novelty	Citations	Breakthrough
Johns Hopkins University Montgomery County Campus	11	**0.0000** (0.0000)	**1.0000** (0.2108185)	**0.0000** (0.0000)

The Illinois Science & Technology Park	11	**0.0000** (0.0000)	**1.666667** (1.054093)	**0.0000** (0.0000)
Progress Corporate Park	42	**0.5** (0.2236068)	**0.0000** (0.0000)	**0.0000** (0.0000)
University of Illinois Urbana Champaign Research Park	52	**0.3750** (0.086951)	**2.46875** (0.5571825)	**0.0625** (0.0434755)
Riverfront Research Park	103	**0.3333333** (0.1259882)	**3.066667** (0.462567)	**0.0000** (0.0000)
Arizona State University Research Park	115	**0.2352941** (0.0738407)	**0.6176471** (0.2025449)	**0.0000** (0.0000)
Iowa State University Research Park	115	**0.2857143** (0.125294)	**0.2857143** (0.125294)	**0.0000** (0.0000)
Miami Valley Research Park	124 265	**0.1847826** (0.0202598)	**3.105978** (0.1873579)	**0.0326087** (0.0092712)
University of Arizona Science and Technology Park	124	**0.2710843** (0.024433)	**4.819277** (0.2904584)	**0.0301205** (0.0093945)
Central Florida Research Park	171	**0.3191489** (0.0687296)	**3.574468** (0.3783511)	**0.0000** (0.0000)
Innovation Village Research Park	202	**0.3333333** (0.3333333)	**4.333333** (1.666667)	**0.0000** (0.0000)
Florida Atlantic University Research Park	265	**0.5** (0.5)	**1.5** (1.5)	**0.0000** (0.0000)
Mound Advanced Technology Center	/	**0.0357143** (0.0357143)	**4.75** (0.9492757)	**0.0000** (0.0000)
Off-park patents		**0.2995886** (0.0006062)	**5.749043** (0.0118453)	**0.0665776** (0.0003299)

Standard errors in parentheses

$^{+} p < 0.10$, $^{*} p < 0.05$, $^{**} p < 0.01$, $^{***} p < 0.001$

Remark that not all science parks are included in Tables 7 and 8. The reason is that not all science parks in the initial dataset provided enough patents to perform a t test. As mentioned in Section 3.1, a full list of US science parks can be found in Appendix 1.

A comparative analysis of (a subset of) these parks could for instance focus on whether the mechanisms as described earlier are more predominantly present in the parks in category 1 and/or absent in category 2. For example, the extent to which a university is credited by firms with making major contributions to their innovations tends to be related directly to the quality of the university's faculty in the relevant department, the size of its R&D expenditures in relevant fields, and to the proportion of the industry's member located nearby (Mansfield, 1995). Note that in the second column of Tables 7 and 8 the ranking ("National University Rankings" 2018) of the affiliated university of the science park is displayed[16]. This ranking gives a first indication that underlying moderators (in this case the quality of the adjacent research facility) may indeed drive the heterogeneity between individual science parks. The mean ranking of category 1 universities amounts to 64 while category 2 science parks' universities are ranked 123th on average.

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[16] Some parks are affiliated with multiple universities. In this case, multiple rankings are shown. Additionally, some parks' research facilities are not officially entitled as university and are hence not included in the source's ranking. In conclusion, remark that it is not unusual that universities are given the same ranking in case of a tie.

5.4.3 Causal Evidence?

Science parks have been researched extensively over the past decades, but to the best of my knowledge, very few have focused their attention on the causal impact of these parks on innovation. The decision to locate on a park, however, albeit for firms, universities or individuals, is likely to be affected by unobservable characteristics that also correlate with inventive output (such as firm strategy, ambition, researcher's ability…). As long as these unobservable characteristics are time-invariant, they have been captured by the fixed effects frameworks in this thesis. However, it is not implausible that also time-variant unobservable characteristics drive the selection in science parks. Therefore, our models may not estimate causal effects.

To address these endogeneity concerns that drive selection into location on a science park, an instrumental variable approach can be adopted. The most evident instrument would be the geographic distance to the nearest science park. Hence, plausibly exogenous variation in the costs to locate on a science park could be exploited.

