Does a stronger patent system stimulate more R&D? Yes, in firms that rely on patents as an appropriation mechanism

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Abstract

We propose a novel empirical strategy for detecting potential effects of patent reforms on R&D investments. Our strategy builds on the insight that there is great variation in the extent to which firms rely on patents as an appropriation mechanism. Increases in patent protection should benefit those firms that rely on patents disproportionately more. We apply such insight by combining measures of industry reliance on patent protection (IRPP) from seminal innovation surveys with the establishment of the U.S. Court of Appeals for the Federal Circuit (CAFC) in 1982, the focal pro-patent reform of interest. Using a difference-in-differences approach, we find a positive effect of stronger patent protection on the R&D investments of firms with greater reliance on patent protection. Such effect is economically significant and only arises in the post-CAFC period for firms located in regional circuits that experienced high increases in patent protection.

Keywords: R&D; Patents; Enforcement; Patent Law; Innovation

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1 Introduction

Patent systems are widely used as a policy lever to encourage investments in research and development (Ginarte & Park, 1997, Park, 2008). Patents confer the temporary right to exclude others from making, using or selling the invention in a given geographic jurisdiction. Exclusion rights provide stronger incentives to invest in research and development (R&D) because innovators expect to appropriate a higher share of the benefits they generate. However, they also entail some efficiency loss because they enable inventors to charge a higher price mark-up and could result in slower diffusion. The premise of a patent system is that the benefits from increased innovation outweigh the costs. Whether this is the case is unclear, which has led to considerable controversy over whether national patent systems should exist in their current form or at all (Boldrin & Levine, 2013; Jaffe & Lerner, 2011; Penrose, 1951).

Much of the skepticism around national patent systems originates from the scarcity of evidence on whether stronger patent regimes serve their primary purpose of incentivizing higher investments in R&D. Boldrin & Levine (2013) argue that "there is no empirical evidence that they [patents] serve to increase innovation". Bloom *et al.* (2019) consider that the conclusiveness of evidence on the effect of intellectual property rights (IPR) reforms on R&D expenditures is low and their net benefits unknown. Williams (2017) states that "we still have essentially no credible empirical evidence on the seemingly simple question of whether stronger patent rights –either longer patent terms or broader patent rights– encourage investments into developing new technologies".

The main contribution of this paper is to propose a novel empirical strategy for identifying the potential effects of patent reforms on R&D investments. Our strategy builds on the insight that there is great heterogeneity in the extent to which firms rely on patents to protect their inventions from imitators. According to the seminal innovation surveys by Levin *et al.* (1987) and Cohen *et al.* (2000), most firms do not rely on patents as a mechanism of intellectual property (IP) appropriation. Consequently, empirical designs aimed at capturing average effects are unlikely to find traction because the average firm does not rely on patents. However, these surveys also indicate that certain firms do rely heavily on patents, particularly in industries specialized in the production of discrete products such as pharmaceuticals and other chemicals. Stronger patent rights could generate positive incentive effects on the subset of firms that do rely on patents as the main protection mechanism. Empirical designs should take such heterogeneity into account.

In order to capture variation in the use of patents as an appropriation mechanism we use measures of "Industry Reliance on Patent Protection" (IRPP) from several innovation surveys. We use Mansfield (1986)'s survey as the baseline because it has two desirable properties. First, it asks a unique counterfactual question on the effect of patents at the invention level (percent of developed inventions that would not have been developed if patent protection could not have been obtained) that is particularly well suited to capture the incentive effect that we are interested in. Second, it is predetermined with respect to the patent reform that we leverage in this study. We also use measures from the seminal surveys of Levin *et al.* (1987), Cohen *et al.* (2000) and Arundel & Kabla (1998), which do not have a counterfactual nature but offer more fine-grained industry breakdowns.

Survey-based measures have two main advantages over other measures that can be calculated from conventional firm-level datasets such as the ratio of patents per dollar of R&D. First, they explicitly capture incentive effects over other possible benefits from patents such as the enhancement of the firm's reputation or the strengthening of the firm's position in negotiations with other firms (Cohen *et al.* , 2000). Second, they measure the importance of patent protection at the product level, which is necessary to correct for the fact that complex products combining a large number of inventions will inevitably result in more patents than discrete products building on just one invention.

