A Study of Patent Thickets

Final report prepared for the UK Intellectual Property Office

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This report analyses whether entry of UK enterprises into patenting in a technology area is affected by patent thickets in the technology area. The aim is to contribute to our understanding of the role of patent thickets as a barrier to entry into patenting for UK enterprises, in particular small and medium sized enterprises (SMEs). To do this we review the literature on patent thickets, discuss factors contributing to thicket formation and growth, and evaluate to what extent patent thickets might be considered to be barriers to entry in some technology areas. We also summarize the limited existing empirical evidence regarding effects of patent thickets on R&D investments and competition.

We find overwhelming evidence in the literature that patent thickets arise in specific technology areas. This conclusion is based on a comprehensive review of the empirical literature on patent thickets of the last 15 years. This literature consists of surveys of firm representatives as well as of econometric analyses of firm level data. The literature on thickets contains more than 100 peer reviewed papers and a number of extensive studies undertaken by competition regulators.

Our main contribution in this study consists of an empirical analysis of the effects of patent thickets at the European Patent Office on entry into patenting by UK firms. Using a new measure of patent thickets developed by Graevenitz et al. (2012), the report provides a descriptive analysis of the growth of patent thickets in the European patent system and an analysis of the exposure to these thickets of UK entrants into patenting. Econometric analysis of the probability of entry into patenting by technology area shows that the density of a patent thicket is associated with reduced entry into patenting in the technology area in the data set used for this study. We discuss limitations of the data used and suggest how further work might test the reliability of our findings.

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1 Introduction

This study investigates a question posed by the UK Intellectual Property Office concerning patent policy and SMEs:

> Are patent thickets a barrier to entry and how do they affect small and medium sized enterprises (SMEs)?

In this introduction we briefly discuss the definition of key terms in these questions, namely "patent thickets" and "barriers to entry". Then we discuss why the question arises now and the reasons that answers matter for policymakers. Finally, we present the structure of this study and provide a brief summary of our main results.

1.1 Patent thickets

A patent thicket is "a dense web of overlapping intellectual property rights that a company must hack its way through in order to actually commercialize new technology" (Shapiro, 2000). Patent thickets consist of patents that protect components of a modular and complex technology. Here modular means that different sets of components can be assembled to yield a variety of technological products. Complex means that products consist of tens or hundreds of such modular components. Each component may end up being used in several products. Often there are partial or complete overlaps in the functionality of components and then the patents protecting the components may also overlap. If overlapping patents belong to different firms, then a patent thicket exists.

Although technology areas with large number of patents often lead to patent thickets, this is not necessarily the case. In principle, an active technology area could have a large number of patents, each clearly delineating the invention concerned and none with overlapping claims or claims with uncertain breadth or scope. Thus it is important not to use numbers of patents as an indicator of patent thickets. Nevertheless, it is undoubtedly the case that one of implications of the presence of patent thickets is active patenting in the sector, so the two phenomena are correlated. Later in this report, we propose a measure of thickets in a technology area that incorporates an indicator of complexity and the possibility of overlapping claims, and controls for the overall level of patenting in the area.

Patent thickets have been a concern of antitrust agencies and regulators in the United States for over ten years (Federal Trade Commission, 2003; U.S. Department of Justice and Federal Trade Commission, 2007; Federal Trade Commission, 2011). In Europe interest in the phenomenon picked up with some delay (Arundel and Patel, 2003; Harhoff, 2006; Harhoff *et al.*, 2007) and has taken a back seat to reforms of the European patent system such as the unified patent court.[1]

While there is a large and growing academic literature on patent thickets (which we survey below) much remains to be learned about the origins and especially the effects of patent thickets. One important question, which is addressed in this study, is the effect of patent thickets on the ability of small and medium sized enterprises to use the patent system in order to protect their inventions or to enter markets with complex products. There is little work on this question to date.[2] This is because patent thickets are a complex phenomenon and the existing literature has focused on determining the factors that contribute to the phenomenon, and the empirical measurement of thickets, and much less on their economic impact.

Next, we briefly review the factors that contribute to the growth of patent thickets and the challenge of evaluating the economic effects of patent thickets. Some of these factors are specific to the United States, where patent thickets were first identified in the patent system. However, the importance of the US economy, especially as a market for high-technology firms from around the globe, has meant that patenting strategies of corporations from outside the United States have adapted to strategies used initially by US corporations.

Where factors contributing to changing patenting behavior are specific to the United States, we point this out below and in the literature review. Whenever possible, we specifically discuss empirical evidence available on the UK.

The current literature has identified the following factors as contributing to the growth of patent thickets:

1. The strengthening of patent rights with the creation of the CAFC in the United States in 1984, the broadening of patentable subject matter and an increased tendency to resolve patent disputes using injunctions in some jurisdictions;
2. The cumulative nature of science and by extension of technology and as a result a shift towards complexity in many technologies;
3. Shifts in the degree of technological opportunity in various key technologies;
4. Strategic patenting by corporations and the assertion of patents by Patent Assertion Entities (PAEs);
5. Lack of resources and misaligned incentives at patent offices dealing with a flood of patent applications that resulted from the aforementioned factors;

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[1] One reason for reduced interest in Europe is the exclusion of software *per se* as patentable subject matter at the EPO. In the U.S., many of the problems in this area are associated with software and internet-related patents.

[2] The recent report by the FTC (2011) specifically considers the role of small and medium sized enterprises in the market for technology in Chapter 1.

6. Growth in trade of high technology products, leading to an increase in demand for patents by foreign firms and to the spread of patenting trends from Japan and the United States to other jurisdictions.

These factors have independent origins; nonetheless they interact to strengthen incentives for large and specialized firms to acquire as many patents as possible. For instance, incentives at the European Patent Office (EPO) appear to have made it cheaper in some complex technologies to acquire additional patents, than to oppose a rival's weak patent that might be used to limit the use of a specific technology.[3] These additional patents could be used to bargain with the rival and can be applied for much more quickly than an opposition process could be brought to a definitive conclusion. Another example is documented by Hegde *et al.* (2009) who analyze continuations at the USPTO.[4] They cite Robert Barr, former patent counsel for Cisco Inc., who states that continuation applications are used by telecommunications firms to separate weak claims that are initially rejected by patent examiners from strong claims. The weaker claims are then pursued in separate patent applications, the continuation applications. The empirical analysis of different types of continuations in Hegde *et al.* (2009) lends support to this claim.

Incentives to patent extensively create a number of feedback loops – in other words the effects of growth in patent applications feed back to the factors that created incentives for patenting and strengthen these even more:

1. Patent offices have found it hard to obtain resources necessary for careful delineation of patents in a period in which larger patent counts were regarded as essential to obtaining freedom to operate via the negotiation of cross licenses. This meant patents were sometimes incompletely examined, which facilitated the emergence of thickets. Firms intensified their patenting efforts as they understood both the weakness of the patent offices and the growing strength of rivals acquired by means of their growing patent portfolios. Microsoft and Google provide recent examples of this phenomenon.

   The quality of patents issued by the USPTO is the focus of the first reports by the FTC and the Department of Justice (Federal Trade Commission, 2003; U.S. Department of Justice and Federal Trade Commission, 2007). The most recent report by these agencies (Federal Trade Commission, 2011) focuses in part on the issue of notice – the clarity with which claims

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[3] This statement is based on direct communication with the former head of the patent division of a leading UK high technology manufacturer.

[4] "Continuation applications permit firms to restart the examination of their patent applications while retaining the filing date of a previous application that discloses the same invention. Inventors can use continuations to revise the claims submitted in their initial application or to pursue claims that have been disallowed after initial examination with new arguments and evidence," from Hegde *et al.* (2009), p. 1214.

in a patent are delineated. As the report shows, funding for USPTO and quality of patents granted there remains an important concern.

2. The very large increases in patent applications have led to increasing backlogs of patent applications and long delays in the examination and issuing of patent applications. This in turn allows applicants to exploit uncertainty surrounding their (possibly) overly broad patent applications (Harhoff, 2006; Harhoff *et al.*, 2007; Federal Trade Commission, 2011). The growing awareness of this opportunity on the part of firms creates incentives for firms to file broad claims that create more uncertainty for rival applicants.

3. At least in the United States, the Court of Appeals of the Federal Circuit, which had been created in 1982 as one of several changes intended to strengthen the incentives to innovate, has handed out injunctions frequently against firms deemed to be infringing or potentially infringing in some jurisdictions. This forced and forces firms to patent and/or to acquire patent portfolios in order to be able to threaten would-be litigators with counter-suits or achieve early settlements. It has also created an environment in which firms specialized in the acquisition and legal enforcement of patents flourished because of the profitability of a hold-up strategy even if a patent was of dubious validity (Reitzig *et al.*, 2007; Farrell and Shapiro, 2008). So-called Non-practicing entities (NPE), Patent assertion entities (PAE) or patent trolls (trolls) have been shown to exploit this possibility for hold-up. There is also evidence of increasing litigiousness in specific technology areas which is generally attributed to the activity of PAEs (Berneman *et al.*, 2009; Federal Trade Commission, 2011). The available evidence suggests that litigation by PAEs may result in a net welfare loss and stifle innovation (Bessen *et al.*, 2011; Tucker, 2011). The issue of remedies and injunctions has been the focus of the most recent report by the Federal Trade Commission (2011).

Although most of these changes began in the United States, they have had knock-on effects on patenting systems in the rest of the world, first in Japan, and then Europe and other East Asian countries.

A side effect of high levels of patenting may be to raise the cost of entry into affected technology areas, excluding some new entrants. To put it another way, in a world of cumulative innovation where one product depends on hundreds of inventions owned by a large number of firms, there is good reason to think that the patent system may discourage innovation overall rather than encouraging it, even as it may encourage innovation by a few large firms (Bessen and Maskin, 2007).

This could happen because large numbers of patents are generated in the course of strategic patenting by large firms. These patent portfolios may create a sunk cost of entry that especially smaller firms would find hard to overcome. This is problematic if the portfolios consist of large numbers of patents that would not survive if challenged in court. The cost of entry consists of the cost of creating a patent portfolio that is sufficiently large to constitute a bargaining chip in negotiations over cross licensing, standards, patent pools, or in court proceedings (Grindley and Teece, 1997; Hall and Ziedonis, 2001; Ziedonis, 2004). This cost is generally sunk because the majority of such patents are marginal – they do not in fact protect a technology that would find a buyer in a market for technology.[5] In addition, there is some evidence that patent offices flooded with patent filings by firms building large portfolios are unable to devote sufficient time to prior art search and therefore may issue patents of low quality in the sense that the invention does not satisfy statutory patentability requirements, in particular novelty and the inventive step (Shapiro, 2000; Bessen and Maskin, 2007).

This report shows empirically that patent thickets have effects on entry into patenting in specific technology areas. The implications of this result depend on the reliability of the data used. We discuss limitations in this regard and suggest which additional work might be undertaken to test our findings.

We also seek to establish the economic significance of the effects we identify, but this is much harder to do than the empirical analysis we present. It requires that we weigh the costs we can measure against potential benefits (due to innovation incentives) that may be associated with some of the six factors we have identified as causes of patent thickets above.

Patent thickets also create substantial transactions costs for the large incumbents caught up in the thickets (Hall and Ziedonis, 2001; Federal Trade Commission, 2003; Somaya, 2003). These costs are not the focus of our analysis in this study, because they do not affect entry directly. Nonetheless, one might surmise that such costs affect the decision to continue operating in a specific technology. If the transactions costs associated with thickets make it difficult for SMEs to survive in the marketplace, then patent thickets affect existing SMEs, even if they do not represent a barrier to entry. This effect of patent thickets on SMEs is not addressed in this study, but will be pursued in future research.

It should be noted that if patent thickets arise, then necessarily in innovative industries. As we show below, economists studying these industries provide evidence that thickets exists and that they increase transactions costs for the majority of firms active in these industries. This does not mean that the industries affected are no longer innovative, but it does mean that costs of doing business in these industries are higher than is necessary and in some cases prohibitively so. The literature also shows that some businesses benefit from higher barriers to entry in these industries and others benefit from new business models arising from patent thickets in these industries.

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[5] Recently a few well-publicised purchases of patent portfolios have suggested that such patents may be valuable at resale for *defensive* purposes, that is, for augmenting the portfolios of other large firms.

1.2 Barriers to entry

While the term "barriers to entry" has a clearly accessible meaning in normal English, this term also has a specific technical meaning in antitrust economics. We use the term in the latter sense in this study. This section provides a brief review of the economics literature on the definition of the term in the antitrust sense.

Competition is widely seen as a positive force in market economies that provides incentives for efficient use of resources and incentives for innovation and finally creates pressures for the exit of inefficient firms (Vickers, 1995, *inter alia*). The benefits of competition are strongly reduced if new competitors find it very difficult to enter into competition with existing firms.

Entry into markets with existing incumbents often requires the entrant to make investments that cannot be recovered on exit – these investments are termed sunk costs. Sunk costs arise in many guises; the most common are due to building brand recognition or investing in firm-specific capital such as technology or knowledge for innovation. Recent work in economics (Sutton, 2007) identifies these sunk costs as the result of activities (product differentiation or innovation) on the part of incumbents seeking to escape the pressures of competition. Desirable though some of this activity may be, sunk costs will also reduce entry and competition, as entrants will need to be able to recoup costs of overcoming the advantages that incumbents derive from their brands or technological expertise.

Economists studying industrial organization have found that sunk costs arising from investments in R&D and to some extent in advertising or distribution facilities increase social welfare,[6] i.e. on balance these investments create benefits to consumers that outweigh the costs of reduced competition to the same consumers. However, there are also cases in which firms raise sunk costs and thereby reduce competition to such an extent, that the sunk costs no longer benefit consumers.

Economists refer to those (sunk) costs that protect incumbents against competitive entry and allow them to earn more rents than are necessary to incentivize socially beneficial investments such as innovation or product differentiation as barriers to entry. Sunk costs are therefore not barriers to entry per se, and often it will be the level of sunk costs that creates the problem and

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[6] Economists use the term social welfare to refer to a measure of well being of a society. If an activity reduces social welfare it is said to create a welfare loss. In the analysis of firm behavior, social welfare is usually considered as the sum of consumer surplus (the gap between the price the consumer is willing to pay and the actual price) and producer profit (the gap between the price and the cost of production). For instance, if a monopoly raises prices beyond marginal cost, then this reduces the number of consumers willing to buy the goods sold by the monopoly. This reduces social welfare, because these consumers would have benefitted from buying the goods at a lower price. Additionally, those consumers still buying would have paid less, which would increase their consumer surplus. The latter effect is at the expense of producer profits, so the net effect on social welfare would be zero.

not the fact that sunk costs arise. As Schmalensee (2004) notes, a cost constitutes a barrier to entry, if it limits competition in such a way that welfare is reduced. Different definitions of barriers to entry exist in the literature (McAfee *et al.*, 2004) and which definition is appropriate can depend on the welfare standard (e.g. total surplus, consumers' surplus) adopted in a particular jurisdiction (Schmalensee, 2004).

A patent is the right to exclude others from practicing an invention. Therefore, in principle a patent will function to increase fixed (and most likely sunk) costs of entry into a market where the invention protected by the patent is practiced. This will reduce entry and therefore competition. From a welfare perspective, this is the price society pays in order to encourage invention and innovation by the initial entrant. What results is a trade-off between the interests of the incumbent holding the patent and the potential entrant excluded by it. In the case of patents, policy makers need to come to a view of how much protection to afford the patentee in order to create incentives for R&D.

To provide an example, individual patents might be considered a barrier to entry, if they protected the technological advantage of the patentee for a very long time. The patent term is set so as to provide the patentee with a period in which the sunk costs of invention may be recouped. If the term were extended beyond this period and if the technology protected by the patent were an important component of a certain type of product, then the patent would constitute a barrier to entry. Later entrants into the market for this product would face low incentives to develop the technology further. When exactly a patent is protecting a technology for too long is hard to determine and is specific to the technology under consideration. Existing patent systems already recognize differences between technologies to some extent. For instance producers of ethical drugs in Europe may apply for supplementary protection certificates (SPCs), which extend patent protection by up to five and a half years beyond the statutory term.

1.3 Can patent thickets be "Barriers to entry"?

The question we address in this report is whether the need to acquire large numbers of patents in specific complex technologies is creating barriers to entry in the antitrust sense. In these technologies firms adopt the strategy of patenting heavily in order to remain competitive. The resulting patent thickets are barriers to entry, if they create important negative externalities for firms not in possession of large patent portfolios and if no offsetting social benefits can be ascribed to the factors causing thickets to arise.

The main aim of our literature review below is to establish which positive incentive effects may be ascribed to factors that caused patent thickets to arise and which social costs have been ascribed to patent thickets thus far. The empirical work in this study analyzes whether thickets affect SME entry and the strength of any such effect. Together these pieces of evidence allow us to assess whether patent thickets can be considered as antitrust barriers to entry and whether they are empirically important. Our answers to this second question are discussed in Section 2 and our empirical evidence on the question is supplied in Section 4.

Our empirical evidence is restricted to entry into patenting as there is currently no data on market entry dates of products that is matched to European patent data. As we note in the literature review there is evidence from the United States, which shows that entry into patenting is correlated with growth of firms. Additionally, it is hard to envisage how firms in sectors in which patenting is very intensive would be able to enter product markets without patent protection.

Patent thickets create costs for the firms whose patents make up the thicket and they also create costs for the firms whose patents cover similar technologies to those covered by patents in the thicket or who are contemplating future invention of that type. For simplicity we refer to the first type of firm as an insider and the second as an outsider. Patent thicket insiders are typically larger incumbent firms, whereas some of the outsiders will be entrants. One definition of the problem we are investigating is the following:

> *Patent thickets constitute a barrier to entry into patenting, if they raise the cost of entry into patenting for outsiders such that social welfare is less than in the absence of patent thickets.*

If we find that patent thickets have economically significant effects on the entry and survival of SMEs, thickets constitute a barrier to entry into patenting provided changes to the patent system can be envisaged that reduce entry costs of SMEs without reducing social welfare significantly. It is important to emphasize that our objective is not to identify whether patents *per se* represent a barrier to entry, but whether patent thickets affect entry into patenting.

1.4 Brief Review of Findings

This report answers two questions:

1. Are there patent thickets and if so what are their effects on patenting, R&D investments and competition?
2. Is there a measurable effect on entry into patenting at the European Patent Office (EPO) by UK firms?

The first question is answered in Section 2 on the basis of a thorough review of the literature on patent thickets, which is now around 15 years old.[7]

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[7] The first paper identifying patent strategies that have given rise to patent thickets in the modern era is by Grindley and Teece (1997). A number of important seminal papers on the topic followed in 2000 and 2001.

The second question is answered in Section 4 on the basis of an empirical analysis that provides the first evidence on the effects of patent thickets on entry into patenting in Europe.

Question 1

A review of the recent economics and management literature shows that there are two strands of empirical research pertinent to the first question set out above: The first is the literature on the entry and growth of SMEs, the second the literature on patent thickets. There is almost no research to date at the intersection of these strands of literature.

The literature on the survival and growth of firms and especially SMEs shows that start-up firms are the source of much employment creation and destruction. Importantly, start-up firms that survive beyond the first five years are an important source of job growth (Haltiwanger *et al.*, 2010). These authors argue further that research into regulatory or market failures that have systematic effects on the survival of SMEs is lacking.