6 Conclusion

The purpose of this thesis is to examine the relation between locating on a science park and inventive output, more specifically the number of filed patents, the novelty of these patents, the citations they receive and the probability of being a breakthrough patent. The econometric design consists of a pooled OLS regression complemented with fixed effects frameworks for inventors and inventors and firms jointly.

In general, science parks seem to have a different relation with indicators of impact (i.e., citations and breakthrough) compared with novelty. The apparent relation with impact however appears to be explained by the individual inventors and firms. We provide evidence that the number of patents is positively and novelty is negatively related to locating on a science park when controlling for time-invariant unobservable traits on the level of inventors and firms. Moreover, the fact that inventors with certain characteristics select themselves (or are selected) to work on a science park seems to have an important influence on the results regarding novelty. This statement is deducted from the observation that the science park coefficient for novelty drops significantly when adding inventors fixed effects (i.e., compared to the pooled OLS). In conclusion, science parks do not provide a higher probability of (high) impact given novelty.

One possible interpretation of the higher prolificacy of inventors on a park is that the social interactions with other highly skilled inventors on a science park may prompt inventors to take the step to filing a patent more easily. This behavior could in addition be stimulated by the available infrastructure and ease of investments within the science park environment. The synergy between these factors may have generated the significant relationship between science parks and the scale of innovation.

In addition, science parks are negatively related with the novelty of their patents. Although this may initially come as a surprise, many researchers already noted that the degree of R&D interaction both among tenants and between tenants and the research facility is often overestimated.

The adopted innovation measures allow us to conclude that although the quantity of on-park patents is higher, the impact and novelty is not. Additionally, the results proof that including fixed effects for inventors and firms influences the results. These should thus be properly accounted for. For example, after reading the summary statistics, one would expect science parks to be positively related to citations and breakthrough (recall Table 1). After controlling for inventors and firms fixed effects however, it becomes clear that this relation is mainly due to the individual inventors and firms, not to science parks.

More research is however needed to study whether the aforementioned mechanisms are generally applicable. Additionally, a further distinction between science parks may reveal underlying differences that govern the ultimate inventive performance of science park tenants and their inventors. The heterogeneity between science parks regarding the innovation measures seems to parallel with their universities' ranking. This relation gives a first indication that underlying moderators may indeed drive important differences between parks, which opens up possibilities for further exploration. In conclusion, little research has focused on the causal impact of science parks on innovation. Adopting an instrumental variable approach can fill this gap.

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8 Appendices

Appendix 1: Dataset Science Parks

An exhaustive list of science parks in the United States could not be found on the Internet. Therefore, various sources[17] were combined to create a list as complete as possible. This resulted in 135 parks/centers (see Table 9). However, not all of these come close enough to the delineation of a science park defined in Section 2.1.2 to be included in the dataset. Therefore, the website of each park was examined to verify whether the park (i) collaborates with a local university; (ii) fosters the formation and growth of innovative new companies; and (iii) is not restricted to incubation (i.e., does not only house start-ups). Unfortunately, information on park management services was not commonly available. Therefore, this could not be used as a criterion. Finally, note that every park in the original list fulfilled the condition to be property-based.

The large majority (around 80%) of parks and centers meet the conditions to be regarded as a science park. In general, it is observed that research parks, innovation parks and technology parks/centres exhibit the aforementioned characteristics, which is in line with Sections 2.1.2 and 2.1.3. For those that do not, the reason is given in the last column and explained more in detail in the legend below. Finally, it should be remarked that around 40 parks meet the definition yet are not included because insufficient information regarding their tenants could be found.

Legend for column "Reason Not Included":

- Broader concept: more focused on urban planning (schools, houses, shops, nature parks…)
- Business park/center: provides premises but little else
- Incubator: the park is (practically) entirely focused on launching new businesses and does not or merely house grown companies
- No business tenants: no companies located on the park
- No information: insufficient information could be found regarding the concept of the park and/or business tenants
- Planning stage: insufficient information could be found regarding the concept of the park and/or business tenants as it is still in the planning stage
- Research campus/centre/foundation/institute: strong focus on (applied) research without (direct) link with business tenants regarding the commercialization of this research

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[17] http://www.unesco.org/new/en/natural-sciences/science-technology/university-industry-partnerships/science-parks-around-the-world/science-parks-in-north-america/; https://en.wikipedia.org/wiki/List_of_research_parks; http://www.iasp.ws/Our-members/Directory?sortfield65=&direction65=asc&&&doshow65=1&filtercontrol651=United%20States&filtercontrol652=0&TechSectors=0&searchword65=&q=&filtercontrolevents_active=

Table 9: List of Science Parks in the US.