We apply such insights using the establishment of the U.S. Court of Appeals for the Federal Circuit (CAFC) in 1982 as the focal pro-patent policy shift of interest. The ability to enforce a patent greatly depends on the patent law and its interpretation by the competent courts. Prior to the establishment of the CAFC, appeals to patent infringement decisions were heard by the regional U.S. Circuit Courts of Appeals, which varied widely in the frequency with which they upheld "valid and infringed" decisions (Seamon, 2003). To the extent that patent owners can only enforce patents that are "valid and infringed", such regional disparities generated substantial variation in the enforcement of patent rights across circuits. The CAFC unified patent law, shifting the interpretation in favor of patent holders.

Consequently, patent protection increased considerably for firms in circuits that were more hostile to patents in the pre-CAFC period ("high-increase" group) and remained relatively unchanged, or even declined, for firms in circuits that were sympathetic to patents ("low-increase" group).

We use a difference-in-differences approach to test whether R&D investments increased relatively more for firms operating in industries with high IRPP (first difference) after the establishment of the CAFC (second difference). An attractive feature of this approach is its ability to isolate the role of the change in policy. While firms in industries with high and low reliance on patents are not identical, comparing outcomes within firms over time isolates the differential impact of the CAFC. We estimate the model on a panel dataset of publicly traded firms in the U.S. that have at least one patent and invest in R&D from five years before to ten years after the establishment of the CAFC. We estimate separate regressions for "high-increase" and "low-increase" groups. We expect incentive effects to concentrate among firms in the former group for which the CAFC triggered the most significant increases in enforcement.

Regression results reveal a positive relationship between patent protection and R&D investments. Such relationship only arises in the post-CAFC period for firms located in geographical circuits that experienced high increases in patent protection. We cannot find positive effects for firms in geographical circuits that underwent low increases, or even declines, in patent protection. Such finding is highly suggestive that the estimated effects are driven by the CAFC and not by other confounding factor such as similarly timed policies. The effects are economically significant. The estimated increase in R&D for firms with IRPP at the seventy-fifth percentile, relative to firms in the twenty-fifth percentile, is of $21.48M for Mansfield's measure. This represents a 15% increase with respect to an average R&D expenditure of $143M in the pre-CAFC period. We also find a 15% in research effort as measured by R&D over employees. The estimates obtained with the IRPP measures from the other three industry surveys point in the same direction.

Our empirical design builds on the assumption that IRPP is stable over time and relatively unaffected by the establishment of the CAFC. We believe this to be a plausible assumption because IRPP is at least partly driven by industry demographics, market structure and exogenous characteristics of inventions which are likely to remain stable. Indeed, comparison across innovation surveys for different time periods indicates considerable stability in IRPP over time. If the CAFC had caused firms to massively switch from informal mechanisms of IP protection to patents, incentive effects should also, or perhaps mostly, have taken place in the group of firms with low IRPP. If the CAFC did tilt some firms to switch their IP protection mechanism along these lines, our strategy would provide downward biased estimates of the true effect of stronger patent protection.

Our empirical strategy is particularly well suited to detect effects localized in firms that rely on patents. However, such localized effects could have diffused through spillovers or technology supply chains (Arqué-Castells & Spulber, Forthcoming). Several studies suggest that the CAFC could have favored specialization and vertical separation in the organization of innovation activities. Without establishing an explicit causal link with the CAFC, Png (2019) finds that firms became increasingly specialized after 1980. Ma (2022) finds that the formation of the CAFC was associated with an increase in specialization in the knowledge economy. Galasso & Schankerman (2010) find that the creation of the CAFC substantially reduced settlement delays, and thus the speed of technology diffusion through licensing.

The patent system generates net benefits if the dynamic efficiency gains from increased research outweigh the static efficiency losses due to temporary supracompetitive pricing. Measuring all the associated gains and losses is a daunting task. Focusing on the gains side alone, Williams (2017) argues that the patent system could affect research investments through its disclosure function, potential blocking effects on follow-on innovators, and incentive effects. This paper is first and foremost concerned with the latter question of whether patents incentivize research investments. In particular, we emphasize that in order to detect possible incentive effects from patent laws, researchers should account for the great variation in IP protection strategies across firms. The more ambitious question of whether the patent system generates net welfare gains is beyond the scope of this paper.