The literature on the growth of patenting, the sources of this growth, and the possible presence of patent thickets identifies patent portfolio races in response to litigation threats as a major source of growth of patenting during the 1980s and 1990s. During the 2000s, this growth has been augmented by the force of globalization, with firms taking out patents in increased numbers of jurisdictions, reflecting the need to protect themselves against competitors from a larger number of countries and increased opportunities for licensing. Accompanying this growth of patenting have been growing patent office workloads and an increased cost of prior art search, leading to more overlapping patents and more patents on minor inventions being granted.

The literature has found that reforms to the courts dealing with patents in the United States increased incentives to patent and also improved the efficiency of the court system there. Otherwise the literature on patent thickets identifies only social costs of increased patenting, such as hold-up and associated increases in litigation, increased pendency of patents and growing uncertainty about validity of pending and granted patents. These changes taken together are considered to be consequences of the existence of patent thickets in some technology areas. This literature also contains a number of indications that entry into technologies affected by thickets is falling and that smaller firms that are actively patenting in these technologies are struggling to maintain a foothold in them.

Question 2

Our empirical analysis of entry into technology areas affected by patent thickets shows that entry decreases as patent thickets become denser, controlling for overall patenting activity in a technology area. We employ a recent measure of patent thicket density, which measures how frequently patent applications indicate high levels of overlap exist between technologies of three or more firms over a period of three years. This measure allows us to detect patent thickets and to quantify their density.

Our empirical results confirm previous findings, surveyed in the literature survey, that patent thickets exist and have effects on firms' patenting activities. Our empirical findings suggest that patent thickets are creating barriers to entry into patenting in some technology areas. However, we find that most new entrants into patenting located in the United Kingdom are not affected by these thickets, precisely because entry by these firms into affected technology areas is low.

1.5 Structure of the Study

The remainder of this text is structured as follows: Section 2 contains a literature review on patent thickets; Section 3 sets out how we measure patent thickets, Section 4 provide empirical findings on the prevalence of thickets and on their effects on entry into patenting. Section 5 concludes the report.

In the Appendix we describe the data used, set out additional material validating our measure of thicket density and provide additional tables and details on our estimation strategy.

2 Literature Review

In this section we review the current literature touching on patent thickets in detail. This literature is very extensive and much additional detail can be found in the careful studies undertaken by the Federal Trade Commission and the Department of Justice in the United States (2003; 2007; 2011). This literature also overlaps with a broader literature on patents and patent systems which are reviewed by Hall and Harhoff (2012) and WIPO (2011a) .

At the end of this section we also briefly review the literature on growth of small and medium sized enterprises.

2.1 Patent thickets

In the introduction we discuss six factors that contribute to the growth of patent thickets. Further, we note that self-reinforcing feedback effects cause patent thickets to grow in intensity once they have emerged.

In this section we first review the literature on the factors that contribute to the emergence and growth of patent thickets. We then discuss possible feedback effects. Finally, we summarize the literature on the effects of patent thickets on competition and innovation.

2.1.1 Causes of Patent Thickets

In the introduction we noted the following six causal factors for the growth of patent thickets:

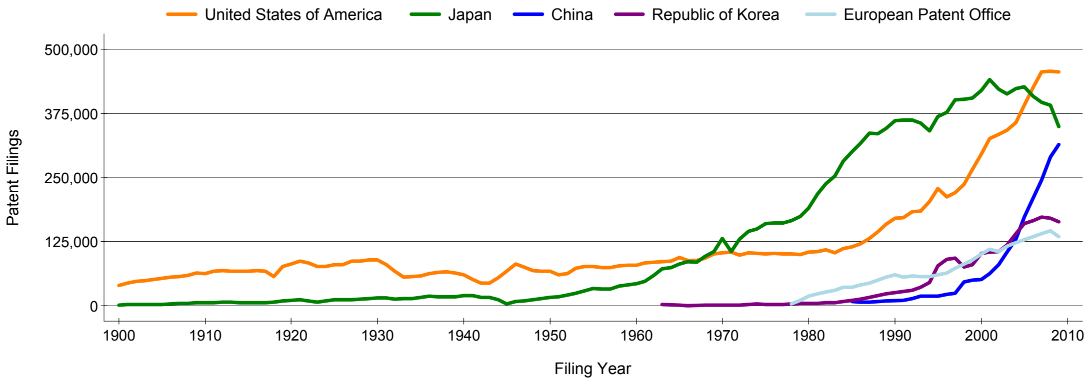
1. The strengthening and broadening of patent rights in the US and frequent use of injunctions in some jurisdictions;
2. The cumulative nature of science and technology and a shift towards complexity in many technologies;

3. Shifts in the degree of technological opportunity in various key technologies;
4. Strategic patenting by corporations and the assertion of patents by Patent Assertion Entities (PAEs);
5. Lack of resources and misaligned incentives at patent offices dealing with the resulting flood of patent applications;
6. Growth in trade of high technology products, leading to an increase in demand for patents by foreign firms and to the spread of patenting trends from Japan and the United States to other jurisdictions.

All of these factors contribute to the emergence and growth of patent thickets. But they are also responsible for an unprecedented level of demand for patents at patent offices around the world. This growth in demand can be seen as a sign that feedback effects are at work and provide incentives for firms to amass increasingly large patent portfolios around the world.

Figure 1 below demonstrates strong growth in the demand for patents in Japan that began after the Second World War and intensified after 1980. This was certainly partly due to the one-patent one-claim policy that existed in Japan in this period. However, this also contributed to a much stronger focus on patent protection and the occurrence of strategic patenting in Japan when patent policy was strengthened in the United States in the 1980's.[8] Figure 1 below shows that this was the second jurisdiction to experience strong growth in patent applications. Whereas the initial increases at the USPTO were most likely attributable to a strategic response to legal changes reviewed above (Jaffe, 2000; Hall and Ziedonis, 2001; Hall, 2005), later increases in applications have also been driven by forces of globalization.

Figure 1 Patent Filings at Selected Patent Offices



Note: Figure 1, drawn from on-going work at WIPO, shows trends in patent filings. Both Japan and the United States exhibit high levels of patenting early on, with growth beginning during the

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[8] There is some evidence that Japanese firms engaged in strategic patenting in technologies we do not associate with patent thickets {Rubinfeld:2004tc}. There is some evidence that Japanese firms engaged in strategic patenting in technologies we do not associate with patent thickets (Rubinfeld and Maness, 2004).

1960s in Japan and the 1980s in the US. Growth at the EPO, in the Republic of Korea, and China begins somewhat later, but is now climbing rapidly, especially in China.

It is important to logically separate these two causes of increased demand for patents. The first, being a response to changes in the institutional framework, may possibly be associated with welfare gains that must be taken into account when evaluating the overall welfare impact of patent thickets. The second cause is secular, just as the increase in technological complexity, but its costs and benefits may lie outside the scope of this study. We discuss below how patent offices have sought to cope with this source of demand.

Now we turn to the survey of factors contributing to growth in demand for patents and growth in patent thickets.

2.1.1.1 Strengthening of Patent Rights and the Role of the Courts

At the end of the 1970s the US patent system was widely perceived to be weak and ineffective. The US Patent and Trademark Office (USPTO) was working inefficiently due to a shortage of staff relative to the workload. Before the USPTO was able to grant a patent, the invention was already obsolete, especially in fast growing high technology sectors (Jaffe, 2000).

In order to overcome this problem Congress passed a series of laws that strengthened and modernized the patent office. Most importantly, Congress passed the Federal Court Improvement Act in 1982. This law created the centralized Court of Appeals for the Federal Circuit (CAFC). The CAFC has exclusive jurisdiction over appeals in cases involving patents and claims against the federal government in a variety of subject matters. This court was created mainly for two reasons: to bring greater uniformity in patent law enforcement, and to reduce the case-load crisis in the federal courts of appeals (Jaffe, 2000).

In a series of studies based partly on practitioner interviews (Hall and Ziedonis, 2001; Ziedonis, 2004), Hall and Ziedonis show that one consequence of the creation of CAFC and the greater willingness of that court to grant injunctions was to increase the hold-up threat to defendants in patent litigation and that this led to an increase in defensive patenting in the semi-conductor industry. The practice of "patent portfolio" racing for defensive purposes soon spread to other parts of the ICT industry (Hall, 2005) and to other jurisdictions (Harhoff *et al.*, 2007).

Galasso and Schankerman (2010) study how the fragmentation of patent rights and the formation of CAFC affected the duration of patent disputes during the period 1975-2000, and thus the speed of technology diffusion through licensing. They have two main empirical findings. First, patent disputes in US district courts are settled more quickly when infringers require access to fragmented external rights, but this effect is much weaker after the introduction of the CAFC. Secondly, the introduction of the CAFC is associated with a direct and large reduction in the duration of disputes, which they attribute to less uncertainty about the outcome if patent disputes go to trial. This is a beneficial result of the formation of this court.

However, there is some evidence that patent litigation in the information and communications technologies as well as in software has increased substantially recently (Berneman *et al.*, 2009; Federal Trade Commission, 2011; Carrier, 2012). The recent report by the FTC (2011) discusses the economic effects of injunctions and the criteria used when deciding on injunctions at great length. The report proposes that the courts should adhere to the 2006 Supreme Court decision in *eBay v. MercExchange*[9] which set out four factors required to obtain a permanent injunction against a later patent. On the whole these factors should make obtaining an injunction much harder than previously, as they require US courts to consider the public interest in coming to a view about injunctions.

In Europe there has recently been a spate of court cases related to smartphones, in which firms have sought to obtain injunctions to delay entry of products while appealing to the European competition authorities to investigate the licensing or not of standards essential patents (Carrier, 2012). German courts have been particularly central in these legal cases as they rule quickly and due a stronger presumption of validity built into its bifurcated enforcement system, preliminary injunctions are more frequently employed. Helmers and McDonagh (2012a), in contrast, find no evidence for changes in litigation behaviour before the relevant courts in England and Wales over the period 2000-2008.[10] They also show that in contrast to the US, the overwhelming share of litigated patents is on pharmaceutical and chemical inventions and around of third of litigating parties are companies in pharmaceutical/chemical industry.

Overall, it is clear that the manner in which the courts interpret patent claims and the extent to which they are willing to provide injunctions play an important role in creating incentives for firms to create broad and imprecise claims and to pursue aggressive litigation strategies. As the recent FTC report (Federal Trade Commission, 2011) shows, there are many ways in which the courts can act to stem the tide of litigation in high technology markets such as Smartphones. A recent example of this type of behavior was provided by Judge Posner in an Illinois court.[11]

2.1.1.2 Cumulative Nature of Technology

Patent thickets arise in complex technologies (Shapiro, 2000). This section reviews the evidence that technology is getting more complex and interwoven,

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9 eBay, Inc. v. MercExchange, LLC, 547 U.S. 388, 391 (2006).

[10] Yet, the Patents Court has recently seen a substantial increase in disputes, effectively tripling in 2011 relative to 2010 (Financial Times, 3 August 2012). It is unclear, however, to which degree these disputes occur about patents on thickets-prone technologies.

11 APPLE, INC. and NeXT SOFTWARE INC. v. MOTOROLA, INC. and MOTOROLA MOBILITY, INC, No. 1:11-cv-08540, 2012

not only in specific technological areas but across a large range of scientific disciplines. This trend is not driven by policy.[12]

Jones (2009; 2010) shows that innovators produce important ideas at greater age as time goes by and that innovators increasingly specialize on narrower bodies of knowledge while working in larger teams. This evidence is consistent with a greater complexity of knowledge as knowledge accumulates. The evidence is derived from an analysis of scientific papers and patents as well as data on Nobel-prize winners and scientists more generally.

Given these trends affecting science generally and patented technologies more specifically, the question remains whether there is evidence that complexity of technology has increased in specific technologies? Somaya, Teece and Wakeman (2011) argue that this is the case citing the volume of patents being issued every year by patent offices.

Another way to look at this question is to examine the number of patents belonging to technology standards. Standards are mostly put in place to regulate the compatibility of technologies. Standards and patent pools are solutions to the bargaining problems that patent thickets create (Shapiro, 2000). As such they tend to arise where there are patent thickets.

Table 1: Standards and Patent Pools

Pool	*Firms that are*		*Patents in the*			*Pool*
	Eligible	*Partners*	*Standard*	*Pool – LL11**	*Standard – Blind11**	*Age in years*
1394	17	9	80	60	30	8
AVC	45	14	55	37	43	2
Bluetooth	25	8	141	116		10
DVB-T	10	4	29	5	51	3
DVD-1	12	4	289	81		9
DVD-2	12	7	289	195		8
MPEG-2	59	19	142	98	45	10
MPEG-4	71	24	106	94	43	9
WCDMA	34	10	348	36	1605 (UMTS)	3

**LL11 = Layne-Farrar and Lerner 2011; Blind11 = Blind et al. (2011)*

Patent thickets are much older than their name: Mossoff (2011) and Lampe and Moser (2010) provide analyses of a sewing machine patent thicket that predates the current literature by 150 years. Their analyses suggest that this patent

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[12] Wang and von Tunzelmann (2000) define technologies as "bodies of knowledge which are person-embodied and software-oriented". These bodies of knowledge can become more complex by becoming either broader, i.e. there is knowledge about more things to be absorbed and integrated, or deeper, i.e. knowledge becomes more intricate. It is in either sense that we discuss technological complexity here.

thicket consisted of a comparatively small number of firms and patents. The patent pool for sewing machines consisted of 7 or fewer independent companies and 9 patents. Overall the number of sewing machine patents in the pool period peaked at just over 150. Lampe and Moser (2012) study 20 pools formed between 1930 and 1938. They show that the largest of these pools (Color Cinematography) was based on 143 patents, while the largest number of participating firms was 5.

In contrast, contemporary standards involve far greater numbers of firms. The number of relevant patents in contemporary standards may be higher, but this is much harder to verify as the patents are not always clearly attributed to the standards. The data set out in Table 1 is derived from two recent studies on patent pools: (Layne-Farrar and Lerner, 2011) and (Blind *et al.*, 2011). This table shows the large number of participants in each standard and the even larger number of firms that were eligible to participate. This shows how difficult bargaining over access to patents on some contemporary technologies has become.

The table is restricted to a set of patent pools that are or were recently active as well as the corresponding standards as identified in Layne–Farrar and Lerner (2011). We include data from Blind *et al.* (2011) on the number of INPADOC patent families associated with the standard where we could match the standards. In case of UMTS it should be noted that WCDMA is a subset of the UMTS standard. Blind *et al.* (2011) list a total of 5 standards with more patents than the Cinematography patent pool, which was by far the largest listed by Lampe and Moser (2012). That pool only had two members so could be considered a cross-licensing agreement rather than a pool. The next largest pool with more than two firms in it that is discussed by Lampe and Moser (2012) is Stamped Metal Wheels with three firms and 90 patents.

Blind *et al.* (2011) also note that standards are most frequently found in telecommunications- and object identification-technologies, audio/video coding standards and computer and consumer electronics hardware technologies, which are the technology areas usually defined as complex (see also Arora *et al.* 2009).

2.1.1.3 Technological Opportunity

Technological opportunity, defined as the productivity of R&D (Klevorick *et al.*, 1995), is very hard to measure. A simple but noisy measure is given by the total count of patents in a technology field. As patenting in high technology areas is affected by strategic considerations this measure is not likely to be very precise, nonetheless it is used by Noel and Schankerman (2006a) who find that growth in this measure of technological opportunity has a positive effect on market value while reducing current patenting. This second finding is in line with the predicted effects of technological opportunity in Graevenitz *et al.* (2012) who argue that falling technological opportunity sharpens competition for patents and intensifies patenting while the opposite is true when technological opportunity is high.

Graevenitz *et al.* (2012) use citations to non-patent references to measure technological opportunity. This measure is only slightly better than the count of patent applications, but has received some support in the literature (Narin and Noma, 1985; Narin *et al.*, 1997; Meyer, 2000). Using this measure Graevenitz *et al.* (2012) find that technological opportunity exerts a strong influence on patenting activity in high technology areas that are affected by patent thickets. This confirms the results reported in Noel and Schankerman (Schankerman and Noel, 2006a; Neumark *et al.*, 2011).

2.1.1.4 Strategic Patenting

Strategic patenting is also sometimes referred to as patent mining (Shapiro, 2000), patent portfolio races (Hall and Ziedonis, 2001) and defensive patenting (Kortum and Lerner, 1998). These terms all refer to the strategic use of the patent system for purposes that go beyond the protection of an individual innovation or innovative product.

Here we begin by reviewing activity which has been referred to as patent mining: "trying to get the most out of their patents by asserting them more aggressively than ever against possible infringing firms, even those who are not rivals (Shapiro, 2000)".

The immediate cause for patent thickets is the behavior of patenting entities, most importantly large corporations, whose products are based on semiconductor, computer hardware, and telecommunications technologies. As of the mid-1980s these firms increased their patenting, not only in technology fields closely related to information technology, but in all technologies in which they were active (Hall, 2005). More recently intermediaries that aggregate patents and then assert these if necessary in courts – so-called patent assertion entities (PAEs) - have taken a more central stage in the patent mining game. This section surveys the literature on strategic patenting or patent mining while the following focuses on defensive patenting. While manufacturing firms pursue both strategies, PAEs do not patent defensively.

We begin the discussion of strategic patenting in this section with semiconductor and information technology firms, although this behavior is not restricted to firms with these technologies.

Grindley and Teece (Grindley and Teece, 1997; Helmers and Rogers, 2010) discuss the fact that IP management became an important consideration for the top management of US corporations in the 1990s. They identify a regulatory shift supporting stronger enforcement of IP rights in the U.S. as a key cause and cite the 1995 DOJ/FTC Antitrust Guidelines for the Licensing of IP. They also discuss the history of technology licensing in the semiconductor industry. Innovation in this industry was dominated by AT&T, which operated as a regulated monopoly until 1984. During this earlier period AT&T sought to minimize its costs by ensuring that new technology was spread quickly to suppliers. Therefore AT&T enforced a licensing regime under which all firms in the semiconductor industry shared technology without seeking to maximize their revenues. IBM is cited as another important source of technology for the early semiconductor industry. This firm too operated as a regulated monopoly and was required to license technology on favorable terms.

In 1985 Texas Instruments began to assert its own patents more aggressively than had previously been customary in the semiconductor industry. This shift in strategy was successful – the company was able to supplement dwindling profits from its semiconductor products with income from its growing technology licensing program. The strategy soon found imitators (Hall and Ziedonis, 2001). These followers were partly seeking higher profits and partly acting defensively. Defensive patenting arose as a response to the assertive IP strategies of firms like Texas Instruments. In the semiconductor industry patents are mostly granted at a time when the technology being protected is already being replaced due to the long grant lags. Therefore patents are not valuable as exclusion rights that protect the original invention. However, as Texas Instruments demonstrated in a number of court cases, patents could be used to extract substantial licensing fees from rival firms who had built incremental innovations on that invention (Grindley and Teece, 1997; Disney *et al.*, 2003).

Hall and Ziedonis (Hall and Ziedonis, 2001) combine interviews with representatives of semiconductor firms with econometric analysis of the patenting activities of these firms. They show that there was a shift in the patenting activity of semiconductor firms in around 1984; after this date firms in this industry started patenting much more actively than before. Interview partners confirmed that individual firms had set themselves targets for the growth of their patent portfolios. While semiconductor firms increased patent applications, their R&D investment levels did not change. This is significant because it rules out an important alternative explanation for increased patenting: that it resulted from increased technological opportunities or demand for innovative products. Hall and Ziedonis thus show that a change in patenting strategy was the more likely explanation for the surge in patent applications by semiconductor firms.

Also, Parchomowsky and Wagner (Parchomovsky and Wagner, 2005) provide a number of case studies of strategic patenting in ICT, which focus on IBM, Qualcomm and Gemstar.