Science Park	Meets Definition?	To Be Included?	Reason Not Included
Innovation Park at Penn State, Pennsylvania	Yes	Yes	
Innovation Park Tallahassee, Florida	Yes	Yes	
LSU Innovation Park (Baton Rouge, Louisiana)	Yes	Yes	
Arizona State University Research Park, Arizona	Yes	Yes	
Arrowhead Business and Research Park, New Mexico State University	Yes	Yes	
Biomedical Research Park, Louisiana	Yes	Yes	
Carolina Research Park, Columbia, SC.	Yes	Yes	
Central Florida Research Park (Orlando)	Yes	Yes	
Cummings Research Park, Alabama	Yes	Yes	
Florida Atlantic University Research Park, Florida	Yes	Yes	
Innovation Village Research Park at Cal Poly Pomona	Yes	Yes	
Iowa State University Research Park, Iowa	Yes	Yes	
Massachusetts Biotechnology Research Park	Yes	Yes	
Maui Research & Technology Park, Hawaii	Yes	Yes	
Miami Valley Research Park, Kettering - in the Greater Dayton area	Yes	Yes	
Milwaukee County Research Park, Wisconsin	Yes	Yes	
Missouri Research Park, Missouri	Yes	Yes	
NASA Research Park, California	Yes	Yes	
Oakdale Research Park, University of Iowa	Yes	Yes	
Piedmont Triad Research Park, North Carolina	Yes	Yes	
Purdue Research Park, Indiana	Yes	Yes	
Research Park at University of Illinois Urbana Champaign	Yes	Yes	
Research Triangle Park, North Carolina	Yes	Yes	
Riverfront Research Park, University of Oregon	Yes	Yes	
SDSU Innovation Campus Research Science Technology Park	Yes	Yes	
Stanford Research Park, California	Yes	Yes	
Thad Cochran Research, Technology and Economic Development Park	Yes	Yes	
University Corporate Research Park, Michigan	Yes	Yes	
University of Colorado Research Park, Colorado	Yes	Yes	
University of Idaho Research Park, Idaho	Yes	Yes	
University of Maryland BioPark, Baltimore, Maryland	Yes	Yes	
University of New Orleans Research and Technology Park, Louisiana	Yes	Yes	
University of Utah Research Park, Utah	Yes	Yes	
University of Virginia Research Park, Virginia	Yes	Yes	
University Research Park Wisconsin-Madison	Yes	Yes	
Virginia Bio Technology Research Park, Virginia	Yes	Yes	

WMU Technology & Research Park, Michigan	Yes	Yes	
Sandia Science & Technology Park, New Mexico	Yes	Yes	
Science & Technology Park at Johns Hopkins (Baltimore, MD)	Yes	Yes	
The Illinois Science & Technology Park (Skokie, IL)	Yes	Yes	
University of Arizona Science and Technology Park, Arizona	Yes	Yes	
Mound Advanced Technology Center Miamisburg, OH	Yes	Yes	
UMBC Technology Centre, Maryland (bwtech)	Yes	Yes	
Virginia Tech Corporate Research Centre, Virginia	Yes	Yes	
California Polytechnic State University Technology Park San Luis Obipso	Yes	Yes	
Delaware Technology Park, Delaware	Yes	Yes	
Mililani Technology Park, Hawaii	Yes	Yes	
Rensselaer Technology Park, New York	Yes	Yes	
Stout Technology Park, Wisconsin	Yes	Yes	
University of Minnesota Valley Technology Park, Minnesota	Yes	Yes	
University Technology Park at IIT, Illinois	Yes	Yes	
BioSquare at Boston University	Yes	Yes	
BioVentures Center (University of Iowa)	Yes	Yes	
California Institute for Quantitative Biosciences	Yes	Yes	
High Technology Development Corporation (HTDC), Hawaii	Yes	Yes	
Johns Hopkins University Montgomery County Campus (Rockville, MD)	Yes	Yes	
LabCentral (Cambridge)	Yes	Yes	
Progress Corporate Park (Gainesville)	Yes	Yes	
Science & Technology Campus Corporation, Columbus, Ohio	Yes	Yes	
Wake Forest Innovation Quarter (downtown Winston-Salem)	Yes	Yes	
University of Nebraska, Nebraska Innovation Campus, Nebraska	Yes	Yes	
Baylor Research and Innovation Collaborative (Waco)	Yes	No	No information
Cape Charles Sustainable Technology Park, Virginia	Yes	No	No information
Clemson Research Park, South Carolina	Yes	No	No information
CURI North Charleston Research Park, South Carolina	Yes	No	No information
EverGreen Technology Park, Pennsylvania	Yes	No	No information
First Union Science Park, Colorado	Yes	No	No information
Florida Gulf Coast University Innovation Hub (Fort Myers)	Yes	No	No information
Florida Network of Research, Science and Technology Parks	Yes	No	No information
Fontaine Research Park, Virginia	Yes	No	No information
Francis Marion Research Park, South Carolina	Yes	No	No information