1.1 Related literature.

Our paper is most closely related to the empirical literature that aims to estimate the effect of stronger patent protection on research investments (see the recent reviews by Budish *et al.* , 2016; Williams, 2017). The main goal of this literature is to measure ex-ante incentive effects triggered by the promise of a stronger right to exclude others from using the invention in the future. This literature can be divided into three major strands, including survey-based evidence, evidence from responses to patent law changes, and evidence drawn from leveraging exogenous variation in exclusivity length. Our empirical strategy combines fundamental elements of the first two.

The early literature on the topic relies on survey-based evidence (see the comprehensive review by Hall *et al.* , 2014). The most influential surveys are the ones by Mansfield (1986), the so-called Yale survey by Levin *et al.* (1987) and the so-called Carnegie Mellon survey by Cohen *et al.* (2000), all of which we leverage in this study. The three surveys document that, on average, firms report that patents have a limited effectiveness as an appropriation mechanism. However, there is substantial variation across industries in the extent to which firms rely on patents with patents being of great importance in a few industries such as chemicals and pharmaceuticals. One limitation of innovation surveys is that they are not directly informative on the responsiveness of research investments to changes in patent protection. Would those firms that rely on patents invest different amounts of R&D under alternative patent protection regimes? We combine survey-based evidence with patent law changes to tease out firm fixed effects from genuine responses to patent protection.

The strand of the literature that leverages patent law changes generally finds no incentive effects. Sakakibara & Branstetter (1999) find no evidence that stronger Japanese patent rights induced higher levels of research investments in Japanese firms. Qian (2007) finds no statistically significant effects of patent protection on pharmaceutical innovations for 26 countries that established pharmaceutical patent laws during 1978–2002. Lerner (2009) finds a negative effect of patent protection on patenting using data on 177 major patent policy shifts across 60 countries over 150 years. Kortum & Lerner (1999) conclude that the establishment of the CAFC was not responsible for the subsequent surge in patenting in the U.S., comparing domestic and international patent applications. One exception is Kyle & McGahan (2012), who find that stronger patent protection due to the adoption of the TRIPS agreement was associated with increased R&D on the diseases that affected high-income countries. One possible explanation behind the lack of support for incentive effects in this literature is that most of these studies search for average effects, while patent reforms are likely to trigger localized effects in firms that rely on patents as an appropriation mechanism.

Recent studies that leverage exogenous variation in the period of exclusivity tend to find positive incentive effects. Budish *et al.* (2015) document that allowing firms to conduct shorter clinical trials would increase research investments, presumably because shorter clinical trials increase the effective patent protection term in pharmaceutical firms, which tend to file for patents prior to starting the clinical trial. Gaessler & Wagner (2019) estimate that a one-year reduction in expected market exclusivity due to patent invalidation lowers the likelihood of drug approval by 4.9 percentage points, using random variation in the participation of the primary examiner in the opposition proceeding to instrument invalidations.

A related literature studies the ex-post effect of the grant or removal of patents for inventions that have already been created. Ex-post effects are informative of the benefits of exclusion rights for the patent holders and as such are also indicative of the reward to ex-ante research efforts. Galasso & Schankerman (2018) find that patent invalidation causes small and medium sized patent holders to reduce subsequent patenting, using the random allocation of judges at the CAFC to identify causal effects. Gaule (2018) finds that patent protection has a positive effect on the success of venture-capital backed firms in life sciences, using patent examiner leniency to instrument patent grants. Building on the same instrument, Farre-Mensa *et al.* (2020) find that patent grants have a positive effect on employment and sales growth, follow-on innovation by the patentee and funding from venture capitalists. Balasubramanian & Sivadasan (2011) find that changes in patenting are positively correlated with changes in total factor productivity using longitudinal variation from matched patent data and U.S. Census microdata.

The remaining of the paper is organized as follows. Section 2 reviews evidence from innovation surveys and describes the main measures of patent protection used in the empirical analysis. Section 3 describes how the formation of the CAFC translated into changes in patent protection. Section 4 describes the data. Section 5 discusses the empirical strategy. Section 6 presents the econometric results. Section 7 concludes.