Finally, Bekkers and West (2009) provide a very detailed analysis of patenting surrounding the GSM and UMTS mobile telecommunications standards. Their evidence indicates that the later UMTS standard contained essential patents belonging to a larger range of entities but that the concentration of patents was also higher. They also indicate that many patents added to the standard by Nokia and Ericsson around 1999, when the standard was set, are less cited and thus potentially of lower quality than patents from prior years. This evidence is suggestive of patent mining in the context of a standard setting process. The authors also document the failure of firms in the standard setting organization (ETSI) to agree on rules that would prevent patent mining in future standard setting contexts.

Turning to other industries, Rubinfeld and Maness (Rubinfeld and Maness, 2004; Lemley and Shapiro, 2007) document strategic patenting by a Japanese firm in the personal watercrafts industry, while Wagner (2008) provides evidence for the franking devices industry. Joshi and Nerker (Joshi and Nerkar, 2011) study three patent pools within the optical disk industry. They show that before firms joined these patent pools they built up their patent portfolios more quickly than a control group of similar firms. Once they had joined the pools the rate of patenting decreased significantly. Similar results are reported by Lampe and Moser (2010; 2012) in two separate studies of patent pools in the 1850's and 1930's. These results are comparable to those of Bekker and West (2009), but provide a stronger case for the assertion that patent mining is caused by competition to build patent portfolios before a standard is set and not by unobserved external factors in this industry.

2.1.1.5 Patent Assertion Entities

Recently, there has been an enormous increase in patent infringement cases filed by patent assertion entities (PAEs) in the US.[13] The increase as well as number of high-profile cases, such as NTP vs. RIM or Eolas vs. Microsoft, triggered a heated debate on the role of PAEs in facilitating the so-called market for technology.[14] Recent empirical evidence by Tucker (2011) suggests that PAE litigation has a negative effect on innovation carried out by alleged infringers. Bessen and Meurer (2012) provide some survey-based estimates that suggest a net loss in social welfare due to PAE litigation. Helmers and McDonagh (2012) look at patent cases at the Patents Court for England and Wales that involve PAEs . In contrast to the US, they cannot find any significant increase in the number of cases involving PAEs in the UK over the 9-year period 2000-2008. They find that only in one minor aspect of the cases a PAE was successful in asserting infringement. Across cases, however, a PAE was much more likely to see its patents revoked. In fact, most of the cases before the Patents Court that involve PAEs are cases in which manufacturers successfully seek the invalidation of patents owned by PAEs. If a high likelihood of invalidation is interpreted as low patent quality, this evidence suggests that PAEs assert low quality patents.[15] If low patent quality is associated with patent thickets, this would imply a link between thickets and PAE litigation. That is, if low quality patents provide incentives for PAEs to acquire and assert such patents, we would expect to see PAEs to assert relatively more patents in areas in which patent thickets exist.[16] This is confirmed by empirical evidence on court cases that involve PAEs in the US (Risch, 2012) and the UK (Helmers and McDonagh, 2012), who show that PAE

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[13] Cf. FTC (2011) Chapter 2, Berneman *et al.* (2009) and https://www.patentfreedom.com/about-npes/litigations/ .

[14] See for example McDonough (2006), Myhrvold (2010), Chien (2009), Bessen *et al.* (2011).

[15] However, Helmers and McDonagh (2012) also present evidence that suggests that the patents involved in the PAE case are not statistically significantly different from all other litigated patents at the High Court in terms of a number of patent value metrics. Moreover, when compared to patents protecting similar inventions, the patents asserted by PAEs score higher on all of these value metrics.

[16] See Reitzig *et al.* (2007) and Farrell and Shapiro (2008) for theoretical evidence that the assertion of low quality patents is a profitable strategy.

litigation occurs mostly in technological fields that are also affected most by patent thickets, such as the information and communication technologies.

2.1.1.6 Defensive Patenting

Now we turn to review defensive patenting. Shapiro (2004) provides the following definition: "Defensive patenting refers to the practice of seeking patents in order to defend oneself from patent infringement actions brought by others. Under this strategy, the company does not plan to assert its patent proactively against others, but it can counterattack with its own patent infringement claims if sued for infringement".

Defensive patenting is a strategy pursued by firms seeking to defend themselves against hold-up – the attempt to extract payments through the threat of legal action and the leveraging of injunctions – by patent mining firms. Defensively patenting firms are reluctant litigants, strategically constructing portfolios of patents to avoid going to court. A commonly adopted defense against hold-up is the threat of countersuits and subsequent cross-licensing. This strategy is less effective when firms are faced with patent assertion entities (PAEs), as these are not susceptible to the threat of hold-up themselves.

Ziedonis (2004) demonstrates that semiconductor firms patent more aggressively, if their patents cite a more dispersed set of rival firms. This effect is particularly pronounced, if firms have themselves invested heavily in technology-specific assets (e.g. manufacturing equipment). This finding shows that firms which were likely to be negotiating with a larger set of rivals for access to their patents sought to build larger patent portfolios, in order to strengthen their bargaining positions.

This logic is also supported by a number of submissions from industry representatives to the 2003 study of the Federal Trade Commission into the balance of Competition and Patent Law (Federal Trade Commission, 2003).

Chien (2008) also studies defensive patenting. Her data suggest that the strategy, which is supposed to keep large firms out of court, is at least an incomplete strategy. She finds that public and large private companies initiated 42% of all lawsuits studied, 28% of the time against another large company. Defensively patenting firms also defend against other suits, brought by individuals, small inventors and non-practicing entities.

While defensive patenting is clearly not always effective, it is most likely the main strategy in generating the large increases in patent filings and grants we have documented above (Hegde *et al.*, 2009). Patent mining requires an enduring strategic commitment and is often adopted by firms that have seen other sources of revenue dry up (Rubinfeld and Maness, 2004; De Korte and Clarkson, 2006). It is not likely that the majority of patent applicants are actively pursuing patent mining; rather the majority are defensive patent applicants seeking to protect themselves against litigation while contributing to the overloading of the patent system in equal measure.

2.1.1.7 Incentives for Patent Examiners and Patent Quality and Patent Backlogs

Jaffe and Lerner (2004) and Bessen and Meurer (2008) argue that the increase in the overall number of patent filings at the USPTO was accompanied by a drop in the average quality of granted patents. While there is no canonical definition of patent quality, the existing definitions centre on the substantive standards of patent examination including the enablement function of a patent. Wagner (2008) defines patent quality as the "capacity of a granted patent to meet (or exceed) the statutory standards of patentability – most importantly, to be novel, non-obvious, and clearly and sufficiently described." Graf (Graf, 2007; Sternitzke *et al.*, 2008) adds the enablement condition: "how well the patent meets the statutory requirements: patentable subject-matter, utility, novelty, non-obviousness, and adequate written description and enablement."

Hall and Harhoff (2004) suggest that in addition to statutory patentability requirements patent quality depends on the uncertainty over the validity and breadth of the patent claims.[17] This is an essential requirement in the context of patent thickets, because the fuzzy boundaries created by poorly defined claims contribute to overlapping patent claims. That is, an increase in the number of patent filings per se is not a sufficient condition for the proliferation of thickets; the fact that more patents with ill-defined boundaries are granted is crucial for thickets to emerge.

Patent quality is also negatively affected by the increased difficulty in searching for prior art. The problem has become more severe as the number of filings has been increasing, especially in countries such as Japan, Korea and most recently China as claims are not necessarily available in English.[18] Also the expansion of patentable subject matter to cover software and business methods has contributed to the problem.[19] The difficulty in finding all existing prior art also favours the granting of patents whose claims overlap with existing patents and hence contribute to the growth of thickets.[20]

Patent quality has also been shown to be negatively affected by the resources patent offices are able to expend to examine patent applications. Lemley and Shapiro (Lemley and Shapiro, 2005) point out that at USPTO patent examiners

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[17] See also Bessen and Meurer (2008) and FTC (2011) for discussion of the failure of "notice" created by fuzzy patent claims.

[18] Chakroun (2012), for example, points out that patent information is only available in electronic format for 80 offices out of 184 member states. Even for offices that make their data available, often only limited bibliographic information is available, for example claims are often not available. Information on the legal status of patents is even harder to obtain.

[19] At the same time, non-patent references play a particularly important role in certain technologies in which low-quality patents are particularly frequent, such as software in the U.S. (Graf, 2007).

[20] While fuzzy claim boundaries are hard to measure empirically, patent quality can be gauged by looking at outcomes of opposition and invalidity court cases. Allison *et al.* (2011), for example, find that software patents are particularly likely to be invalidated in court in the US, which may be interpreted as indicative evidence of their low quality.

spend on average only 18 hours working on each patent over a period of three years. In a series of papers Quillen *et al.* (2001; 2003; 2009) document the extent of the pro-applicant bias at USPTO, to the extent that this is manifested in the probability of a patent eventually being granted in spite of initial and subsequent rejections of the application.

Lei and Wright (2009) find that paradoxically examiners at the USPTO spend more time searching for prior art on patents that are later rejected at the EPO than on patents that are granted by the EPO. They argue that this shows that examiners at the USPTO are able to identify weak patents, but that they may be unable to reject as many as would be socially optimal due to pro-applicant rules. A problem of this "pro-applicant approach," which presumes patentability of an invention, is that the USPTO has difficulties in rejecting patent applications, which contributes to the patent quality problem (Allison *et al.*, 2011). Because of the quality problems surrounding patents issued by the USPTO, the FTC has called for more funding to be provided to the patent office for the purpose of improving patent quality and notice, cf. page 16 in (Shapiro, 2000; Federal Trade Commission, 2011).

Harhoff *et al.* (2012) show that patent thickets have a significant negative effect on the probability that a patent application is opposed at EPO. They argue that in a patent thicket the incentive for firms to oppose each other's patent applications falls as each new patent overlaps with the patents of many other firms and a public goods effect arises when one of these opposes the patent. Additionally, firms may avoid opposing a rival's patent if they can expect the rival to retaliate by opposing their own applications. In keeping with this Harhoff *et al.* (Graevenitz *et al.*, 2012; 2011; Harhoff *et al.*, 2012) show that opposition is lowest for firms at the center of patent thickets. This suggests that post-grant opposition cannot be relied upon to reduce the effects of patent thickets on patent quality.

The steep increase in patent filings and their complexity have caused patent offices around the world to build up large backlogs of pending patent applications. Backlogs introduce uncertainty into patent systems by increasing the length of pendency and by exerting additional pressure on patent offices to process more patent applications with the same amount of resources. The increased uncertainty may affect firms' filing behaviour directly, but backlogs can also affect thickets indirectly through the impact they have on the resources available for the examination of patent applications, i.e., the effect on thickets works through the negative impact on patent quality.

The most recent data for USPTO indicate that there were 536,604 patent applications in 2011 and that there were 690,967 patents awaiting a first action by an examiner. This is down from a peak of 771,529 patents in 2008 (United States Patent and Trademark Office, 2011). Hegde (2012) shows that the number of pending patents at USPTO has been increasing since 1997 and had quadrupled by 2009. He reports that first-action pendency[21] nearly quadrupled between 1991 and 2010, from 7.6 months to 25.7 months. Meanwhile Quillen *et al.* (2009) indicate that a comparison of the USPTO application backlog at the end of 2008 with the Net Disposal rate in 2008 a 60 month examination backlog emerges there.[22]

Harhoff and Wagner (2009) document that at the European Patent Office (EPO) the number of pending patent cases per examiner increased from 24 in 1978 to 120 in 1998 and that the average number of claims per patent increased from just under 10 to just over 15 in the same period. The examination period in 1994 lasted on average between 4 years for withdrawn patents to 5 years for refused patents. For granted patents the average duration of examination was 4.57 years. They report that in 1998 EPO received 90,479 patent applications and 330,332 pending applications. Ten years later Brimelow (2011) cites 226,000 applications and 490,000 pending applications. The most recent figure comparable to those provided by Harhoff and Wagner (2009) suggests that average duration of examination at EPO has increased to 5.24 years for 2011.[23]

2.1.1.8 Growth in International Patent Applications

Another important driver of the observed overall surge in worldwide patent filings over the past two decades is the strong increase in the number of subsequent patent filings. They account for more than half of growth in overall worldwide patent filings between 1995 and 2007. According to WIPO (2011), first filings grew on average at 4.2 percent between 1990 and 2007, but subsequent filings grew even faster at 6.8 per cent. These subsequent filings consist overwhelmingly of non-resident filings, which means they are patent applications on the same invention in multiple jurisdictions. The most likely explanation for this increase in the average international patent family size is increased international activity by companies in the form of exporting, foreign direct investment, and licensing. This explanation is supported by at least three observations (WIPO, 2011b). First, PCT national phase entries account for the largest share in the increase in subsequent filings. Second, the increase in non-resident filings comes to a large extent from increased patenting among the world's largest economies, including China. Third, in countries that became more integrated in the world economy, such as Mexico, Russia or South Africa, most of the growth in incoming filings is due to subsequent filings. This would suggest that at least some of the rapid growth in patent applications is driven simply by the increased economic need for international patent protection. Nevertheless, the perceived need to file the same patent application in several jurisdictions is also likely to be influenced by any of the other aforementioned factors.

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[21] First-action pendency measures the time between filing of a patent application and the examiner's formal communication of a preliminary decision regarding patentability.

[22] It should be note that according to USPTO data pendency rates reached a maximum there in 2008 and have slightly declined since.

[23] This number is reported by the Patentia blog here: http://patentia.co.uk/?p=7.

2.1.2 Feedback Effects

Above we discuss six factors that drive the observed growth in worldwide patent thickets. While each these factors are each separately at work, they are likely to interact and create powerful self-reinforcing feedback effects. We note three avenues of feedback in the introduction:

1. The inability of the patent office to weed out a rival's marginal patents creates incentives to register more of these, once it is established that the rival is benefitting from these patents.
2. The increased pendency of patent applications at patent offices creates incentives to apply for vague and overly broad patents to create uncertainty for rival applicants. These patents initially claim much more subject matter than the office finally accepts as patentable subject matter.
3. The threat of injunctions creates immensely strong incentives for firms to build up large portfolios of patents in order to be able to counter patent litigation. As noted above this strategy is only partly successful (Chien, 2008) since it does not protect the applicant faced with a suit from a PAE.

There is to date no work that seeks to identify or is able to quantify the strength of these feedback mechanisms. There is much descriptive and anecdotal evidence for the fact that firms reacted to rivals entering into a portfolio building effort by doing the same in Hall and Ziedonis (2001), Rubinfeld and Maness (2004) and Wagner (2008). Ziedonis (2004) shows that fragmentation of cited patents increases incentives to patent, which is consistent with feedback of this kind. Graevenitz *et al.* (2012) find that the persistence of patenting is reduced in complex technologies. Here firms' patenting efforts react much more strongly to rivals' patenting than in discrete technologies. This too is consistent with feedback. What is lacking in the literature are studies that use shocks to the level of scrutiny provided by a patent office to identify the extent of feedback to the number of marginal patents that firms apply for.

The effects of increasing pendency are even harder to study in such a way that its causal effect can be identified as pendency rates do not display discrete jumps.

In the case of injunctions we also have a number of anecdotes indicating that firms react to these (Grindley and Teece, 1997; Hall and Ziedonis, 2001; Federal Trade Commission, 2003; 2011), but no studies providing solid evidence of causal effects. This is slightly more surprising than in the two cases discussed above, as such studies are possible in principle.

2.1.3 Effects of Patent Thickets on Competition and Innovation

The previous sections of this literature review have shown that patent thickets arose from changes in relatively few firms' patenting strategies, which then fed back to change patenting behavior of many more firms. This raises the question of whether the growth of patent thickets has also affected firms R&D investments and possibly competition in product markets.

The literature on patent systems and patent thickets does not provide systematic analysis of these questions, mostly because they are very difficult to address: collecting the type of data that would allow a comprehensive analysis and developing models that encompass competition, entry, investments and feedbacks between these is challenging. However, there are studies that provide partial answers by studying R&D investments and or market outcomes. These studies are surveyed in this section. At the end of the section we review the findings and connect them to theoretical work that sheds some light on their significance. This also allows us to link this discussion to the question of sunk costs and possible barriers to entry.

2.1.3.1 Review of empirical findings[24]

In their paper on patent thickets in the semiconductor industry Hall and Ziedonis (2001) discuss the level of R&D investment by incumbent firms and show that the propensity to patent (count of granted patents / R&D investment) rises for semiconductor firms after 1982 and is level for manufacturing firms until 1993. This implies that semiconductor firms applied for increasing numbers of patents per R&D dollar between 1982 and 1993. By extension, changes in R&D investment levels cannot account for all of the increase in patent applications that they document. Their analysis is restricted to semiconductor firms for whom they are able to collect information on R&D investments and patent stocks. Also, they exclude firms, which are so large, that it becomes difficult to relate R&D investments to a specific technology or product market.

Their interview analysis supports the view that the patenting increases they observe in the semiconductor industry, are the result of strategic changes in patenting behavior, that are largely divorced from R&D investment choices. While this may seem improbable, there is ample evidence of this in the literature on the semiconductor industry (Federal Trade Commission, 2003; Somaya, 2003). Further evidence supporting the view that R&D investment is not very responsive to patenting incentives is provided by Nicholas (2011). He shows that a reform of the patent system in the United Kingdom in 1883, which significantly reduced patenting fees, had a very strong effect on the number of patents being applied for, but no measurable impact on the level of innovation in Britain, as measured by citations to British patents in the United States.

Once patent thickets arise, effects on levels of R&D spending and on the degree of competition are hard to predict. On the one hand the need to engage in patent portfolio races could be regarded as an increasing cost of doing business, which might reduce investment and activity in affected technologies. On the other, those firms that have successfully built the largest patent portfolios may have gained a strategic advantage. If this strategic advantage leads to greater

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[24] Most of the papers cited in this section identify technology areas affected by patent thickets using counts of patents or use prior knowledge of thickets from other sources such as interviews. In several cases the fragmentation measure is used to identify thickets. The intensity of the thicket is then related either to the count of patents or to fragmentation.

concentration of sales and higher profits in affected product markets, then an increase in R&D investments by some firms could be expected. This mechanism is discussed in more detail below.

Schankerman and Noel (2006a) investigate patenting in the computer software industry. They find that R&D efforts of the software firms in their sample did not change significantly between 1980 and 1999. However, there is some weak evidence of heterogeneity of R&D investment across firms, depending on the concentration of patent portfolios of the firm's four main rivals. Greater concentration of citations in these rivals' patent portfolios implies that a firm undertakes less R&D in some specifications.

Cockburn *et al.* (2010) present evidence from a representative survey of innovating firms in Germany. They have information on the introduction of new products into the market and find significant differences between firms that rely on licenses and those that do not. The ability of firms that must license-in patents to introduce a larger share of innovative products is reduced, if the references in their patents are to a more fragmented set of firms. In contrast, they find a positive effect of fragmentation on innovative performance of firms that do not rely on licenses. These results support the view that effects of patent thickets on R&D investments and competition are not evenly spread amongst firms. In particular, those firms that are not easily held up benefit, whilst those that must license-in technologies, are at a disadvantage. This paper is one of the few to provide direct evidence of effects of thickets on product market competition.

Additional evidence of heterogeneous effects is provided by Cockburn and MacGarvie (2011), who study entry in relatively narrow software markets over the period 1990-2004. They construct counts of patents relevant to a given product market based on a text-search algorithm and IPCs that assigns patents to markets. While this measure certainly captures thickets, it does not measure directly the degree of overlap in these patents. Cockburn and MacGarvie find substantial effects: a 1% increase in the number of existing patents is associated with a .8% drop in the number of product market entrants. They also find that firms that hold relevant patents before entry are substantially more likely to eventually enter a market. Concerns over endogeneity of patent counts are somewhat mitigated by fact that the authors exploit arguably exogenous variation in patent eligibility of software over time. These findings demonstrate that the presence of large numbers of patents affect entry and by extension competition in software markets.