Gateway University Research Park (Greensboro, North Carolina)	Yes	No	No information
Indiana University Research Park, Indiana	Yes	No	No information
Innovation Technology Park (Prince William County)	Yes	No	No information
Los Alamos Research Park, New Mexico	Yes	No	No information
Medical City at Lake Nona, (Orlando)	Yes	No	No information
Michigan Centre for High Technology, Michigan	Yes	No	No information
Milwaukee Technopole, Wisconsin	Yes	No	No information
Nebraska Technology Park - Lincoln, NE	Yes	No	No information
Pittsburgh Technology Center, Pittsburgh	Yes	No	No information
Riverside Regional Technology Park	Yes	No	No information
Science Park at Yale (New Haven, CT)	Yes	No	No information
Sorrento West Life Science Park	Yes	No	No information
Sunset Science Park, Oregon	Yes	No	No information
TechTown at Wayne State University - Detroit, MI	Yes	No	No information
Texas A&M University Research Park, Texas	Yes	No	No information
Texas Research Park Foundation, Texas	Yes	No	No information
Tri-Cities Science and Technology Park, Washington	Yes	No	No information
Tuskegee University Research Park (Tuskegee)	Yes	No	No information
UAB Research Park at Oxmoor	Yes	No	No information
UCI Research Park	Yes	No	No information
University Heights Science Park, Newark, New Jersey	Yes	No	No information
University of Houston Energy Research Park (Houston)	Yes	No	No information
University Research Park (University City - Charlotte)	Yes	No	No information
Wallops Research Park (Wallops Island)	Yes	No	No information
West Virginia Regional Technology Park(South Charleston)	Yes	No	No information
University Park SIUE, Inc. Edwardsville, Illinois	Yes	No	No information
National Cyber Research Park (Bossier City, Louisiana)	Yes	No	No information
NC State University Centennial Campus (Raleigh)	Yes	No	No information (link does not work)
USF Research Park (Tampa)	Yes	No	Only start-ups or services; not sure if business tenants still located on the park
University of North Texas Research Park (Denton)	Yes	No	Transformed from research into discovery park; no info on current tenants
The University of South Carolina's Innovista (Columbia, South Carolina)	No	No	Broader concept
Illinois Technology and Research Corridor	No	No	Business centre
Foundation Park (Alachua)	No	No	Business park