2 Survey-based measures of industry reliance on patents

Companies have the choice between a range of mechanisms to protect their innovative outcomes. Firms can choose patenting but they can also rely on informal appropriation mechanisms such as secrecy, confidentiality agreements, lead time, or complexity (Cohen *et al.* , 2000; Levin *et al.* , 1987). Patents are a viable option when the subject matter is patentable and the invention meets the novelty and non-obviousness requirements for patentability (Hall *et al.* , 2014). Patents are also particularly fitting for appropriating the returns from "discrete" products that are inherently easier to describe in the claims of a single patent, which in turn facilitates enforcement. A case in point is the chemicals sector, where patents protect a specific compound that can be described in a precise chemical formula.

Empirical evidence from innovation surveys suggests that the average firm relies on informal mechanisms of appropriation such as secrecy or lead time much more than on patents. However, there is substantial heterogeneity across industries with patents being found to be the favorite tool to secure the returns to innovation in industries characterized by discrete products like pharmaceuticals and other chemicals (Cohen *et al.* , 2000; Levin *et al.* , 1987; Hall *et al.* , 2014). Such insights imply that empirical designs aimed at estimating average effects of patent reforms will find little traction because the average firm does not rely on patents. Empirical designs aimed at detecting responses to shifts in patent protection should search for effects within the group of firms that rely on patents as an appropriation mechanism.

In order to measure variation in industry reliance on patent protection (IRPP) as an appropriation mechanism, we use information reported in the innovation survey by Mansfield (1986). Such survey has two distinctive features. First, it asks for the percent of developed inventions that would not have been developed if patent protection could not have been obtained. This type of counterfactual question on the effect of patents at the invention level is unique and particularly appropriate to measure incentive effects. Second, it covers the period 1981-1983 so it is unlikely to capture strategic responses to the CAFC, which was established in April 1982. Mansfield found that in two industries, pharmaceuticals and chemicals, patent protection was essential for thirty percent or more of the inventions. In another three industries (petroleum, machinery, and fabricated metals), patent protection was essential for about 10–20 percent of the inventions. The remaining seven industries showed little or no reliance on patents.

In robustness checks we also use information from Levin *et al.* (1987), Cohen *et al.* (2000) and Arundel & Kabla (1998). These surveys use slightly different definitions of the importance of patent protection, industry aggregations and cover different sample periods. The survey by Levin *et al.* (1987) covers U.S. manufacturing firms during the period 1981-1983. The survey by Cohen *et al.* (2000) covers U.S. firms in 1994 and could capture strategic responses to the CAFC. Arundel & Kabla (1998) also cover the post-CAFC period but focus on European firms, which are less likely to have reacted to the CAFC. The main advantage of these surveys is that they provide information for a finer break down of industry groups, which allows us to exploit richer variation in the extent to which firms rely on patent protection. Also, unlike Mansfield (1986), these surveys distinguish between product and process innovations. Table 2 describes the main features of each survey.

Figure 1 graphs the measures of industry reliance on patent protection reported in the four surveys. The most important insight is that there is great variation in the extent to which firms in different industries rely on patent protection. The different surveys are consistent in identifying Pharmaceuticals and Chemicals as the industries that more heavily rely on patents. Similarly, they are fairly consistent in identifying a few industries such as Basic Metals, Textiles, Food or Motors as having the lowest rates of reliance on patents. The industries commonly reporting intermediate levels of reliance on patents include Medical Instruments, Electrical Equipment, Fabricated Metal Products, Semiconductors or Machinery. Another consistent pattern is that the reliance on patents is greater for product innovations than for process innovations in almost every industry.

Importantly, direct survey-based measures of the reliance on patents as an appropriation mechanism are more informative than indirect metrics that can be constructed with firm-level data such as the ratio of patents per dollar of R&D. The latter are likely to embed substantial measurement error for two main reasons. First, firm level data does not include information on the nature of the underlying innovations that are protected with patents. Discrete products that can be safely protected with just one or two patents will inevitably result in a lower number of patents per dollar of R&D. Yet, these are precisely the products for which patents are particularly effective according to the innovation surveys. Therefore, the number of patents per R&D could happen to be inversely correlated with the actual reliance of patents as an appropriation mechanism for firms with at least one patent. Second, patents could generate profits but not directly through the commercialization or sale of patented inventions. For instance, patents could generate profits through the enhancement of the firm's reputation, the prevention of infringement suits, or the strengthening of the firm's position in negotiations with other firms (Cohen *et al.* , 2000). In such cases, the number of patents per dollar of R&D would be a poor measure of the incentive mechanism that we intend to capture.