In an analysis of determinants of patenting in Europe, which accounts for effects of patent thickets using the same measure as this report, Graevenitz *et al.* (2012) show that large and small firms react to patent thickets differently. They find that increases in patent thicket density increase patent applications of owners of large patent portfolios but decrease patent applications by owners of smaller patent portfolios in technology areas covering complex technologies like telecommunications. In discrete technologies, such as pharmaceuticals, where thicket density is significantly lower, large and small firms react to variation in thicket density in the same way. These findings are noteworthy because they are consistent with a process in complex technologies through which holders of large patent portfolios increasingly dominate these technologies, making it more difficult for firms holding smaller portfolios to establish a foothold.

Finally, recent work on a number of patent pools reveals that these arrangements, which are created to prevent hold-up, have the effect of reducing innovation and patenting by those firms that are members of the pools (Lampe and Moser, 2010; Joshi and Nerkar, 2011; Lampe and Moser, 2012). These studies focus on small numbers of firms that are caught up in patent thickets and are using cooperative mechanisms to reduce the problem of hold-up. The significance of these studies is that they are able to provide detailed and objective measures of innovative success. For instance, (Lampe and Moser, 2010) study the Sewing Machine Combination (1856-1877) and show that the number of stitches per minute remained constant at about 2000 stitches per minute while the Sewing Machine Combination was active.

The consistency with which authors have recently found that different patent pools have had a stultifying effect on innovation is important. The result suggests that private resolution of hold-up through patent pools does not yield outcomes that would allow us to simply rely on market mechanisms to resolve the problem of thickets as has been suggested by some (Mossoff, 2009).

2.1.3.2 Further findings on specific technologies and specific types of firms:

Here we briefly review the discussion of patent thickets in four specific technology areas. These are semiconductors and information technology, software, biotechnology and nanotechnology. Apart from Nanotechnology, all of these are already cited by Shapiro (2000) as harboring patent thickets. While semiconductor technology and software are areas of research connected to established product markets, biotechnology and especially nanotechnology are more recent technologies for which markets are still nascent or only just developing. This has implications for the effects of patent thickets as this section shows.

- Semiconductors, Telecommunications

  These technologies are the most intensively studied in the literature on patent thickets. As outlined in Section 2.1.1.4 commercially relevant patent thickets arose in semiconductor technology first (Hall and Ziedonis, 2001; Ziedonis, 2004). Here the threat of hold-up had such strong commercial implications that firms changed their patenting strategies (Grindley and Teece, 1997; Hall and Ziedonis, 2001; Somaya, 2003). The patent portfolio races taking place in these technologies overwhelmed USPTO and subsequently also other offices, leading to the backlogs documented in Section 2.1.1.7 (Hall, 2005).

  It is these technologies that are most seriously affected by patent trolls (Berneman *et al.*, 2009) and where patent litigation is affecting important commercial decision such as mergers and acquisitions (Carrier, 2012).

- Software

Software became patentable in the United States via a sequence of court decisions (Bessen and Hunt, 2007; Hall and MacGarvie, 2010). Initially these decisions were viewed as negative for downstream application software firms by financial markets. It appears that its main consequence was an increase in software patenting by hardware firms rather than an increase in inventive activity by software firms, most of which still do not patent today.[25] Thus the result of this subject matter expansion was an increase in defensive patenting rather than an increase in invention.

Innovation in the software industry is typically cumulative and relies heavily on the combination of existing components and processes, which means that interoperability standards are particularly important (Hall and MacGarvie, 2010). Patents on software face considerably uncertainty over patent eligibility and patentability,[26] and built-in difficulties in defining claims (Cockburn and MacGarvie, 2011).

- Biotechnology

Heller and Eisenberg (1998) raised the specter of patent thickets affecting the progress of biomedical research in a widely cited paper. Their argument was based on the increasing use of patents by academic researchers working in this field and the complexity and modularity of biotechnology research (Pénin and Wack, 2008). More recently Cohen *et al.* (Walsh *et al.*, 2003; 2005; Cohen and Walsh, 2008) find that academic researchers are not much impeded by patents. Rather it may be secrecy amongst researchers that is holding back progress. Their results are based on surveys of biomedical researchers in the United States.

Most recently, Huys *et al.* (2009) undertake a detailed analysis of the claims contained in patents related to 22 inherited diseases. From this very detailed analysis they conclude that there is a patent thicket, which affects genetic diagnostic methods. However, this thicket affects mainly non-profit applicants, which may mean that currently the thicket does not have strong commercial implications. The authors also show that many claims on the patents studied are broad and imprecise, leading to high levels of uncertainty. This is likely to be as important, if not more important, than the thicket itself in creating obstacles to commercialization and future research in this technology area.

In 2010 the validity of certain claims in US patents covering genes was thrown into question by Judge Robert W. Sweet (Hemphill, 2012). This case has created additional uncertainty in the field of biotechnology at a time

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[25] Also see Graham and Sichelman (2010) for evidence that patents in this sector are relatively unimportant in obtaining venture capital financing.

[26] In particular prior art search for software patents used to be and continues being problematic.

when the commercial application of the genetic testing and genetic treatments is coming within reach. Thus far there is little evidence of strategic patenting in this technology area that would resemble anything that has been seen in semiconductor technology. However, this may simply be the consequence of the small number of products currently in the market that are using patents held by private entities willing or able to go to court (Holman, 2012).

- Nanotechnology

Nanotechnology is not mentioned by Shapiro (2000). The first discussions of a potential patent thicket in this field are provided by Bawa (2005) and Lemley (2005). However, both of these papers and others at the time are outlining a possibility based on large volumes of patenting and a complex technology. Since then no hard evidence of a thicket in this technology has emerged in the literature.

2.1.3.3 Discussion of empirical findings in the light of theoretical work on market structure

The empirical studies we have reviewed in the previous section indicate that patenting levels are only weakly connected to R&D investment levels, but that patenting strategies are having measureable and economically significant effects on entry and on the competitive position of firms with weaker patent portfolios.

Are these effects of patent thickets linked to the question whether patent thickets create barriers to entry? This section briefly discusses what recent economic theory contributes to answering this question.

As was briefly noted above within patent thickets those firms with larger patent portfolios may be at a strategic advantage. This explains the scramble to buy the patent portfolios of companies such as Nortel in 2011, pitting Google against an alliance of Apple, Microsoft, Sony and RIM. Similarly it explains why Google bought a substantial part of Motorola a little later on that year. Hall and Ziedonis (2001) characterize patenting in the semiconductor industry as a series of “patent portfolio races”. These races have winners and losers. Over time the losers will find it increasingly costly to do business in technologies affected by patent thickets. As patenting strategy becomes increasingly important for high technology firms, competition to build larger patent portfolios is becoming an activity similar to competition to build strong brands or competition to create better innovations.

Competition for stronger brands, better technology (Sutton, 2007) or even a better distribution network (Ellickson, 2007) leads to concentration of markets through a process of escalation of expenditures on advertising, R&D or distribution. As expenditures (sunk costs) necessary to compete effectively rise, more and more firms exit affected markets and these become concentrated. Where sunk costs on R&D are concerned it is mostly assumed by economists that these are beneficial to society and therefore these sunk costs are not usually regarded as antitrust barriers to entry.

The evidence we reviewed in the previous section is consistent with the effects of an escalation of expenditure on patenting by some firms. If these firms can make it harder for others with weaker portfolios to compete, then we can expect more exit and less entry into technologies affected by patent thickets. We would also expect to see firms with weaker patent portfolios struggle to compete in product markets, as it becomes increasingly costly to supply new products that do not infringe on rivals' patents.

In evaluating the welfare effects of an escalation of expenditure on patenting it is clear that no direct social benefits arise from patent portfolio races – firms have generally not increased R&D investments, they have only increased the number of patent applications. Thus if the escalation of expenditure on patenting is not to be classified as creating barriers to entry, then this must be because of a socially beneficial side effect of one of the causes of the escalation of expenditure on patenting. Our review of these causes above uncovered only the reduction in litigation duration and the decreases in uncertainty that were consequences of the creation of the CAFC in the United States. These benefits are very much restricted to that jurisdiction, so that it seems unlikely that they could counterbalance any effects on entry or the composition of firms that escalating expenditure on patenting may have.

The main question our empirical analysis below seeks to answer is whether the process of escalation of expenditure on patenting is having economically measurable effects on entry of UK firms into specific technology sectors. If so, we would argue that this literature review has provided much evidence in favor of the view that patent thickets are creating barriers to entry into patenting in affected technology areas.

2.2 Small and medium-sized enterprises

Policy makers widely believe that small and medium sized (SMEs) businesses create most of the new jobs in modern economies. Therefore, it is often thought that support for SMEs is an important element of policy that is directed towards creation of more employment and growth. It is also true, that previous work for the UK (Anyadike-Danes *et al.*, 2010) has shown that growth comes from a small share of SMEs. Anyadike-Danes *et al.* (2010) find that between 2005 and 2008, only around 6 per cent of registered companies accounted for more than half of total employment growth.

In this section we briefly review work on the survival and growth of SMEs in the literature, with a particular focus on the UK. We focus in particular on the link with firms' patenting activity. This will help us gauge the implications of our findings on how firms' patenting activity is affected by thickets for their performance in the market place.

The most recent study on SMEs and job creation in the United States is by Haltiwanger *et al.* (Haltiwanger *et al.*, 2010). This paper focuses mainly on the question whether SMEs create most private sector jobs. The paper provides new evidence as well as a review of methodological and statistical problems that plague the literature on SMEs and job creation. One main finding is that 40% of jobs created by young start-up firms are eliminated by the exit of these firms after five years. However, those young firms that survive are found to grow much faster than previously existing firms. Haltiwanger *et al.* (2010) seek to replicate results of Neumark *et al.* 2011 (Neumark *et al.*, 2011) who find that small firms contribute disproportionately to net job growth in the U.S. economy. Haltiwanger *et al.* (2010) show that controlling for age removes any correlation between firm size and net job creation. The reason for this is that young firms and especially start-up firms are generally also small firms. In the United States young and small firms disproportionately create and destroy jobs. This means that it is not so much the size of the firm that matters for job creation rather than the age of the firm.

Balasubramanian and Sivadasan (2011) use matched census data for the US manufacturing sector to show a strong, positive correlation between first-time patenting and subsequent growth. They suggest that first-time patentees experience exceptionally high growth as a consequence of introducing new products. While it remains unclear to which degree the patenting decision itself causes the increase in the number products, this evidence is relevant to our study. We look at entry in form of first-time patenting, which means that evidence provided by Balasubramanian and Sivadasan (2011) could suggest that a negative correlation between first-time patenting and thickets is indicative of a negative association between thickets and growth. Helmers and Rogers (2011) offer some evidence on the link between patenting and growth for the UK. They look at start-up companies' patenting decision shortly after they enter the market. They also find a strong positive correlation between start-up firms' patenting decision and their subsequent growth performance.

Regarding firm survival, there are two relevant studies in the United Kingdom: Helmers and Rogers (Helmers and Rogers, 2010) and Disney *et al.* (Disney *et al.*, 2003).

Disney *et al.* (Disney *et al.*, 2003) use the Annual Business Inquiry Respondents Database (ARD), which starts from 1972. The data contains information on all UK manufacturing establishments over 100 employees and a sample of smaller establishments. The authors have to restrict analysis to the period 1986 to 1991 for their study due to changes in methodology in the underlying data. The study is undertaken at the establishment level, but firm level variables are taken into account in the econometric analysis. In 1986 there are 143,000 establishments in the data. Focus of the study is on exit rates, i.e. on survival. Similarly to the US studies it is shown that the unconditional probability of survival declines with age. The decline is greater for single establishments which are typically smaller establishments. Once the authors condition on firms' and establishments' characteristics, they show that it is the firms' initial size that reduces the probability of exit significantly. This effect gets weaker with age. Overall the study shows that in the UK as in the United States small firms are more likely to exit. However, this study does not show whether the probability is disproportionately higher for smaller firms. Also due to the econometric specification chosen it is hard to analyze the effects of age clearly. The authors find that after five years 65% of new establishments exit. For establishments that are part of multi-establishment firms this figure falls. Unfortunately the authors do not provide information on the extent of the reduction for such establishments.

Helmers and Rogers (Helmers and Rogers, 2010) track the survival of a complete cohort of firms registered in Britain in 2001. Of the 162,000 firms in this cohort, just over 30% of the firms have exited after four years. The authors show that "IP active" firms (i.e. firms that have obtained either a patent or a trade mark) are significantly less likely to exit than other firms. This is true both in descriptive results provided and in results conditional on a large number of firm, sector and location specific controls.

The papers reviewed here demonstrate that high rates of entry and exit are characteristic of SMEs in the UK and elsewhere. The more recent literature notes that SMEs which survive beyond the first five years often make an important contribution to job growth and productivity improvements in an economy. Haltiwanger *et al.* (2010) also note the need for a better understanding of the challenges faced by SMEs in these first five years. The literature on the growth and patenting nexus discussed above suggest that firms' decision to patent may contribute to their growth success, especially so in the case of first-time patentees. It is against this background that we analyze the effect of thickets on firms' first-time patenting decision.

3 Empirical Methodology

3.1 Methodology to identify entry and exit of firms

In this report, we are concerned with the ability of firms to compete in particular technology spaces. Therefore we define entry and exit in terms of the patenting behavior of firms rather than as market entry or survival in a market. In the case of entry, this approach has the advantage of providing us with a pool of all potential entrants, that is, we also observe those firms that could have entered a given technology, but chose not to do so. If we were to consider product market entry, we would only observe the set of firms that entered the market but not the entire pool of potential entrants, which makes a study of entry impossible.

In addition, linking the analysis of market entry in a specific market context to patenting activity requires a great deal of work on linking patents to products and product markets. We are not aware of any research that contains this kind of analysis at the level of an entire patent system. For this reason we limit our analysis to entry into patenting activity, which is a reasonable proxy for a firm's ability and desire to compete in a certain area.

3.2 Methodology for the measurement of patent thickets

In this section we discuss a number of ways in which economists have sought to quantify the extent of patent thickets. Some of these measures have also been used to identify effects of patent thickets for different types of patent applicants.

The main problem that patent thickets create for firms are the costs of adequate patent search, the ability to identify all relevant technology, and the consequent threat of hold-up *ex post*, even if adequate due diligence has been done. This problem is most likely to arise for firms producing and selling products that use a complex technology, for instance the producer of a mobile phone. Such a firm cannot effectively ensure that its products do not infringe on patents granted to another firm, because there are usually very many relevant patents (Shapiro, 2000), because the claims in these patents are not always precise (Hall and Harhoff, 2004; Lemley and Shapiro, 2007) and because it is increasingly in the strategic interest of some applicants to hide their applications within the system for as long as the rules allow (Hegde *et al.*, 2009), leading to uncertainty over exactly which patents and claims will be granted in the end.

Therefore, a measure of patent thicket density measuring the hold-up potential existing in different parts of the patent system is needed. In the early literature on patent thickets these were identified using qualitative techniques such as interviews (Hall and Ziedonis, 2001). Both in this paper and in Hall (2005) changes in the number of patent applications that are the result of the growth of patent thickets are documented. While increased patent applications can be a signal that a patent thicket is growing, there are many other possible explanations for increased patent applications such as greater technological opportunity. The measure we describe below uses information on blocking claims to identify technology areas with thickets more precisely.

3.2.1 Capturing hold-up potential

Building on the work cited above Ziedonis (2004) introduced the first measure of hold-up potential into the literature. This measure uses citations from a focal firm's patents to prior art owned by other firms. It then measures the fragmentation (which is the opposite of concentration) of these citations to prior art. The more rival firms are cited by the focal firm, the higher the degree of fragmentation. Ziedonis (2004) argues that as a firm faces a more fragmented set of prior art the firm must build a larger portfolio of patents in order to insure itself against hold-up. The logic here is that of an arms race and it is invoked frequently by patent counsel of large firms in the semiconductor and information technology industries (Hall and Ziedonis, 2001; Federal Trade Commission, 2003; Somaya *et al.*, 2007).

Ziedonis (2004) shows that the degree of fragmentation of prior art has a significant positive effect on the patenting efforts of capital intensive semiconductor firms. The measure has subsequently been used in a number of other studies of patent thickets (Schankerman and Noel, 2006b; Graevenitz *et al.*, 2012; Galasso and Schankerman, 2010).

While the measure captures hold-up potential in the sense that the firm faces many rival firms with similar technological competencies, it does not identify the 'web of overlapping patent rights'. As we have noted above patent thickets affect firms' costs in several ways and hold-up may not be the most significant of these in all jurisdictions. Where hold-up is less important as an immediate threat based on injunctions, the costs of disentangling overlapping property rights may still be significant. Thus an identification of the web of overlapping patent rights as a web or network is useful.

3.2.2 A Measure derived from Social Network Analysis

If patent thickets are "dense webs of overlapping patent rights", the extent of thickets can be measured by the overlap in patents in a technology. This leads us to consider measures of patent thickets derived from the methods of social network analysis (Watts, 2004; Jackson, 2008; Borgatti *et al.*, 2009). Here the patent thicket is conceived of as a network of firms. Within this network the firms are the nodes and the edges represent the degree of overlap between two firms' patent portfolios. In this section we discuss various attempts to implement measures of patent thickets derived from network analytic methods.

Clarkson (Clarkson, 2005) and Clarkson and DeKorte (2006) discuss the use of density measures as applied to citations of prior art on each patent to identify patent thickets. The density measure used is derived from the field of social network analysis (Watts, 2004; Jackson, 2008). Two problems arise with this method: first, it is carried out at the level of the patent while the strategic actor in the thicket is the firm and second, it is based on citations that do not necessarily indicate that the owner of the cited patent is in a position to limit the use of the citing patent. Sternitzke *et al.* (2008) further pursue the idea of network analysis on patent data and they use patent families rather than individual patents and they aggregate up to the applicant. While they use the concept of patent thickets, they do not discuss a method of identification for these.

Building on the idea of overlapping patent rights Graevenitz *et al.* (2012; 2011) define a measure of patent thickets by focusing on the critical references to older patents (prior art) inserted in recent patent applications. Building on the EPO's classification of citations on patent documents (Webb *et al.*, 2005) they identify critical references – also known as X and Y citations - that indicate that the cited firm's patent application contains prior art which limits one or more claims in the citing patent application. This type of citation indicates that at the application stage there is overlap between the patent claims of two firms. Graevenitz *et al.* (2012; 2011) then define a patent thicket as a network of links based on critical references between firms' patent portfolios. Most likely, the patent thicket as defined by Shapiro (2000) is more extensive than that defined by these links. Nonetheless, we expect that both thickets overlap substantially.

Graevenitz *et al.* (2012; 2011) introduce the concept of firm triples to identify patent thickets. A *triple* is defined as a group of three firms in which each firm has critical prior art limiting claims on recent patent applications of each of the other two firms. Clearly such a group of firms is caught in the most basic type of a patent thicket created by potentially overlapping patent portfolios. While two firms holding mutually limiting or blocking patents may resolve the threat of hold-up by contract, this is no longer as simple for firms in a triple. Here the relative value of any two firms' patents depends on the actions of a third firm, making bargaining more difficult. Where multiple triples arise within the same network of firms it is highly likely that these will overlap creating ever more complex bargaining problems that require recourse to patent pools or standards for their resolution.