Kapolei Business Park, Hawaii	No	No	Business park
The MS e-Center at Jackson State University - Jackson, MS	No	No	Incubator
Bayer CoLaborator (San Francisco)	No	No	Incubator
Innovation Depot, University of Alabama	No	No	Incubator
Innovator.net University of North Dakota, North Dakota	No	No	Incubator
Sid Martin Biotechnology Incubator (Alachua)	No	No	Incubator
University City Science Center, Philadelphia	No	No	Incubator
University of Maryland, Technology Advancement Program, Maryland	No	No	Incubator
Treasure Coast Research Park (Fort Pierce)	No	No	No business tenants
Olentangy River Wetland Research Park, Ohio	No	No	No business tenants
Metrotech Center at Polytechnic Institute of New York University	No	No	No information
Montana State University Innovation Campus - Bozeman, MT	No	No	No information
Utah University - Innovation Campus	No	No	No information
Dandini Research Park, Nevada	No	No	No information
Minnesota Innovation Park (Formerly Minnesota Innovation Center)	No	No	Planning stage
Coldstream Research Campus - University of Kentucky	No	No	Research campus
North Carolina Research Campus (Kannapolis)	No	No	Research campus
California Institute for Biomedical Research	No	No	Research centre
Clemson ICAR, Greenville, South Carolina	No	No	Research centre
Northwestern University Evaston Research Centre	No	No	Research centre
Rheology Research Centre, Wisconsin	No	No	Research centre
Russ Research Center, Beavercreek, Ohio - in the Greater Dayton area	No	No	Research centre
University of Pittsburgh Applied Research Center, Harmarville	No	No	Research centre
Washington State University Research Foundation, Washington, DC	No	No	Research foundation
Georgia Tech Research Institute (Atlanta)	No	No	Research institute
Southwest Research Institute (San Antonio)	No	No	Research institute
University of North Carolina at Chapel Hill - Carolina North Campus	No	No	University, not park
Bettis Atomic Power Laboratory, West Mifflin	No	No	Work exclusively on innovation for US Navy
Vivint Innovation Center (Lehi, Utah)	No	No	Work exclusively on innovation for Vivint
University Park at MIT - Cambridge, MA	/	No	No information
Miami Civic Center (Miami)	/	No	No information

Appendix 2: Total Citations Relative to an On-Park Move

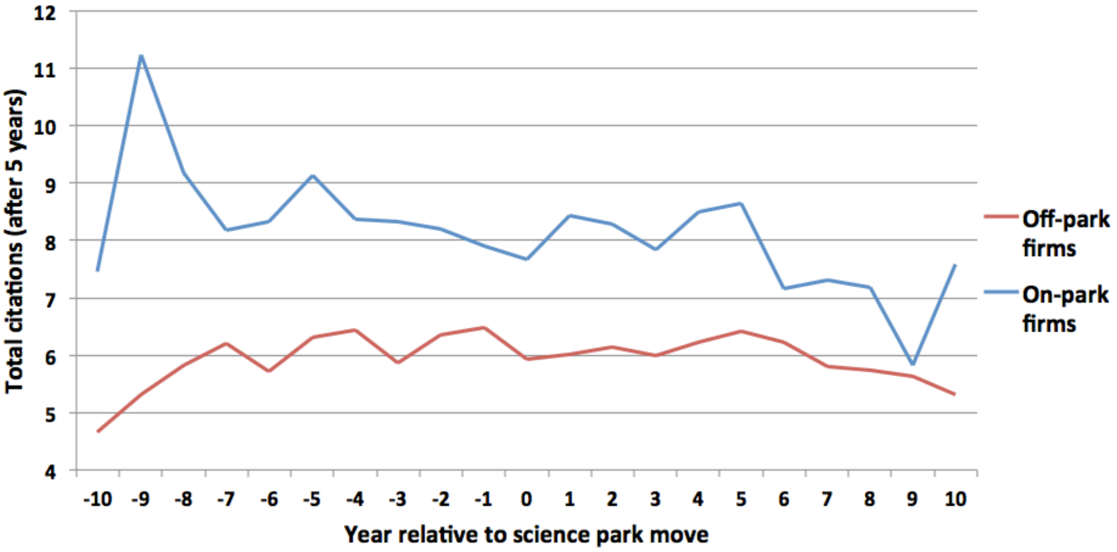

Figure 4a: The number of citations does not seem to be influenced when a firm moves to a science park.