3 The CAFC and patent enforcement

Until 1982, appeals over patents were tried by two different courts. The Court of Customs and Patent Appeals tried appeals against decisions of the USPTO such as ex parte patent cases, interference proceedings and trademark cases. The regional U.S. Circuit Courts of Appeals heard appeals to patent infringement decisions by the federal district courts (Seamon, 2003). Decisions on patent infringement suits are consequential for the enforcement of patents because a patent owner cannot effectively enforce the exclusion rights conferred by the patent title unless it is found or there is an expectation that it will be found to be "valid and infringed". Owners of valid and infringed patents are entitled to compensatory damages. They are also entitled royalty payments if the infringer is allowed to keep using the invention under certain terms or to injunctive relief otherwise. Therefore, decisions by the circuit courts of appeals carried a great weight for enforcement purposes.

Prior to the establishment of the CAFC, the regional Circuit Courts were notoriously inconsistent in the administration of the law and varied widely in the frequency with which they upheld "valid and infringed" decisions (Harmon, 1991; Seamon, 2003). According to Henry & Turner (2006), the percentage of "valid and infringed" decisions in district courts that were affirmed on appeal varied from a high of 82.9 percent in the Tenth Circuit to a low of 43.4 percent in the Second Circuit. Decisions by the courts of appeals have a great impact on first district-court decisions because judges do not want to have their decisions overturned by higher instance courts. Consequently, the rates of "valid and infringed" decisions by first district-courts also varied greatly across circuits from a high of 57.4 percent in the Tenth Circuit to a low of 16.7 percent in the Third Circuit.

In April 1982, the U.S. Congress passed the Federal Courts Improvement Act which established the Court of Appeal for the Federal Circuit (CAFC). The CAFC merged the Court of Customs and Patent Appeals and the appellate division of the Court of Claims. It assumed exclusive jurisdiction over all appeals against USPTO and district court decisions involving patents and claims against the federal government in a variety of subject matter. One of the primary objectives pursued with the establishment of the CAFC was to bring greater uniformity in patent enforcement (Seamon, 2003). In its first decision, the CAFC adopted the previous holdings of the Court of Customs and Patent Appeals and the appellate division of the Court of Claims as binding precedents, circumventing the disparate precedents from the circuit courts. Such decision unified patent law at the national level (Dreyfuss, 1989).

Early jurisprudence by the CAFC shifted the interpretation of patent law in favor of patent holders. A series of decisions between 1982 and 1986 strengthened the statutory presumption of patent validity (Quillen, 1993), lowered the standards required to grant preliminary injunctive relief (Merges & Duffy, 1997) and increased the availability of monetary remedies for patent infringement (Chisum, 1985; Dreyfuss, 1989; Quillen Jr, 1993). A detailed overview of such decisions can be found in Galasso & Schankerman (2010). There is considerable evidence that such early decisions by the CAFC strengthened patent enforcement (Henry & Turner, 2006; Lanjouw & Lerner, 2001). Importantly, the intensity of such changes in patent enforcement varied greatly across regional circuit courts because the unification in patent law essentially eliminated pre-CAFC differences in enforcement rates across circuits.

Patent protection increased considerably in circuits that were more hostile to patents in the pre-CAFC period and remained relatively unchanged, or even declined, in circuits that were sympathetic to patents. Figure 2 graphs the increase in the rate of "valid and infringed" decisions made by first district courts in the different circuits based on information from Table 1 in Henry & Turner (2006). According to such measure, the greatest increases in patent protection are found in the Third, Eighth, Second, First and Sixth circuits. Hou *et al.* (2020) develop an index of the increase in patent protection based on a more systematic regression-based analysis, using microdata on patent decisions from Henry et al. (2013). The advantage of their approach is that it allows them to tease out pure CAFC effects from a host of patent characteristics, litigation characteristics and year fixed effects. Their index identifies statistically significant increases in patent protection in the same five circuits.