It might be argued that the EPO identifies critical references in order to allow examiners to redraw claims in a patent document so as to reduce or eliminate the overlap that is identified. If this were completely successful the triples measure would not correlate with real patent thickets or any of their effects. This view is to place extreme faith in the ability of the EPO to remedy overlapping claims. In our view the EPO is unlikely to identify all potentially overlapping claims nor are examiners likely to remove all threats arising from them. This becomes apparent in studies showing that critical references are highly significant predictors of post grant opposition at EPO (Harhoff and Reitzig, 2004). Thus the triples measure identifies groups of firms who are likely bound together by further overlapping patents covering similar technologies used by them.

Graevenitz *et al.* (2011) show that counts of triples by technical area are significantly higher for technologies classified as complex than for areas classified as discrete by Cohen *et al.* (2000). More interestingly Graevenitz *et al.* (2012) provide a model of patenting efforts in complex and discrete technologies that provides counter-intuitive predictions for effects of technological opportunity on patenting in complex technologies. They show that their predictions are supported empirically, when they use the triples measure as a proxy for complexity of technologies. Also, Harhoff *et al.* (2012) show that post-grant opposition is affected by patent thickets in ways predicted by Farrell and Merges (2004). This study shows that patent applications of firms in the midst of patent thickets are less likely to be opposed than applications of firms on the fringes of thickets. This finding is hard to rationalize, in the absence of patent thickets. In sum, these studies, which all compare patenting behavior across technology areas and time, indicate that the measure successfully proxies changes in the density of thickets.

Graevenitz *et al.* (2011) also point out that the concept of a triple is the same as a fully transitive triad. Triads were first identified by Holland and Leinhardt (Holland and Leinhardt, 1976), as local structures that characterize the global characteristics of a network, when they introduced the triad census. More recently, Milo *et al.* (2002; 2004b) provide comparisons of the information contained in different components of the triad census for different types of networks. They show that the citation networks between websites on the World Wide Web and several social networks can be best characterized using the fully transitive triad (or triple).

In Section 4.1 we discuss the first evidence we know of that triples are also highly significant network motifs in networks of critical patent references, such as those analyzed by Graevenitz *et al.* (Graevenitz *et al.*, 2012; 2011) and Harhoff *et al.* (Harhoff *et al.*, 2012).

Table 2: Descriptive Statistics on Triples by Technology Area 1981-2009

	Area	*Total Triples*	*Average per year*	*Median per year*	*Min.*	*Max.*
1	Electronics / energy	2,472	181	208	1	245
2	Audiovisual	6,561	423	466	3	682
3	Telecom	15,815	1161	1165	2	1860
4	Digital communication	4,035	397	426	1	525
5	Basic Comm. processes	455	44	38	1	90
6	Computer technology	7,818	625	703	3	908
7	IT Methods	10	2	2	1	3
8	Semiconductors	4,423	335	374	1	559
9	Optics	3,000	197	255	1	277
10	Measurement	373	35	36	1	60
11	Control	66	8	6	1	15
12	Medical technology	711	53	58	3	78
13	Organic chemistry	1,618	104	91	2	181
14	Biotechnology	185	50	55	1	77
15	Pharmaceuticals	316	40	30	1	73
16	Polymers	891	44	36	1	86
17	Food chemistry	17	2	2	1	3
18	Materials chemistry	604	30	29	1	53
19	Materials / metals	94	8	8	1	14
20	Surface technology	32	3	3	1	4
21	Chemical engineering	46	5	5	1	7
22	Environmental technology	76	10	7	1	22
23	Handling	96	9	10	1	14
24	Machinetools	104	14	17	1	20
25	Engines/pumps/turbines	2,212	203	225	1	305
26	Textiles/paper machines	672	57	53	1	99
27	Other machines	37	6	4	1	11
28	Thermal processes	51	6	6	1	9
29	Mechanical elements	244	28	27	1	43
30	Transport	2,770	295	314	1	441
31	Furniture/games	21	3	3	1	6
32	Other consumer goods	114	20	18	1	30
33	Civil engineering	90	9	9	1	16
	Total	**56,029**	**567**	**441**	**1**	**1860**

4 Effects of Patent Thickets on Entry and Survival

In this section we use the triples measure described above to provide a descriptive analysis of patent thickets in European patent data and we describe the exposure of UK SMEs to these thickets. We then examine the possible impact of the presence of patent thickets on SMEs in the UK by looking at the probability of entry into patenting in a particular technology sector as a function of EPO patent application thickets in that sector.

4.1 A descriptive analysis of patent thickets

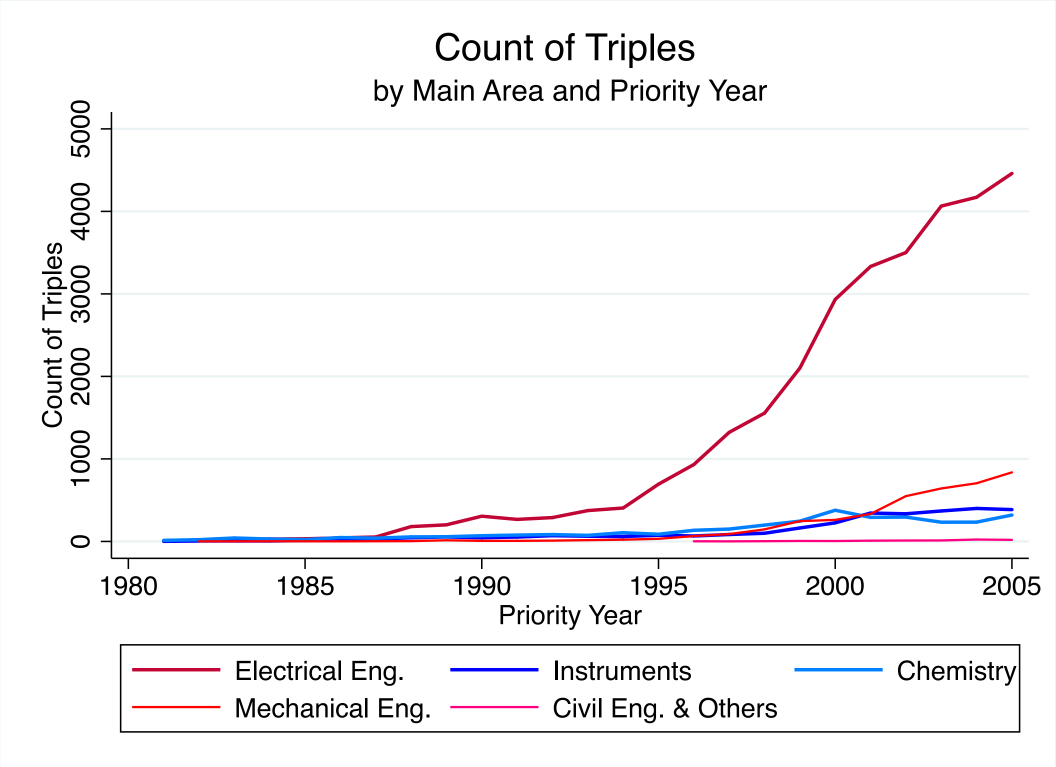
This section provides a descriptive analysis of patent application thickets in the patent system of the European Patent Office (EPO) using the triples measure of patent thicket density introduced in Section 3.2.2. In Appendix 6.1 we provide a validation analysis of this measure. It shows that the triples measure is a statistically highly significant measure of network structure, just as in the examples analyzed by (Milo *et al.*, 2004b).

4.1.1 Descriptive analysis of triples counts

Table 2 above sets out descriptive statistics for the triples measure by technology area. In Figure 2 below we segment patent applications at the EPO into five main technology areas based on the 2008 version of the ISI-OST-INPI technology classification (Schmoch, 2009). We then plot the number of triples for each of these technology areas between 1978 and 2005.

Figure 2 clearly shows that the count of triples in Electrical Engineering far outstrips the counts of triples in any of the other main technology areas. This is commensurate with the earlier finding of Hall (2005) that the increase in patent applications at USPTO after 1984 was primarily due to firms operating in Information and Communications Technologies (ICT). At the EPO these firms patent primarily in the main technology area of Electrical Engineering.

Figure 2



In an earlier version of this graph Graevenitz *et al.* (2012) show that the increases in triples are not affected by differential rates of patenting in the five main technology areas. We have checked that this remains true also when normalizing by the total weighted patent applications at EPO - compare Table 3 below.

The ISI-OST-INPI technology classification (Schmoch, 2009) also allows us to further segment each main technology area into constituent technology areas. Below we document the evolution of the number of triples in three main technology areas by technology area, these are: Electrical Engineering (Figure 3), Instruments (Figure 4) and Chemistry (Figure 5)

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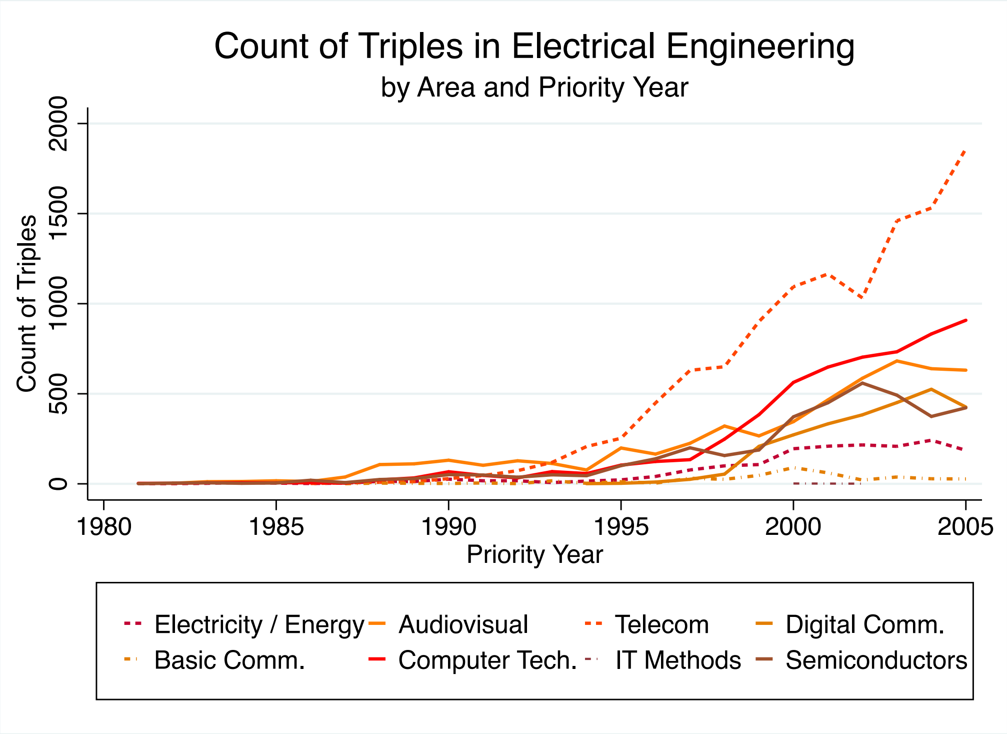
Figure 3



These three figures largely confirm, what Figure 2 already indicated. The increases in triples counts are very high in almost all technology areas within the main area Electrical Engineering, while they are significantly lower in almost all technology areas within the main areas Instruments and Chemistry.

Some noteworthy detail emerges, however:

- In Electrical Engineering triple counts are particularly high in the areas of Telecommunications, Audiovisual Technology, and Computer Technology.
- In Instruments there is a five-fold increase in the level of the triples count between 1995 and 2000 in Optics. We found that the initial growth in triples was driven mainly by patenting of the following firms: Canon, Matsushita, Seiko, and Epson. Subsequently the high level of triples is due to Sony, Ricoh and Samsung.
- In Chemistry we would not expect patent thickets to play a major role, with the possible exception of Biotechnology where it has been repeatedly argued that they may exist. Figure 5 indicates that if at all a

patent thicket may be growing in the area of Organic Chemistry where triples counts doubled between 2000 and 2005.

Figure 4

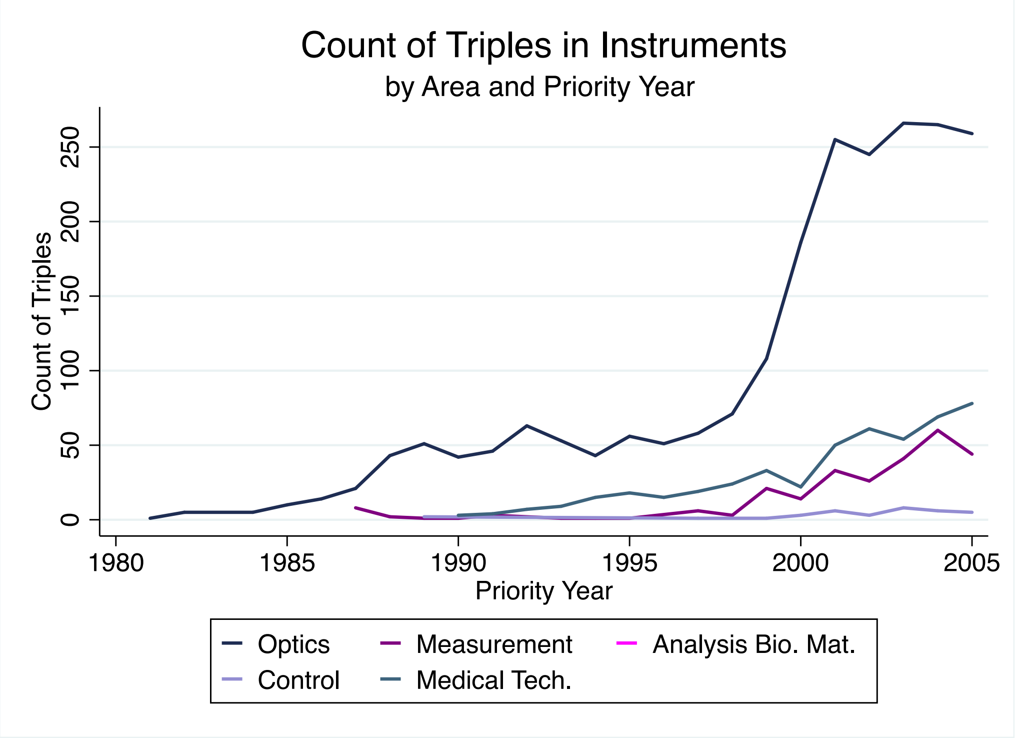
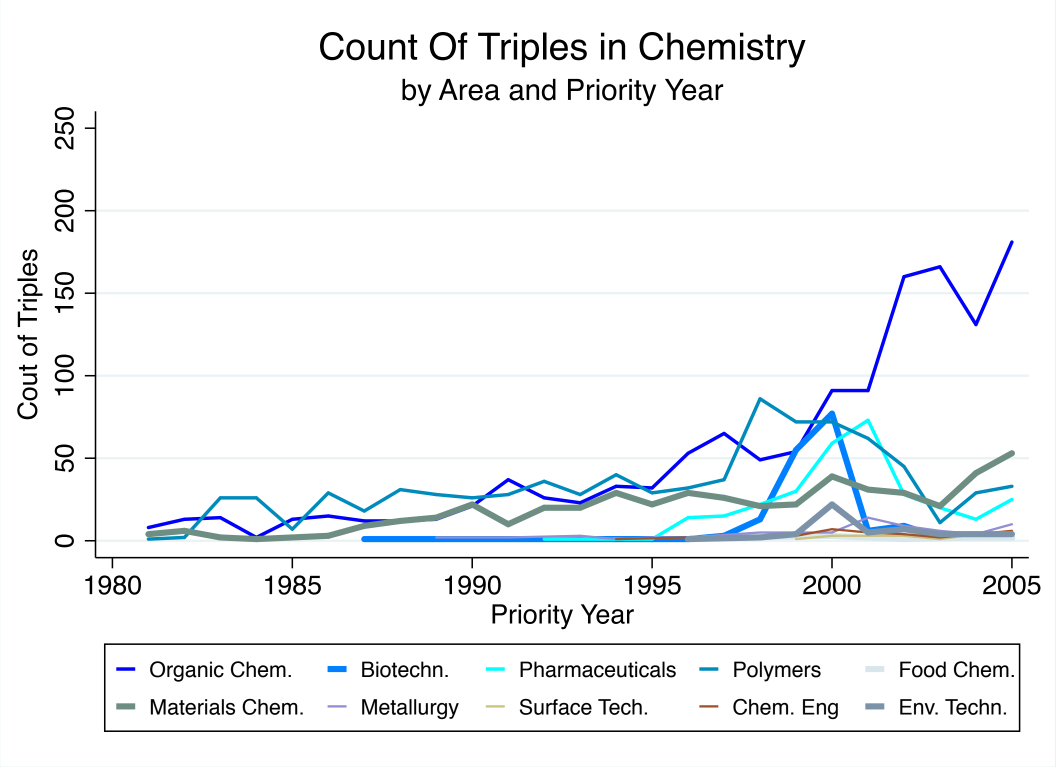
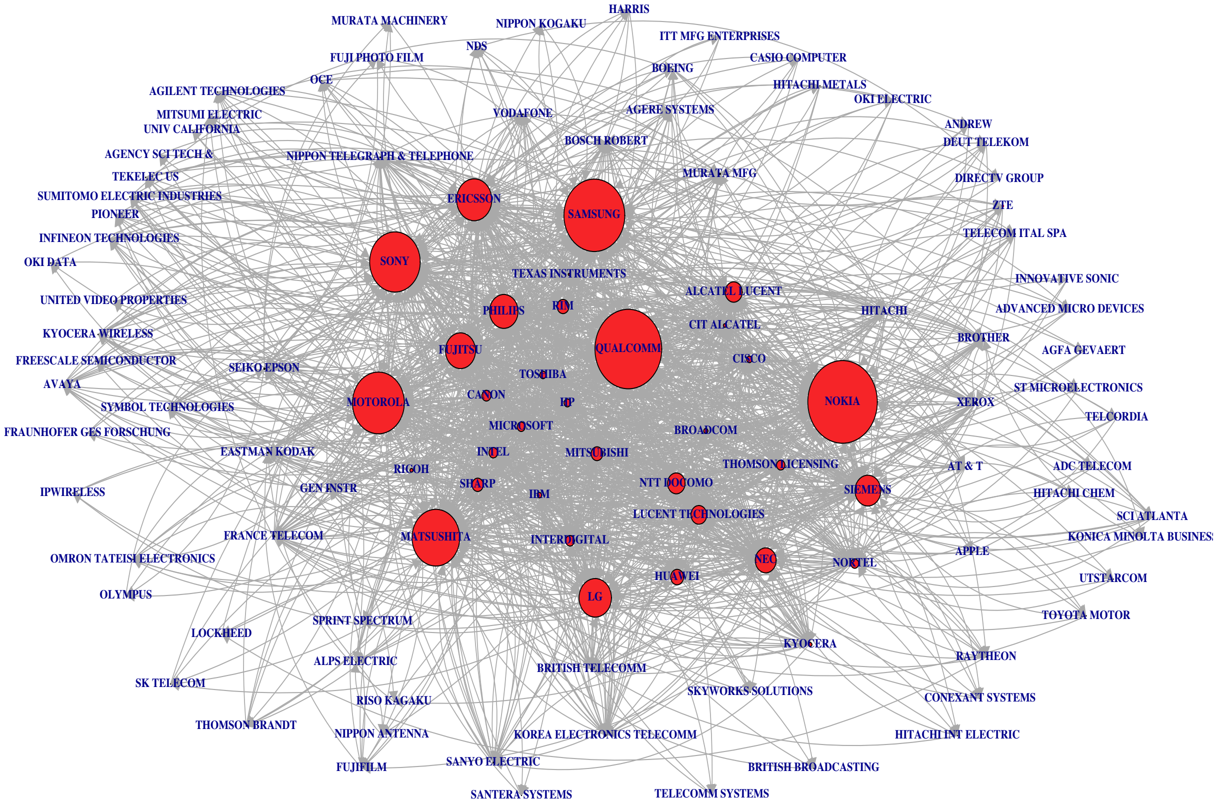


Figure 5



While these figures provide an indication of how dense patent thickets are in different technology areas, they do not show the structure of thickets and the firms involved in it. Figure 6 below shows the network of critical references, which contributed to one or more triples, in the technology area Telecommunications in the year 2005. The nodes in this figure represent individual firms. The size of the node represents the number of limiting citations to the firm's prior art. This can be interpreted as the importance of the firm's patents for the commercialization of telecommunications technology by rival firms. The position of individual nodes is random. Most of the firms in Figure 6 that own many limiting patents are also frequently involved in patent litigation.[27] This is an additional indication that the measure of thicket density based on critical references is a helpful way of capturing patent thickets.[28]

Figure 6 – Network of Critical References in the Technology Area Telecommunications in 2005



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[27] A discussion of patent litigation maps related to smartphones can be found here: http://www.techdirt.com/blog/wireless/articles/20101007/22591311328/meet-the-patent-thicket-who-s-suing-who-for-smartphone-patents.shtml .