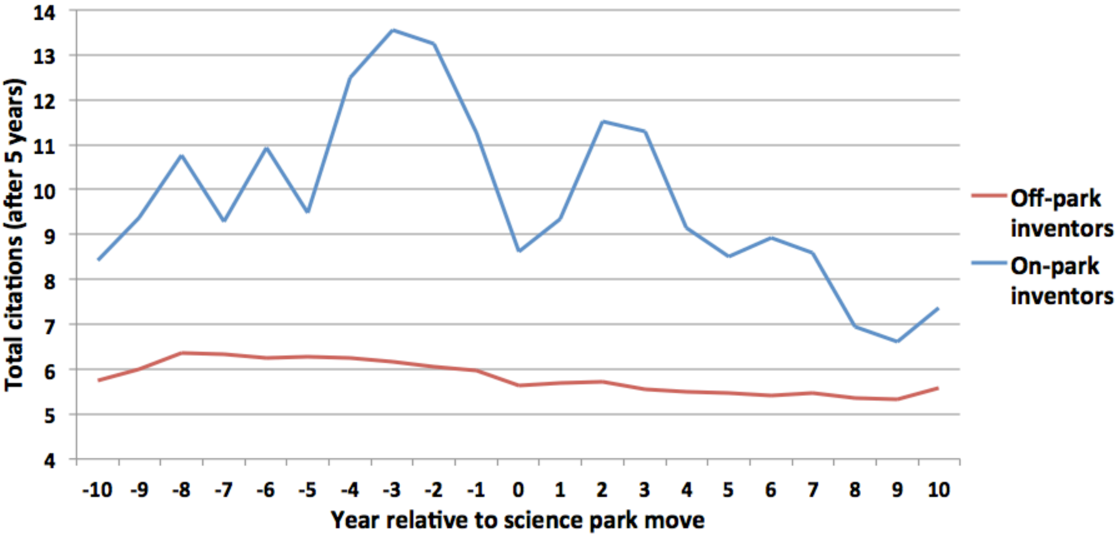

Figure 4b: The number of citations does not seem to be influenced when an inventor moves to a science park.

Appendix 3: Novelty Relative to an On-Park Move

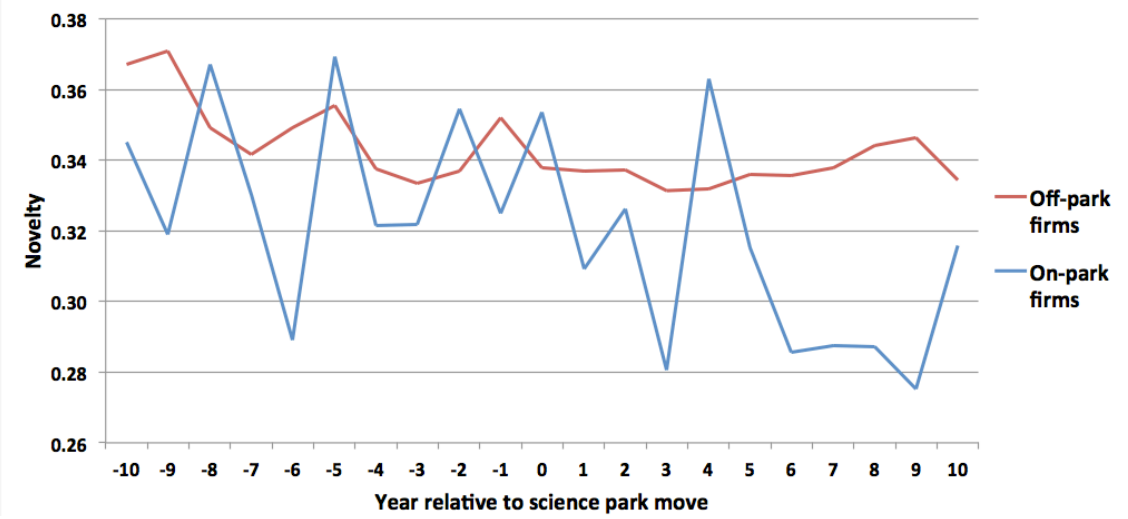

Figure 5a: Moving on-park does not seem to spark the novelty of firms' patents, which even appears to reduce compared to the off-park group.