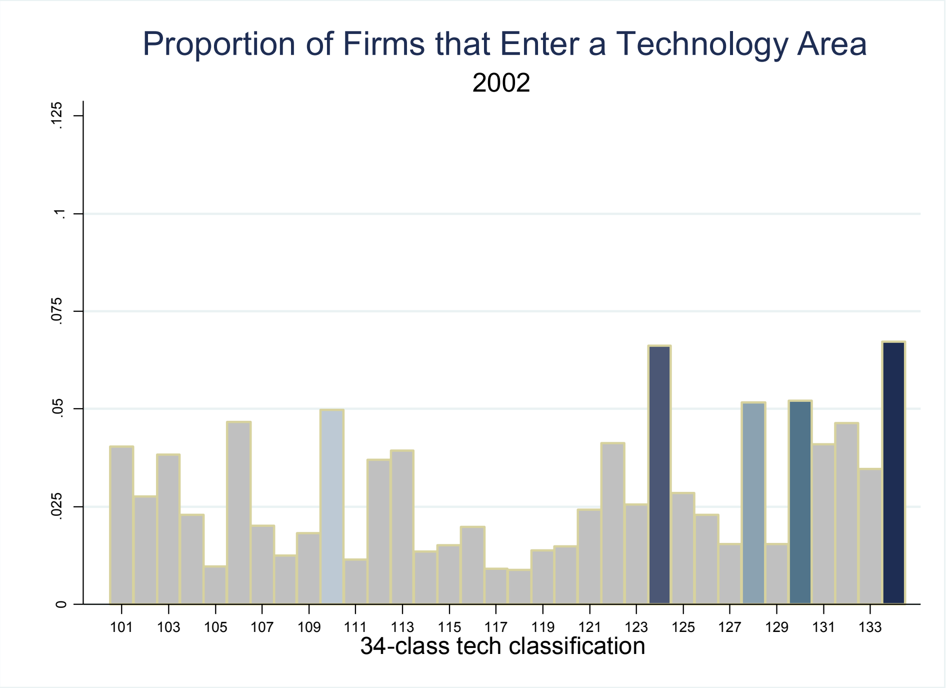
[28] It is possible to create multiple snapshots of a figure like Figure 6 below to show the evolving nature of the patent thicket in Telecommunications. However, we prefer to depict the evolution of the thickets using time series of the triples counts as set out in Figures 2-5 above as a series of figures such as figure 6 below contain too much information to be easily analyzed.

4.2 Exposure of UK SMEs to patent thickets at the EPO

In this section we set out a descriptive analysis of the technology areas and industry sectors that UK firms are active in. The graphs set out below show that UK firms tend not to enter those technology areas that are most heavily affected by patent thickets.

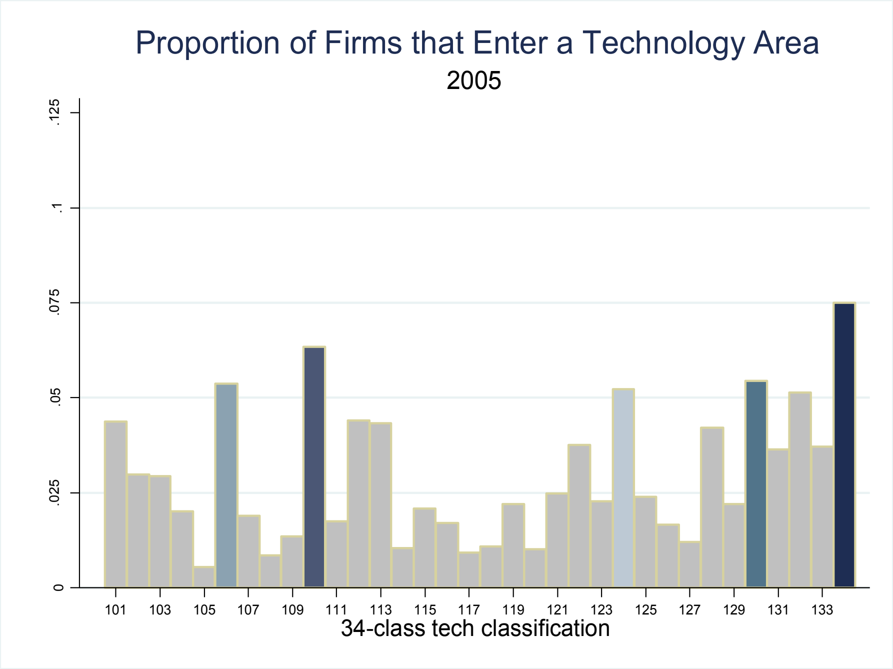
The first three figures below (Figures 7-9) describe which proportion of entrants in a given cohort chose to enter a given technology area. We highlight those five technology areas, which are chosen most frequently in each cohort. The histograms reveal that Civil Engineering has persistently attracted the highest proportion of new patenting entrants out of each cohort. Within the technology areas most affected by patent thickets, those in the main area Electrical Engineering, we find that the proportion of UK firms entering Electricity/Energy, Computer Technology and Measurement is persistently at or close to 0.05% of each cohort. The histograms do not reveal strong visual evidence that the growth of patent thickets in some technology areas is having strong effects on the proportion of entrants choosing those technology areas.

Figure 7



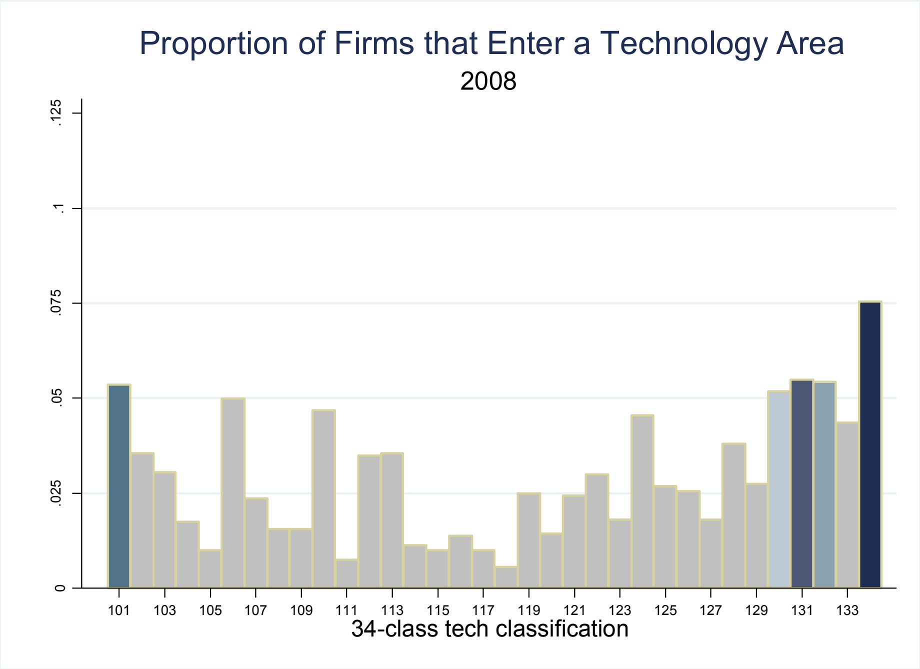
Note: 34-class tech classification, in bold face the five classes highlighted above which attract the highest share of entry: 101 Electricity/Energy, 102 Audiovisual Technology, 103 Telecoms, 104 Digital Communication, 105 Basic Communications Processes, 106 Computer Technology, 107 IT Methods, 108 Semiconductors, 109 Optics, 110 **Measurement**, 111 Analysis Bio Materials, 112 Control, 113 Medical Technology, 114 Organic Chem, 115 Biotechnology, 116 Pharmaceuticals, 117 Polymers, 118 Food Chemistry, 119 Materials Chemistry, 120 Materials/Metallurgy, 121 Surface Technology, 122 Chem Engineering, 123 Environmental Technology, 124 **Handling**, 125 Machine Tools, 126 Engines/Pumps/Turbines, 127 Textiles/Paper Machines, 128 **Other Machines**, 129 Thermal Processes, 130 **Mechanical Elements**, 131 Transport, 132 Furniture/Games, 133 Other Consumer Goods, 134 **Civil Engineering**.

Figure 8



Note: Refer to Figure 8 above for the list of class names.

Figure 9

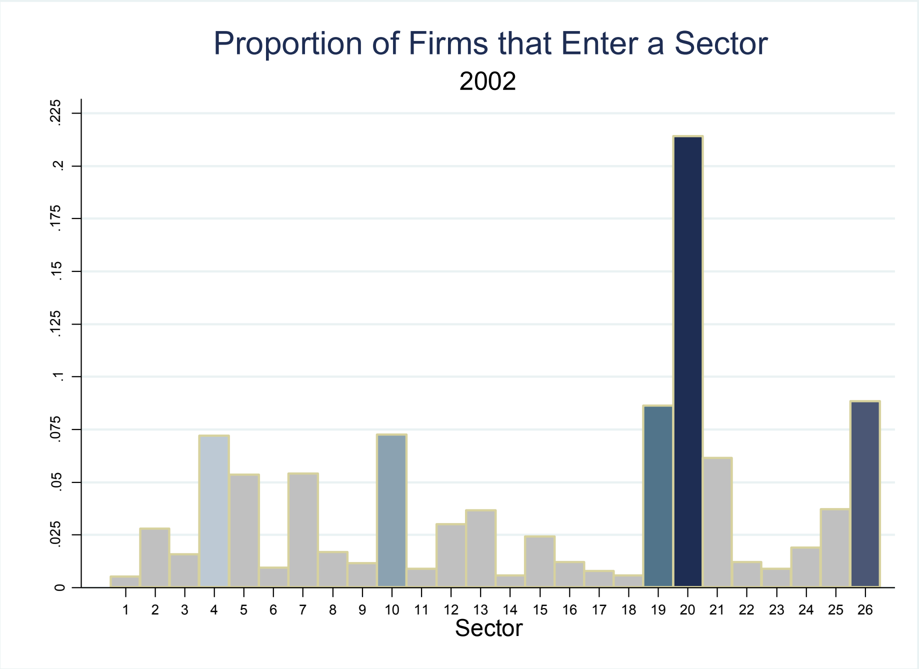


Note: Refer to Figure 8 above for the list of class names.

Figures 10-12 provide a descriptive breakdown of entry by market sector in which firms are active. We assign each firm to a principal sector on the basis of information contained in a number of waves of the FAME data sets. These figures show that the business sectors giving rise to new entry into patenting most frequently change much less over time than the technology areas shown in

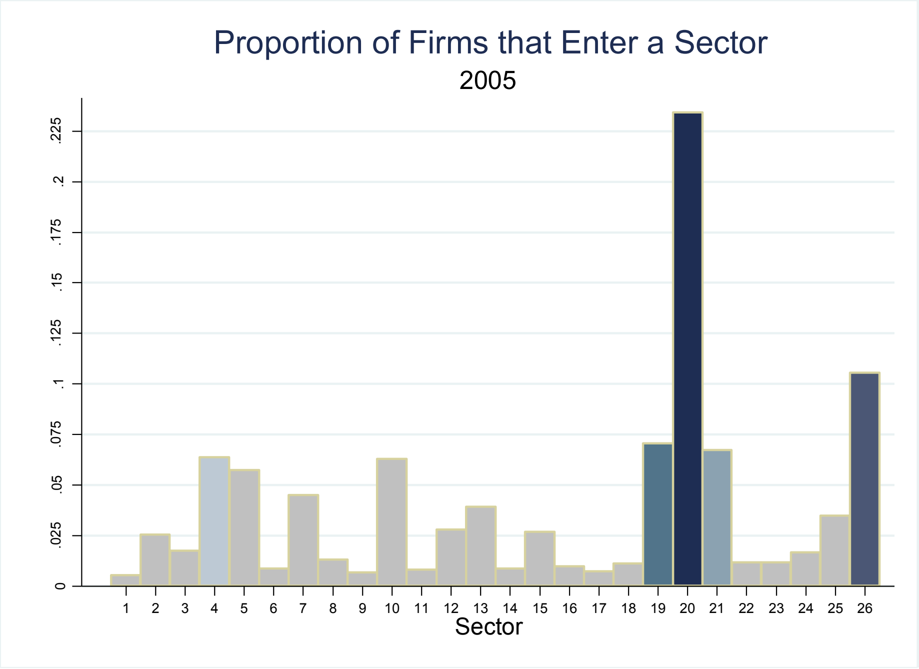
Figures 7-9. Most entrants are active in Business Services, R&D services or Wholesale Trade.

Figure 10



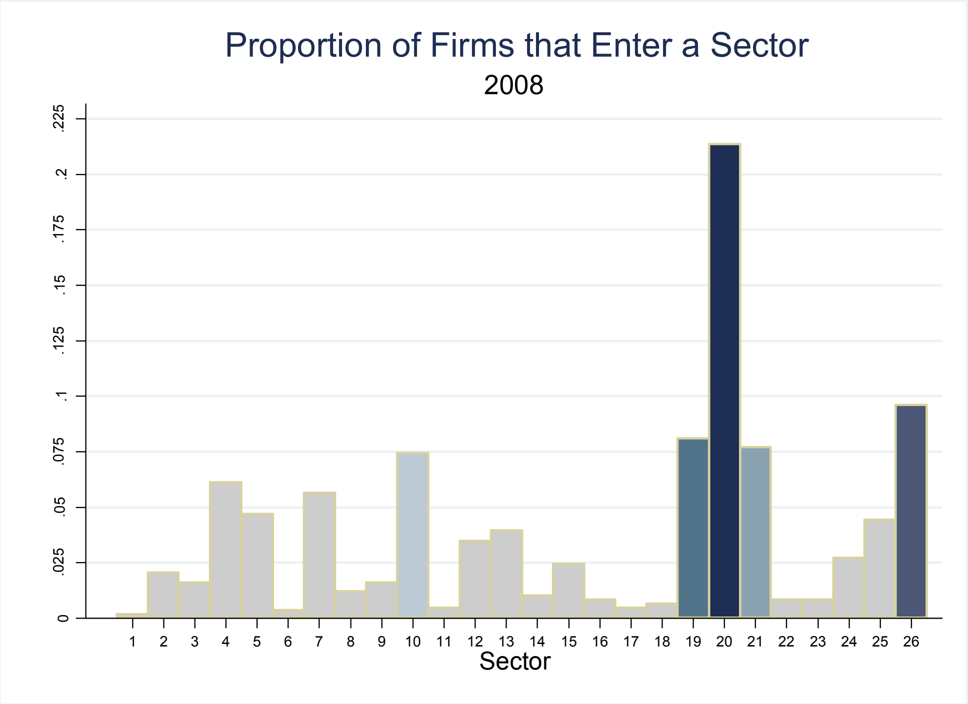
Note: 1 Basic metals, 2 Chemicals, 3 Electrical machinery, 4 **Electronics & instruments**, 5 Fabricated metals, 6 Food, beverage, & tobacco, 7 Machinery, 8 Mining, oil&gas, 9 Motor vehicles, 10 **Other manufacturing**, 11 Pharmaceuticals, 12 Rubber & plastics, 13 Construction, 14 Other transport, 15 Repairs & retail trade, 16 Telecommunications, 17 Transportation, 18 Utilities, 19 **Wholesale trade**, 20 **Business services**, 21 Computer services, 22 Financial services, 23 Medical services, 24 Personal services, 25 Publishing, 26 **R&D services**.

Figure 11



Note: Refer to Figure 10 above for the list of class names.

Figure 12



Note: Refer to Figure 10 above for the list of class names.

Combining this finding with the clear variability in the proportion of entrants choosing specific technology areas, we see that UK firms active in specific product markets change the type of technology area they enter over time. Whether this is in response to growing patent thickets cannot be determined from the descriptive analysis. The econometric results provided in the following section show this to be the case.

4.3 Patent thickets and entry

As we discuss earlier in this report, one of the functions of the patent system is to allow inventors to exclude others from practicing their invention. The implication of this fact is that in technology areas where there are large numbers of patents, it might be more difficult for new firms to enter because the technology space is effectively covered by patents held by existing firms. By itself, this is not necessarily a phenomenon requiring some kind of policy intervention, as it is to be expected if the patent system is doing its job. However, in sectors where firms must draw on technologies for which their competitors hold patents in order to produce, it is possible that the presence of many overlapping patents held by incumbent firms could discourage the entry of new firms with novel ideas, because such entry requires negotiating access to a prohibitively large number of other technologies in order to incorporate their invention(s) in a product. As we review earlier in this report, many researchers have identified sectors based on complex technologies and standards as sectors of this kind (Shapiro, 2000; Hall and Ziedonis, 2001; Arora *et al.*, 2008).

In order to capture the idea that some sectors may be characterized by collections of patents held by different firms, but at least some of which are jointly required for production, we use the previously described measure of patent thickets developed by Graevenitz *et al.* (2012, 2011), henceforth vGWH. The idea of this measure, which is based on patent applications to the EPO, is that it can proxy for the extent to which a sector contains many patents with possibly overlapping claims. Because it identifies situations where groups of firms are applying for similar patents that potentially block each other, it identifies technology areas where there is active patenting by existing firms that have strategic relationships with one another. As argued earlier, such technology areas are usually those where products are also complex and draw on technologies held by multiple firms. The inquiry we undertake here is whether UK firms are discouraged from entering such technology areas. Therefore we examine the influence of this measure on the probability that a UK firm enters a technology sector, where entry is defined as the priority year of the first patent in the relevant technology sector that is applied for at the European Patent Office (EPO) or the UK Intellectual Property Office (UKIPO). The sample we use for estimation includes all the firms with at least one patent application at the IPO in the UK or the EPO during the 2001-2009 period.

The information for UK firms is drawn from the FAME database described in the appendix. Because this database includes all firms, it is very large, and includes mostly non-patenting firms. We do two things to deal with this problem: 1) we delete all firms in the industrial sectors with little patenting (amounting to less than 2 per cent of all patenting); and 2) we choose a one per cent sample of non-patenting firms to compare to our patenting firms.[29] The latter selection results in about equal numbers of patenting and non-patenting firms for estimation. In principle, this approach will result in an endogenous (choice-based) sample, but because we analyze at the firm-34 technology class level rather than at the firm level, we do not expect this to introduce a large amount of bias to the estimates. In addition, we delete all firms for which we have no size measure (the assets variable is missing).[30] The resulting sample is the set of FAME firms with non-missing assets in manufacturing, oil and gas extraction and quarrying, construction, utilities, trade, and selected business services including financial services.[31]

The technology sectors that we use are those defined by vGWH and based on the 2008 version of the ISI-OST-INPI technology classification (denoted TF34 classes).

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[29] Because each firm can in prinicple generate 34 sectors*8 years = 272 observations, we are unable to include the full FAME dataset in our estimation. In practice, we found including the non-patenters made little difference to our estimates.

[30] Earlier estimations included these firms along with a dummy for missing assets, and we found that the results were almost identical with and without the firms that were missing data. In the interests of computing time and space, we therefore removed them.

[31] We have excluded a number of sectors such as agriculture, other mining, education services, and hotels and restaurants where patenting was negligible. These sectors accounted for less than 2 per cent of total patenting in the UK.

Table 3
Patenting by Fame firms on Patstat (priority years 2002-2009)

	*Weighted by #owners & #classes**			*Sector shares*		*Total # of EPO patents*	*Number of EPO triples@*	*Triples per 1000 patents*
Technology categories	*GB pats*	*EP pats*	*Total*	*GB pats*	*EP pats*			
Elec. machinery, energy	1,741	1,251	2,992	6.5%	4.2%	54,560	1,590	29.1
Audiovisual technology	822	644	1,465	3.1%	2.2%	32,935	3,708	112.6
Telecommunications	1,425	1,434	2,859	5.3%	4.9%	58,402	10,176	174.2
Digital communication	696	816	1,512	2.6%	2.8%	34,759	3,129	90.0
Basic comm processes	347	159	506	1.3%	0.5%	9,709	149	15.3
Computer technology	1,916	1,560	3,476	7.1%	5.3%	58,231	5,251	90.2
IT methods for mgt	327	275	601	1.2%	0.9%	8,499	8	0.9
Semiconductors	316	313	629	1.2%	1.1%	23,555	2,485	105.5
Optics	472	574	1,046	1.8%	1.9%	27,504	1,818	66.1
Measurement	1,504	1,716	3,220	5.6%	5.8%	42,544	278	6.5
Analysis bio materials	175	506	681	0.6%	1.7%	10,815	0	0.0
Control	754	657	1,411	2.8%	2.2%	17,022	52	3.1
Medical technology	1,258	1,887	3,144	4.7%	6.4%	61,448	492	8.0
Organic fine chemistry	231	1,840	2,071	0.9%	6.2%	38,544	941	24.4
Biotechnology	242	1,076	1,317	0.9%	3.6%	29,926	27	0.9
Pharmaceuticals	357	2,241	2,598	1.3%	7.6%	48,661	100	2.1
Macromolecular chem	141	300	441	0.5%	1.0%	20,234	175	8.6
Food chemistry	125	520	645	0.5%	1.8%	9,248	9	1.0
Basic materials chemistry	372	1,174	1,546	1.4%	4.0%	26,212	260	9.9
Materials metallurgy	201	347	548	0.7%	1.2%	16,024	53	3.3
Surface tech coating	372	363	735	1.4%	1.2%	16,492	25	1.5
Chemical engineering	631	854	1,485	2.3%	2.9%	23,179	26	1.1
Environmental tech	384	449	833	1.4%	1.5%	12,054	42	3.5
Handling	1,245	984	2,229	4.6%	3.3%	29,114	56	1.9
Machine tools	508	402	909	1.9%	1.4%	23,146	95	4.1
Engines,pumps,turbine	1,021	1,149	2,170	3.8%	3.9%	31,491	1,673	53.1
Textile and paper mach	288	339	627	1.1%	1.1%	22,460	429	19.1
Other spec machines	892	722	1,614	3.3%	2.4%	28,581	27	0.9
Thermal process and app	501	305	806	1.9%	1.0%	14,664	47	3.2
Mechanical elements	1,437	988	2,424	5.3%	3.4%	31,590	220	7.0
Transport	1,289	1,111	2,400	4.8%	3.8%	47,497	2,381	50.1
Furniture, games	1,309	766	2,075	4.9%	2.6%	19,048	17	0.9
Other consumer goods	768	572	1,341	2.9%	1.9%	18,888	114	6.0
Civil engineering	2,864	1,191	4,055	10.6%	4.0%	27,954	68	2.4
Total	**26,927**	**29,483**	**56,409**			**974,988**	**35,921**	**36.8**
Electrical engineering	7,589	6,451	14,040	28.2%	21.9%	280,648	26,496	94.4
Instruments	4,162	5,339	9,502	15.5%	18.1%	159,332	2,640	16.6
Chemistry	3,055	9,164	12,219	11.3%	31.1%	240,574	1,658	6.9
Mechanical engineering	7,179	6,000	13,179	26.7%	20.4%	228,543	4,928	21.6
Other Fields	4,942	2,529	7,470	18.4%	8.6%	65,891	199	3.0

* Weighting by owners is innocuous, since they all get added back into the same class cell.
Weighting by classes means that a patent in multiple TF34 sectors is downweighted in each of the sectors.
@ Triples based on all EPO patenting, priority years 2002-2009 (see text for definition and further explanation).

The list is shown in Table 3, along with the number of EPO and UKIPO patents applied for by UK firms in the Fame database with priority dates between 2002 and 2009. A comparison of the frequency distribution across the technology classes in the two patent offices clearly shows that firms prefer to apply for chemical patents at the EPO whereas in other technologies they slightly prefer to apply at the UKIPO.

A complication is that each firm can enter into any one of the 34 technology sectors, and many of the firms enter more than one, as one might have expected. More than half the firms patent in more than one sector, and 10 per cent patent in more than four. Our solution to this problem is to treat each entry possibility separately for each firm. That is, we have about 29,000 firms, each of which can potentially enter into each one of the 34 technology sectors, yielding about one million observations at risk. We cluster the standard errors by firm, so the model is effectively a firm random effects model for entry into the 34 sectors.

In order to isolate the possible impact of triples on entry into patenting, it is important to control for other characteristics that affect the probability that a firm chooses to patent in a particular technology sector. First, it is well known that firm size and industry are important predictors of whether a firm patents at all (Bound *et al.* 1984 for US data). Hall *et al.* (2012) show this for UK patenting during the period studied here. In our entry regressions, we include the logarithm of the firm's reported assets and a set of two-digit industry dummies to control for these characteristics.[32] Second, we would expect that technology sectors with many triples are also sectors with many patents, and it is therefore more likely that a firm will patent in that sector, other things equal. To control for this effect, we include the logarithm of the aggregate EP patent applications in the technology sector during the year, and we normalize the count of triples by aggregate patenting in the same sector, so that the triples variable represents the intensity with which firms potentially hold blocking patents on each other *relative to* aggregate patenting activity in the technology.

In the appendices, we describe in some detail the hazard models that we estimate (section 6.3) and we show a number of exploratory regressions made using various models and specifications in the appendix tables A3 and A4 (Section 7). None of the choices made substantive differences to the effects of interest and in this part of the report we focus on the results from our preferred specification, the log-logistic accelerated failure time model, estimated with stratification by two-digit industry. The effect of the stratification is that we allow firms in each of the industries to have different means and standard deviations of the time until entry into patenting. That is, each industry has its own "failure" time distribution, where failure is defined as entry into patenting in a technology area, but this distribution is also modified by the firm's size, aggregate patenting in the technology, and the triples density.

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[32] The choice of assets as a size measure reflects the fact that it is the only size variable available for the majority of the firms in the FAME dataset.

Our estimation sample has about 29 thousand firms and one million firm-TF34 sector combinations. During the 2002-2009 period there are 12,991 entries into patenting for the first time in a technology sector by these firms. Table A1 shows the distribution of the number of entries per firm: 3,507 enter one class, and the remainder enter more than one. Table A2 shows the FAME population of UK firms in our industries, together with the shares in each industry that have applied for a UK or EP patent during the 2001-2009 period. These shares range from over 10 per cent in pharmaceuticals and R&D services to less than 0.1 per cent in construction, oil and gas services, real estate, law, and accounting.

Our estimates of the model for entry into patenting are shown in Table 4 below. The first column is for estimates that have not been corrected for the fact that we sampled non-patenting firms rather than including the entire population, and the next two columns are weighted estimates that do adjust for the sampling strategy. Correcting for sampling made little difference to the coefficients of interest, although it reduces the firm size coefficient quite a bit, because non-patenters tend to be smaller firms.[33] The coefficient estimates shown are elasticities of the probability that a firm will enter into patenting in a particular technology in response to a change in the variable.

Table 4

Hazard of entry into patenting in a TF34 Class

998,219 firm-TF34 observations with 12,991 entries (29,435 firms)

	Accelerated failure time - Log Logistic		
Variable	*Unweighted*	*Weighted by sampling probability*	
Log (triples density	-0.121***	-0.123***	-0.128***
in class)	(0.007)	(0.007)	(0.008)
Log (patents in class)	0.678***	0.696***	0.738***
	(0.020)	(0.020)	(0.022)
Log assets	0.156***	0.048***	0.052***
	(0.006)	(0.006)	(0.006)
Log (triples density)			0.004**
* Log assets			(0.002)
Log (patents)			-0.032***
* Log assets			(0.007)
Industry dummies	***stratified#***	***stratified#***	***stratified#***
Year dummies	***yes***	***yes***	***yes***
Log likelihood	-59,813.9	-51,369.1	-51,357.8
Degrees of freedom	35	35	37
Chi-squared	2178.2	1982.1	1992.5

Coefficients for the hazard of entry into a patenting class are shown.

Standard errors are clustered on firm. *** (**) denote significance at the 1% (5%) level.

Time period is 2002-2009. Sample is all UK firms with nonmissing assets

Estimates are stratified by industry - each industry has its own baseline hazard.

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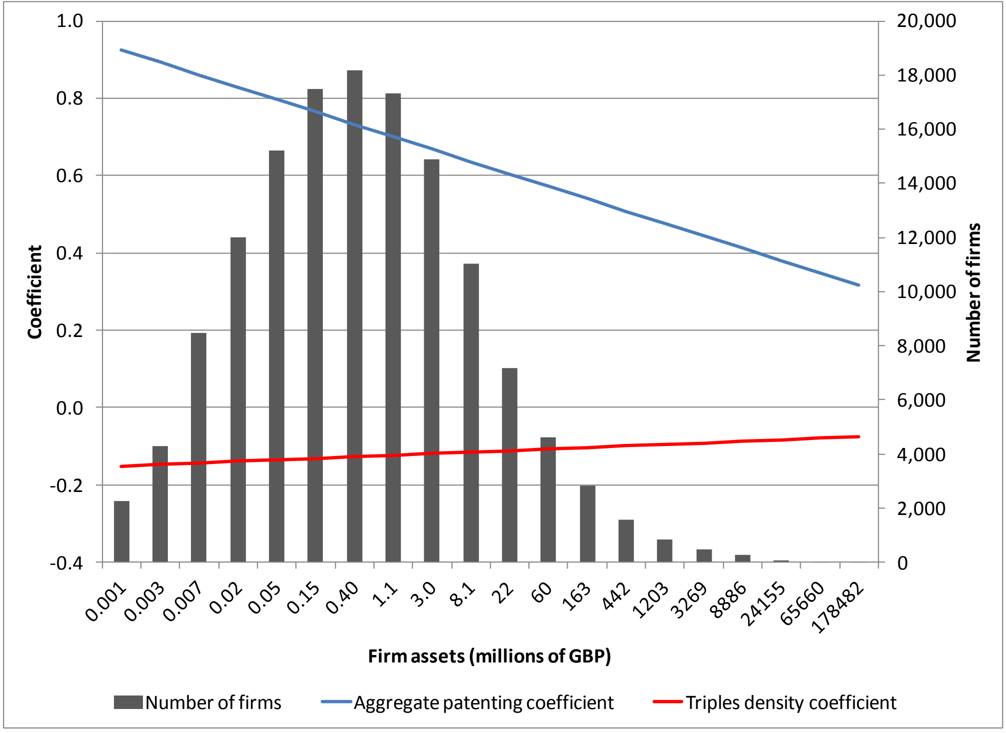
[33] The sampling weights effectively downweight the non-patenters, so the fact that they are smaller has less impact on the prediction.

Focusing on our variables of interest and on the weighted estimates, we see that aggregate patenting in a technology class is a strong predictor of whether a firm enters that class. A doubling of patenting is associated with a 70 per cent higher probability of entry (standard error 2.0%). However, when we include the triples density in the class, we find that it depresses entry. Doubling the intensity of triples in a class is associated with a highly significant 12 per cent lower hazard of entry into that class (standard error 0.7%).

In the last column we interact the log of assets with the log of patents and the log of triples density to see whether these effects vary by size.[34] They do, and in the expected way. The impact on larger firms from aggregate patenting weakens and the impact of triples strengthens slightly. That is, the impact of both aggregate patenting (positive) and triples density (negative) on SMEs is stronger than it is for larger firms. We show this graphically in Figure 13, which overlays the coefficients of aggregate patenting and triples density as a function of firm size on the actual size distribution of our firms. From the graph one can see that the impact of aggregate patenting in a sector is higher and more variable than the impact of the triples density. Firms in the lower range of the size distribution (assets less than 10,000 pounds) are much more likely to enter a sector with high aggregate patenting if they enter at all, but their hazard of entry falls 15 per cent if the triples density doubles in that sector. On the other hand, for the few firms in the upper range of the size distribution (assets greater than 100 billion pounds), the hazard of entry falls only 7 per cent if the triples density doubles.

Figure 13



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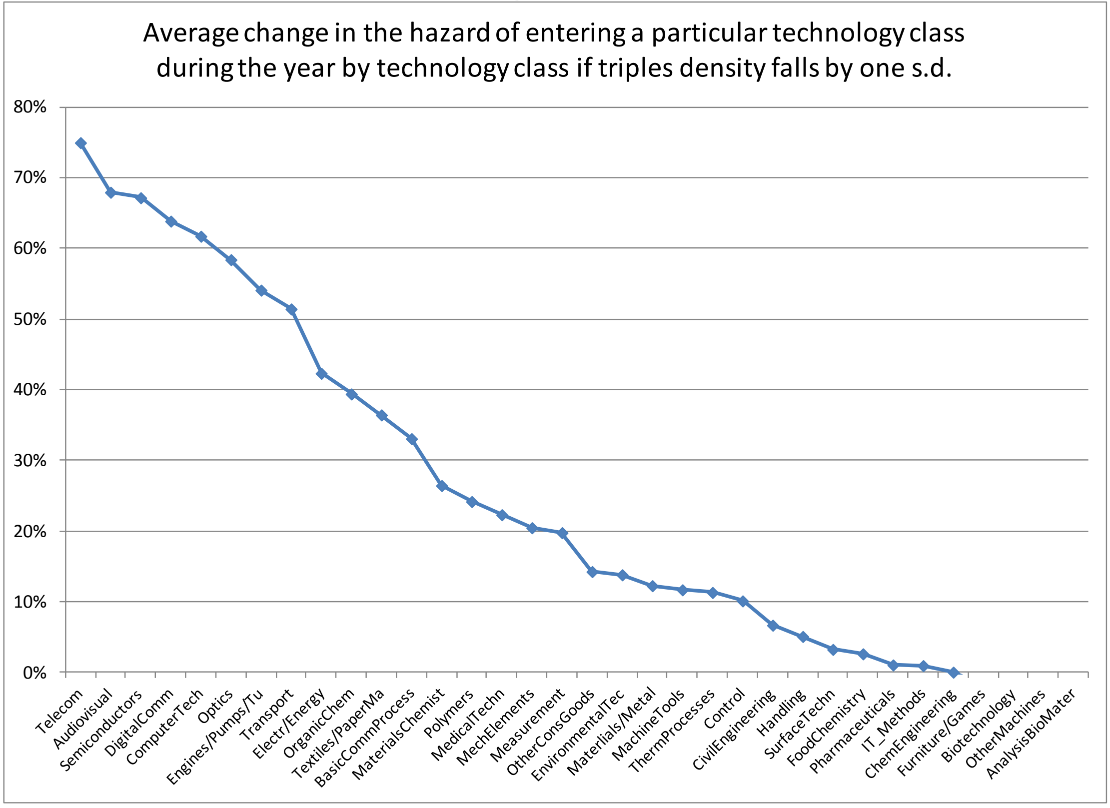
[34] Note that all the variables have been centered at their means, so that the coefficients on the non-interacted variables are coefficients at the mean of the data and can be compared across the columns directly.

We also simulated the effect of reducing the log of the triples density by one standard deviation. Because the triples density has a wide range (0.0002 to 0.2407), a one standard deviation reduction in the log is quite large and corresponds to reduction the density fivefold). Figure 13 shows the corresponding increase in entry hazard by technology class. It is clear that entry into patenting increases greatly in those technologies where there are a large number of triples per patent: Telecommunications, Computer technology, Audio-visual technology, Digital communications, Semiconductors, etc.

Figure 14



Average change in the hazard of entering a particular technology class during the year by technology class if triples density falls by one s.d.

5 Conclusion

Patent thickets are defined by a number of observers as a dense web of patents with overlapping claims that are held by several (competing) companies. As discussed in our report, such thickets can arise for a multitude of reasons; they are mainly driven by an increase in the number of patent filings (and its consequences for patent quality) as well as increased technological complexity and interdependence. This report investigates the effect of patent thickets on firm behavior. Specifically, we analyse whether patent thickets represent a barrier to entry into particular technologies for UK SMEs.

Our report reveals a lack of empirical evidence on the effect of thickets on firm behavior, both in terms of performance and innovative activity. Nevertheless, we show that there is a substantial body of research investigating the factors that lead to the emergence and growth of thickets. The literature review offered in this report also highlights the concentration of this evidence on US data. There is also an active, more recent, literature on the empirical measurement of patenting in complex technologies and the resulting thickets that focuses mainly on EPO data. Both literatures provide a considerable amount of empirical evidence for the existence and growth of patent thickets, especially in ICT-related technologies.

To analyse the possible impact of thickets on UK firms, we measure entry as a firm's decision to patent for the first time in a given technology area rather than entry into product markets. This choice is partly driven by the lack of precise data on entry into product markets, but can be defended by the argument that competition in patent-intensive sectors will per force require some effort to patent in the relevant sector. Our report reviews empirical evidence that associates improved economic performance at the firm-level, both in terms of growth and the number of new products marketed, with first-time patenting. This implies that analysing whether thickets affect firms' propensity to file a patent for the first time in a given technology may have direct implications for firm performance, both in terms of growth and innovation. Focusing on entry into patenting also has the advantage of providing us with the complete set of potential entrants, i.e., any registered firm in our database that has not previously patented. If instead we had studied entry into the product market, potential entrants would have become observable only after entry into the market. The absence of information on those firms that chose not to enter would complicate our analysis considerably.

In our context, patent thickets can represent a barrier to entry if potential social benefits of the factors that give rise to thickets do not outweigh the social costs induced by lower entry rates than in the absence of thickets. Obviously, this is hard to measure in practice. However, our review of the literature on thickets has revealed few reasons to believe that thickets are associated with factors that have raised social welfare and many that indicate that thickets are creating important welfare losses. As noted above, there is so far very little evidence on the effects patent thickets have on firm entry. Therefore, we resort to assessing directly the impact of thickets on the propensity to enter a given technology.

Using the triples measure our descriptive evidence shows strong increases in the density of thickets in almost all technologies related to Electrical Engineering, especially in Telecommunication, Audiovisual- and Computer-technology. Our data show that patent thickets are significantly less dense in all other technology areas, although we also find some evidence of an increase in the area of Optical instruments.