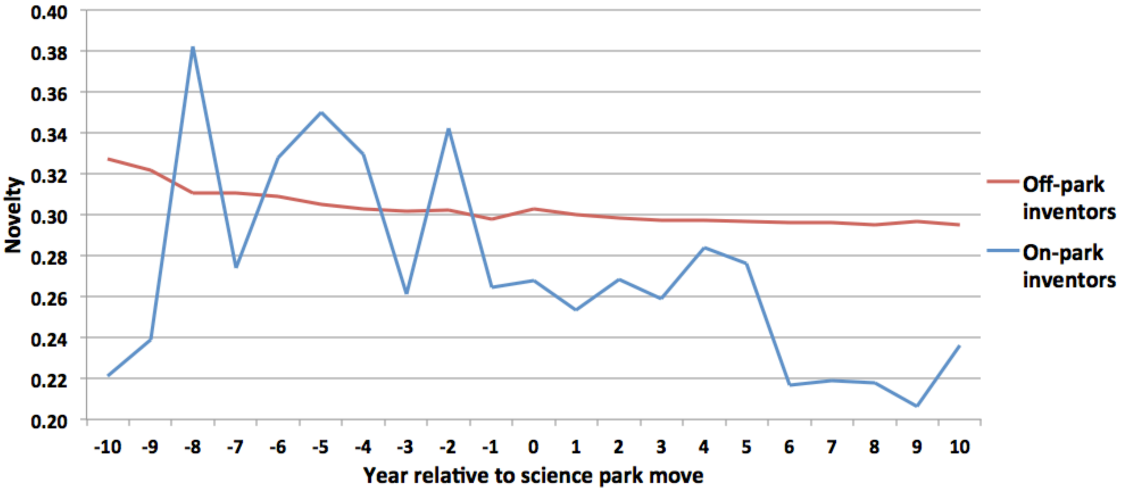

Figure 5b: Moving on-park does not seem to spark the novelty of inventor's patents, which even appears to reduce compared to the off-park group.

Appendix 4: Science Park Coefficients for All Innovation Measure Variants

On the following page, the science park coefficients are shown for the variants of the innovation measures used in this thesis, together with their significance and standard error in parentheses.

SCIENCE PARK COEFFICIENTS

	Pooled OLS				Inventor fixed effects				Inventor-firm fixed effects		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
patent_count	**-0.119*****	**-0.0909*****	**-0.0790*****	**0.0491*****	**-0.0169**	**0.0663**	**0.0658**	**0.461*****	**0.193*****	**0.178*****	**0.179*****
	(0.0116)	(0.0123)	(0.0128)	(0.0134)	(0.0691)	(0.0691)	(0.0695)	(0.0858)	(0.0522)	(0.0528)	(0.0529)
total_cit_3y	**2.051*****	**1.631*****	**1.776*****	**0.578*****	**1.569*****	**0.973*****	**0.959*****	**0.265**	**0.135**	**0.189**	**0.233**
	(0.0742)	(0.0692)	(0.0663)	(0.0799)	(0.311)	(0.282)	(0.266)	(0.266)	(0.317)	(0.305)	(0.295)
total_cit_5y	**3.583*****	**2.947*****	**3.196*****	**1.069*****	**2.993*****	**1.419****	**1.413****	**0.152**	**-0.328**	**-0.0959**	**-0.0252**
	(0.121)	(0.112)	(0.107)	(0.133)	(0.542)	(0.479)	(0.452)	(0.443)	(0.576)	(0.543)	(0.523)
total_cit_7y	**4.807*****	**4.014*****	**4.355*****	**1.436*****	**3.735*****	**1040**	**1054**	**-0.710**	**-1.960+**	**-1517**	**-1433**
	(0.159)	(0.147)	(0.141)	(0.178)	(0.810)	(0.757)	(0.718)	(0.731)	(1.056)	(0.994)	(0.969)
total_cit_10y	**5.954*****	**5.055*****	**5.506*****	**1.949*****	**4.355*****	**0.471**	**0.510**	**-1697**	**-3.993***	**-3.236***	**-3.129***
	(0.201)	(0.185)	(0.178)	(0.228)	(1.131)	(1.101)	(1.050)	(1.115)	(1.668)	(1.571)	(1.540)
bt1_2sd	**0.0507*****	**0.0455*****	**0.0522*****	**0.0122*****	**0.0355*****	**0.0233***	**0.0230****	**0.00757**	**0.00390**	**0.00688**	**0.00895**
	(0.00251)	(0.00246)	(0.00234)	(0.00300)	(0.00929)	(0.00932)	(0.00876)	(0.0104)	(0.0135)	(0.0134)	(0.0129)
bt1_5sd	**0.0166*****	**0.0129*****	**0.0148*****	**0.00130**	**0.00428**	**-0.000815**	**-0.000891**	**-0.00965**	**-0.00873**	**-0.00823**	**-0.00842**
	(0.00135)	(0.00131)	(0.00127)	(0.00159)	(0.00559)	(0.00577)	(0.00536)	(0.00626)	(0.00823)	(0.00812)	(0.00792)
bt1_10sd	**0.00668*****	**0.00510*****	**0.00592*****	**0.000729**	**0.00510+**	**0.00177**	**0.00181**	**0.000597**	**0.000992**	**0.000766**	**0.000672**
	(0.000768)	(0.000724)	(0.000709)	(0.000827)	(0.00300)	(0.00287)	(0.00274)	(0.00276)	(0.00374)	(0.00371)	(0.00363)
bt1_2sd_5y	**0.00668*****	**0.00510*****	**0.00592*****	**0.000729**	**0.00510+**	**0.00177**	**0.00181**	**0.000597**	**0.000992**	**0.000766**	**0.000672**
	(0.000768)	(0.000724)	(0.000709)	(0.000827)	(0.00300)	(0.00287)	(0.00274)	(0.00276)	(0.00374)	(0.00371)	(0.00363)
bt1_5sd_5y	**0.0446*****	**0.0396*****	**0.0453*****	**0.00754***	**0.0482*****	**0.0432*****	**0.0426*****	**0.0207***	**0.0198**	**0.0227+**	**0.0243***
	(0.00246)	(0.00242)	(0.00231)	(0.00303)	(0.00932)	(0.00896)	(0.00846)	(0.0100)	(0.0130)	(0.0127)	(0.0122)
bt1_10sd_5y	**0.0446*****	**0.0396*****	**0.0453*****	**0.00754***	**0.0482*****	**0.0432*****	**0.0426*****	**0.0207***	**0.0198**	**0.0227+**	**0.0243***
	(0.00246)	(0.00242)	(0.00231)	(0.00303)	(0.00932)	(0.00896)	(0.00846)	(0.0100)	(0.0130)	(0.0127)	(0.0122)
novelty	**-0.0440*****	**0.00413**	**0.00956****	**0.00405**	**-0.0182+**	**-0.0213***	**-0.0224***	**-0.0282***	**-0.0405***	**-0.0392***	**-0.0432****
	(0.00352)	(0.00322)	(0.00312)	(0.00405)	(0.0109)	(0.0104)	(0.0102)	(0.0128)	(0.0161)	(0.0154)	(0.0148)
novelty_nto	**-0.0527*****	**-0.00217**	**0.00503+**	**0.00278**	**-0.0179+**	**-0.0168**	**-0.0175+**	**-0.0186**	**-0.0299+**	**-0.0288+**	**-0.0348***
	(0.00338)	(0.00312)	(0.00303)	(0.00397)	(0.0105)	(0.0102)	(0.0101)	(0.0126)	(0.0156)	(0.0153)	(0.0150)
novelty_nso	**0.0393*****	**0.0329*****	**0.0239*****	**0.00236**	**0.00109**	**-0.00643**	**-0.00768**	**-0.0193***	**-0.0299****	**-0.0289****	**-0.0291****
	(0.00200)	(0.00196)	(0.00185)	(0.00220)	(0.00678)	(0.00658)	(0.00619)	(0.00827)	(0.0109)	(0.0108)	(0.00988)
novelty_nf	**-0.00653*****	**0.00620*****	**0.00938*****	**0.00120**	**0.00815**	**0.00375**	**0.00484**	**-0.00864**	**-0.00896**	**-0.0120**	**-0.00876**
	(0.00183)	(0.00167)	(0.00166)	(0.00221)	(0.00542)	(0.00526)	(0.00516)	(0.00663)	(0.00893)	(0.00869)	(0.00836)
nto6	**0.214****	**0.487*****	**0.447*****	**0.149****	**0.0839**	**0.0497**	**0.00355**	**-0.314**	**-0.223**	**-0.267**	**-0.393**
	(0.0696)	(0.0600)	(0.0543)	(0.0558)	(0.249)	(0.200)	(0.186)	(0.218)	(0.261)	(0.259)	(0.267)
nso6	**0.247*****	**0.219*****	**0.157*****	**0.0337***	**0.0189**	**-0.0253**	**-0.0373**	**-0.149***	**-0.199***	**-0.194***	**-0.198***
	(0.0182)	(0.0166)	(0.0154)	(0.0146)	(0.0691)	(0.0570)	(0.0522)	(0.0667)	(0.0833)	(0.0830)	(0.0809)
nf6	**0.0172+**	**0.0454*****	**0.0509*****	**0.00733**	**0.00213**	**-0.0158**	**-0.00639**	**-0.0403**	**-0.0490**	**-0.0589**	**-0.0360**
	(0.00892)	(0.00828)	(0.00805)	(0.00850)	(0.0330)	(0.0312)	(0.0289)	(0.0314)	(0.0419)	(0.0414)	(0.0394)

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Standard errors in parentheses

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