Using regression analysis, we study the probability of entry into patenting in a particular technology sector as a function of patent thickets in that sector, conditional on aggregate patenting in that technology. Our results suggest a substantial and statistically significant negative association between the density of thickets and the propensity to patent for the first time in a given technology area.

As we find thickets to affect entry negatively, there is a strong indication that thickets represent some kind of barrier to entry in those technology areas in which they are present. However, we must emphasize that the simple finding of a barrier to entry created by patent thickets is not proof positive that reducing that barrier and increasing entry would lead to welfare improvements in the innovation/competition space. Rather it is the existence of evidence that the presence of thickets reduces entry combined with the large literature we have reviewed that shows that currently patent systems do not work as well as they should. This literature documents quality issues with patents in technology areas affected by patent thickets, a large decline in the relationship between R&D spending and patenting in some sectors and a substantial increase in resources devoted to patent litigation leading to the partial or complete revocation of patents in areas identified as prone to thickets. All of this may lead one to the conclusion that the operation of the patent system could use some improvement.

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6 Appendix

6.1 Description of Datasets Created

The report relies on an updated version of the Oxford-Firm-Level-Database, which combines information on patents (UK and EPO) with firm-level information obtained from Bureau van Dijk's Financial Analysis Made Easy (FAME) database (for more details see Helmers *et al.* (2011) from which the data description in this section draws).

The integrated database consists of two components: a firm-level data set and IP data. The firm-level data is the FAME database that covers the entire population of registered UK firms.[35] In FAME, 'firms' represent registered firms, i.e., the legal entity that organizes production (administrative unit), in contrast to census-type data that often uses the plant or production unit. This unit of analysis corresponds to the enterprise in the BSD. In contrast to ONS data, FAME is a commercial database provided by Bureau van Dijk. The advantage of using FAME over ONS data is that it is freely accessible under a licensing agreement and that firms can be identified by name.

The original version of the database, which formed the basis for the update carried out by the UKIPO, relied on two versions of the FAME database: FAME October 2005 and March 2009. The main motivation for using two different versions of FAME is that FAME keeps details of `inactive' firms (see below) for a period of four years. If only the 2009 version of FAME were used, intellectual property could not be allocated to any firm that has exited the market before 2005, which would bias the matching results. FAME is available since 2000, which defines the earliest year for which the integrated data set can consistently be constructed. The update undertaken by the UKIPO used the April 2011 version of FAME. However, since there are significant reporting delays by companies, even using the FAME 2011 version means that the latest year for which firm-level data can be used reliably is 2009.

FAME contains basic information on all firms, such as name, registered address, firm type, industry code, as well as entry and exit dates. Availability of financial information varies substantially across firms. In the UK, the smallest firms are legally required to report only very basic balance sheet information

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[35] FAME downloads data from Companies House records where all limited companies in the UK are registered.

(shareholders' funds and total assets). The largest firms provide a much broader range of profit and loss information, as well as detailed balance sheet data including overseas turnover. This is why our study focuses on total assets as a measure of firm size and growth.

The patent data come from the EPO Worldwide Patent Statistical Database (PATSTAT). Data on UK and EPO patent publications by British entities were downloaded from PATSTAT version April 2010 and April 2011. Due to the average 18 months delay between the filing and publication date of a patent, using the April 2011 version means that the patent data are presumably only complete up to the third quarter in 2009. This effectively means that we can use the patent data only up to 2009 under the caveat that it might be somewhat incomplete for 2009. Patent data are allocated to firms in the year in which a firm applied for the registration of the corresponding intellectual property.

Since patent records do not include the registered number of a company even if the applicant is a registered business, it is not possible to merge data sets using a unique firm identifier; instead, applicant names in the IP documents and firm names in FAME have to be matched. Both a firm's current and previous name(s), were used for matching in order to account for changes in firm names. Matching on the basis of company names requires names in both data sets to be `standardized' prior to the matching process in order to ensure that small (but often systematic) differences in the way names are recorded in the two data sets do not impede the correct matching. For more details on the matching see Helmers *et al.* (2011).

6.2 Methodological analysis of the triples measure

This appendix contains results of a statistical test of the triples measure similar to that provided by Milo *et al.* (2002; 2004a) . As discussed in Section 3.2.2 above counts of triples have been shown to be statistically significant measure of the structure of networks in a number of contexts such as the World Wide Web. To date such an analysis has not been performed in the context of patent data. The aim of the analysis is to determine whether triples or any other network motif are likely to arise with such frequency randomly that their occurrence in the real data we analyze cannot be interpreted as a signal of any kind of real structure.

We use the FANMOD software developed by Wernicke and Rasche (2006) to count and test the significance of various network motifs. The test of the significance of these motifs is undertaken by comparing the frequency of occurrence of a given motif in the data obtained from the EPO with the occurrence of the motif in 1000 comparison datasets obtained by perturbing the original data randomly. We set the parameters of the software such that the randomly created comparison data preserve the characteristics of the original data as closely as possible.

To perform this test we segmented patent applications at the EPO into 34 technology areas based on the 2008 version of the ISI-OST-INPI technology classification (Schmoch, 2009). We then used data on critical references in three of these areas (Telecommunications, Optics and Medical Technology) for the periods 1997-1999 and 2003-2005 to analyze the significance of different network motifs as measures that could characterize the structure of the underlying data. We chose these three technology areas because it is well known that Telecommunications is affected by a patent thicket, while we expect Optics and Medical Technology to be much less affected. In the next subsection we show that Optics presents an intermediate case between Telecommunications and Medical Technology.

Table 1: Z-Scores for the Triples Measures in Selected Technology Areas

Area	Years	Z-Score
Medical Technology	1997-99	115.6
Optics	1997-99	24.8
Telecommunications	1997-99	9.7
Medical Technology	2003-05	81.6
Optics	2003-05	39.2
Telecommunications	2003-05	9.0

Table 1 above presents the Z-scores[36] for this measure. While there is a broad range in these values they are always so high that we can be sure that triples arise far more frequently in all of these data sets than we would expect if the triples just arose randomly.

Following Milo *et al.* (2004b) we summarize our findings using significance profiles for each of these areas. A significance profile is the vector of Z scores normalized to length 1. This normalization allows us to view the relative importance of the Z-scores for different motifs abstracting from their absolute values which are affected by the number of observations in the six different data-sets we analyze.

Figure 15 below presents the six triad significance profiles based on the Z-scores we extracted from our data using FANMOD for each of the three technology areas in each of . The figure contains 9 of the 13 network motifs presented by Milo *et al.* (2004b). The remainder did not arise in our data or were not significant. A comparison with the significance profiles presented in Figure 1 of their paper for the World Wide Web and social networks reveals that the shape of our significance profiles for the network motifs 7-13 is quite similar. There are clear peaks for the motifs 9, 10 and 13 and similarly minima and 8 and 11. It is noticeable that in Telecommunications and Optics where patent thickets are present there is a significant minimum for the network motif 12 while this is not the case for the networks analyzed by Milo *et al.* (2004b). Network motif 12 is one in which one firm has mutually limiting patents with both other firms, whilst only one of these two is limiting the other. The fact that this motif is not present

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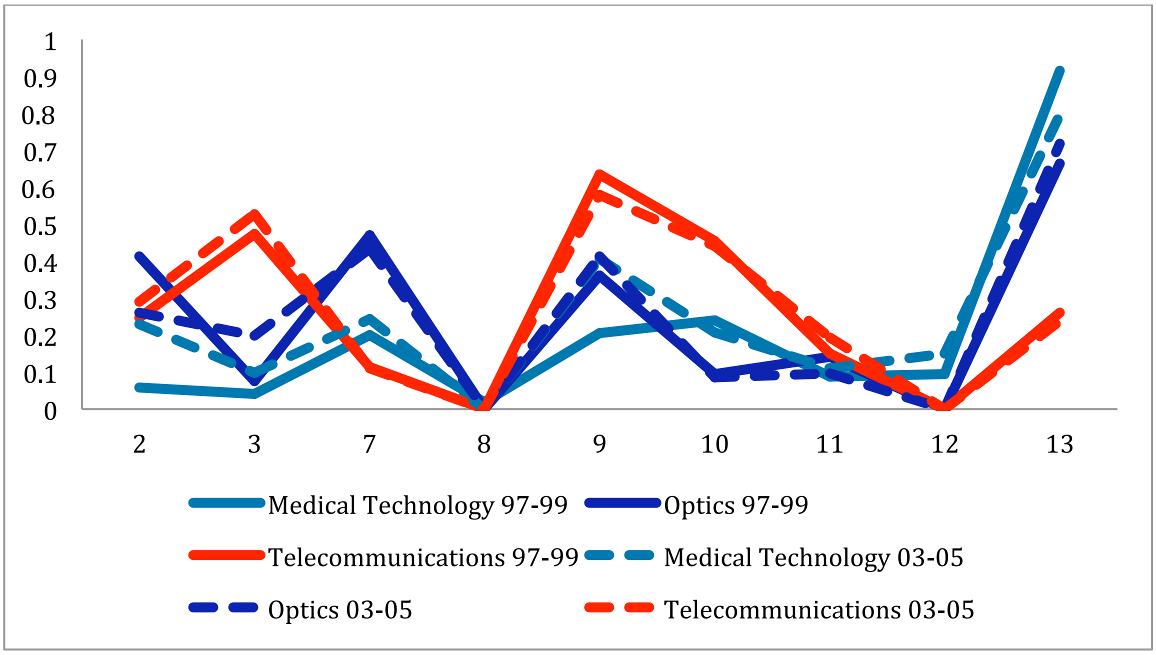
[36] A measure of statistical significance indicating how many standard deviations the real triples count is higher than that of the mean of the simulated random samples.

with significant frequency might be evidence for strategic patenting by firms caught in patent thickets. More study on this point is required before we may be sure however.

Figure 15 Triad Significance Profiles for Selected Technology Areas and Years



This section has demonstrated that the triples measure of patent thicket density is a statistically significant measure of the structure of networks constituted between firms' patent portfolios by critical references. In the following section we will analyze the development of patent thickets using this measure.

6.3 Hazard models of entry

This section of the appendix describes that hazard or survival models that are used to estimate the probability of entry into a technology. These models express the probability that a firm enters into patenting in a certain sector conditional on not having entered yet as a function of the firm's characteristics and the time since the firm was "at risk," which is the time since the founding of the firm. Obviously in some cases, our data does not go back as far as the founding date of the firm, and in these cases the data are "left-censored." When we do not observe the entry of the firm into a particular technology sector by the last year (2009), the data is referred to as "right-censored."

We estimate two classes of "failure" or "survival" models: 1) *proportional hazard*, where the hazard of failure over time has the same shape for all firms, but the overall level is proportional to an index that depends on firm characteristics; and 2) *accelerated failure time*, where the hazard of entry ("failure") is accelerated or decelerated by the characteristics of the firm.

The first model has the following form:

$$\Pr(i \text{ first pats in } j \text{ at } t \mid i \text{ has no pats in } j \ \forall\ s < t, X_i)$$
$$h(X_i, t) = h(t)\exp(X_i\beta)$$

where *i* denotes a firm, *j* denotes a technology sector, and *t* denotes the time since entry into the sample. *h(t)* is the baseline hazard, which is either a non-parametric or a parametric function of time since entry into the sample. The impact of any characteristic *x* on the hazard can be computed as follows:

$$\frac{\partial h(X_i, t)}{\partial x_i} = h(t)\exp(X_i\beta)\beta \quad \text{or} \quad \frac{1}{h(X_i, t)}\frac{\partial h(X_i, t)}{\partial x_i} = \beta$$

Thus if *x* is measured in logs, *β* measures the elasticity of the hazard rate with respect to *x*. Note that this quantity does not depend on the baseline hazard *h(t)*, but is the same for any *t*. We use two choices for *h(t)*: the semi-parametric Cox estimate and the Weibull distribution pt^{p-1}. By allowing the Cox *h(t)* or *p* to vary freely across industrial sector, we can allow the shape of the hazard function to be different for different industries while retaining the proportionality assumption.

In order to allow even more flexibility across the different industrial sectors, we also use two accelerated failure time models, the log-normal model and the log-logistic model. These have the following basic form (see *streg* in the Stata Survival Analysis manual for details):

$$\text{log-normal:} \quad S(t) = 1 - \Phi\left[\frac{\log(t_i\lambda_i)}{\sigma}\right]$$
$$\text{log-logistic:} \quad S(t) = (1 + (t_i\lambda_i)^{1/\gamma})^{-1}$$

where *S(t)* is the survival function and $\lambda_i = \exp(X_i\beta)$. We allow the parameters *σ* (log-normal) or *γ* (log-logistic) to vary freely across industries. That is, for these models, both the mean and the variance of the survival distribution are specific to the 2-digit industry. In the case of these two models, the elasticity of the hazard with respect to a characteristic x depends on time and on the industry-specific parameter (*σ* or *γ),* yielding a more flexible model. Note also that the hazard rate is given by *–dlogS(t)/dt* in general (Lancaster 1990).

7 Additional Tables

Table A1

Number of TF34 sectors entered between 2002 and 2009

Number of sectors	*Number of firms*	*Number of entries*
1	3,507	3,507
2	1,901	3,802
3	781	2,343
4	313	1,252
5	158	790
6	72	432
7	42	294
8	20	160
9	10	90
10	6	60
11	10	110
12	4	48
14	2	28
15 or more	4	75
Total	**6,830**	**12,991**

Table A-2

FAME Population of UK firms, by industry

Industry	*2-digit SIC (2007 UK classification)*	*Number of firms*	*Number of patenters*	*Share patenting 2001-2009*	*Number of patents*
Oil & gas extraction	06	57,686	48	0.08%	231
Quarrying	08	48,182	87	0.18%	126
Oil & gas services	09	84,619	115	0.14%	727
Food mfg	10	10,110	106	1.05%	444
Beverage mfg	11	1,881	24	1.28%	70
Tobacco	12	72	3	4.17%	29
Textiles	13	5,625	96	1.71%	313
Apparel	14	7,029	38	0.54%	96
Leather	15	1,234	11	0.89%	22
Wood	16	8,004	58	0.72%	150
Paper	17	3,170	110	3.47%	551
Printing	18	18,663	109	0.58%	590
Oil,coke refining	19	355	5	1.41%	59
Chemicals	20	5,032	333	6.62%	6274
Pharmacueticals	21	1,306	132	10.11%	2324
Rubber & plastics	22	7,658	497	6.49%	2096
Stone, Clay, & glass	23	5,100	134	2.63%	621
Basic metals	24	4,160	84	2.02%	428
Fabricated metals	25	33,321	857	2.57%	3608
Electronics & instruments	26	13,539	888	6.56%	6757
Electrical machinery	27	2,852	228	7.99%	1132
Machinery	28	12,026	718	5.97%	4930
Motor vehicles	29	2,942	139	4.72%	1419
Other transport	30	4,542	120	2.64%	1194
Furniture	31	6,324	73	1.15%	168
Other manufacturing	32	22,366	1,016	4.54%	5673
Repairs	33	5,911	174	2.94%	1704
Utilities	35	3,848	37	0.96%	121
Water distribution	36	1,003	29	2.89%	112
Sewers	37	861	8	0.93%	9
Recycling	38	6,001	37	0.62%	69
Construction	41	201,216	186	0.09%	855
Site preparation	42	6,223	28	0.45%	31
Construction trades	43	182,441	393	0.22%	1161
Auto trade	45	50,491	77	0.15%	378
Wholesale trade, except autos	46	134,296	996	0.74%	4486
Retail trade	47	152,133	252	0.17%	699
Land transport	49	53,264	57	0.11%	173
Water transport	50	3,838	8	0.21%	20
Air transport	51	3,533	8	0.23%	138
Cargo handling & travel agencies	52	17,576	37	0.21%	111
Post & telecomm	53	4,313	7	0.16%	53
Publishing	58	65,015	209	0.32%	608
Telecommunications	61	17,393	161	0.93%	2682
Computer consulting	62	191,290	996	0.52%	4367
Data processing, hosting	63	9,714	54	0.56%	77
Banks and other financial services	64	44,921	75	0.17%	131
Insurance	65	13,581	15	0.11%	50
Securities	66	11,461	21	0.18%	204
Real estate	68	130,182	84	0.06%	266
Law and accounting	69	49,404	27	0.05%	189
Management consulting	70	205,811	618	0.30%	4124
Engineering services	71	48,517	272	0.56%	1626
R&D services	72	10,291	1,168	11.35%	11214
Advertising	73	25,454	78	0.31%	250
Non-trading companies	74	20,529	304	1.48%	4727
Other business activities	82	625,553	2,066	0.33%	9898
Medical services	86	44,865	161	0.36%	923
Other personal services	96	123,321	428	0.35%	1385
Dormant	99	2,464	23	0.93%	1259
Unknown		428,208	0	0.00%	408
Total		**3,262,720**	**15,123**	**0.46%**	**94,540**

Table A-3

Hazard of entry into patenting in a TF34 Class - Proportional Hazard (Cox) Model

998,219 firm-TF34 observations with 12,991 entries (29,435 firms)

Variable	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Log (triples density		-0.112***	-0.112***	-0.119***	-0.112***	-0.119***
in class)		(0.006)	(0.006)	(0.007)	(0.006)	(0.007)
Log (patents in class)	0.470***	0.643***	0.644***	0.702***	0.644***	0.703***
	(0.017)	(0.019)	(0.019)	(0.022)	(0.019)	(0.022)
Log assets	0.064***	0.064***	0.067***	0.072***	0.070***	0.075***
	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
Log (triples density)				0.005**		0.005**
* Log assets				(0.002)		(0.002)
Log (patents)				-0.037***		-0.038***
* Log assets				(0.006)		(0.006)
Industry dummies	***no***	***no***	***yes***	***yes***	***stratified#***	***stratified#***
Year dummies	***yes***	***yes***	***yes***	***yes***	***yes***	***yes***
Log likelihood	-145,999.7	-145,815.9	-145,773.0	-145,755.2	-108,086.4	-108,068.2
Degrees of freedom	9	10	34	36	10	12
Chi-squared	2293.4	2660.8	2746.7	2782.4	2676.4	2712.9

All estimates are weighted estimates, weighted by sampling probability. Coefficients shown are elasticities of the hazard w.r.t. the variable.

*** (**) denote significance at the 1% (5%) level.

Time period is 2002-2009. Sample is all UK firms with nonmissing assets

Estimates are stratified by industry - each industry has its own baseline hazard

Table A-4

Hazard of entry into patenting in a TF34 Class - Comparing models

998,219 firm-TF34 observations with 12,991 entries (29,435 firms)

	Proportional hazard		*AFT*
Variable	*Cox PH*	*Weibull*	*Log logistic*
Log (triples density	-0.112***	-0.112***	-0.123***
in class)	(0.006)	(0.006)	(0.007)
Log (patents in class)	0.644***	0.645***	0.696***
	(0.019)	(0.017)	(0.020)
Log assets	0.070***	0.045***	0.048***
	(0.004)	(0.005)	(0.006)
Industry dummies	***stratified#***	***stratified#***	***stratified#***
Year dummies	***yes***	***yes***	***yes***
Log likelihood	-108,086.4	-51,393.4	-51,369.1
Degrees of freedom	10	35	35
Chi-squared	2676.4	2415.9	1982.1

All estimates are weighted estimates, weighted by sampling probability. Coefficients shown are elasticities of the hazard w.r.t. the variable.

*** (**) denote significance at the 1% (5%) level.

Time period is 2002-2009. Sample is all UK firms with nonmissing assets

AFT - Accelerated Failure Time models

Estimates are stratified by industry - each industry has its own baseline hazard.