In the remaining of the paper we split firms into two groups based on whether they were located in one of the five geographical circuits that underwent high increases in patent protection (i.e. the Third, Eighth, Second, First and Sixth circuits) or one of the remaining circuits that did not experience significant increases in patent protection (i.e. the Fourth, Fifth, Seventh, Ninth, Tenth and other). We refer to the first group as "High increase" and to the second group as "Low increase". It is mostly firms in the first group that experienced an improvement in their ability to enforce patents and for which we should expect to observe a positive response.

As Hou *et al.* (2020) point out, such divide is imperfect because parties to patent disputes might move their cases to more favorable jurisdictions. For the most part of the sample period in this study, patent owners had to sue infringers in the district where the infringer was incorporated or where the infringer had committed infringement and had a regular and established place of business (Adams, 1984). If a patent owner was located in the "High increase" circuits but the infringing firms were in the "Low increase" group, its ability to enforce would have remained low. Or alternatively, if a patent owner was in the "Low increase" group but the infringer was in the "High increase" group, its ability to enforce would have increased. To the extent that infringers had good reason to be located in circuits with a reputation for being hostile to patents during the pre-CAFC period, we would expect patent owners in "High increase" group to have experienced substantial increases in their ability to enforce against infringers. At the same time, patent owners in "Low increase" group could have experienced positive increases in their ability to enforce.

4 Data

We combine five different data sources. First, we rely on Compustat data to measure our dependent variables and a series of firm-level control variables. Second, we use information from the NBER Patent Data Project (Bessen, 2009; Hall *et al.* , 2001) to measure patent counts per firm, which we use as controls. Third, we use industry measures of the importance of patent protection from the innovation surveys of Mansfield (1986), Levin *et al.* (1987), Cohen *et al.* (2000) and Arundel & Kabla (1998). Such information is matched to Compustat by mapping the industry definitions used in the different surveys to two, three or four digit historical SIC codes in Compustat. Fourth, we use information on CAFC-induced increases in patent protection across circuits, and hence U.S. states belonging to the different geographical circuits, from Henry & Turner (2006) and Hou *et al.* (2020). In order to define firm states we do not rely on Compustat locations, which are based on cover information from the latest updates (2020 in our case). Instead, we define a firm's state from the assignee location of patents matched to the firm with application date prior to the establishment of the CAFC. This means that we only retain firms with at least one patent application in the pre-CAFC era in our analysis. Finally, we use deflators from the BEA Satellite Account.

We use two dependent variables in our analysis, the natural logarithm of real R&D expenditures and a measure of R&D effort defined as the natural logarithm of real R&D investment over the number of employees. The main explanatory variable is the interaction of a post-CAFC binary indicator with the survey-based measures of industry reliance on patent protection (IRPP). We also use as controls a series of interactions of the post-CAFC indicator with fixed firm level characteristics defined as pre-sample means (for the years 1975-1977) of deflated physical capital, the number of employees, deflated revenue, deflated R&D investments and counts of eventually granted patent applications.

In the regressions we restrict to the years 1977-1993, that is five years prior to roughly ten years after the establishment of the CAFC. We drop firms in heavily regulated sectors, including "Agriculture, forestry and fishing (SIC codes starting with 0)", "Mining and construction (SIC codes starting with 1)", "Electric, Gas and Sanitary services (SIC codes starting with 49)", "Finance, insurance and real estate (SIC codes starting with 6)", and

"Public administration (SIC codes starting with 9)". For the remaining observations we retain a balanced panel of firms that invest in R&D in every single year during the sample period, with non-missing information for the explanatory variables or controls.

Table 2 reports descriptive statistics. The number of firms in the final sample varies somewhat depending on the IRPP measure of interest because not all the innovation surveys provide information on patent protection for the same industry groups. On average, firms located in circuits with higher increases in patent protection have higher R&D expenditure and are larger across multiple dimensions during the pre-CAFC period. Industry groups with higher values of IRPP have higher mean values of R&D and patents per employee. However, the same is not true for the average number of patents per dollar of R&D, which is negatively correlated with IRPP. This is reasonable because the higher values of IRPP are found in discrete industries where fewer patents are needed to protect each product. Therefore, conditional on firms having at least one patent, the average number of patents per firm seems a rather noisy measure of the importance of patent protection relative to survey-based measures.

5 Empirical strategy

We study the link between stronger patent protection and R&D investments using a difference-in-differences (DID) specification that examines whether the R&D investments of firms operating in industries with higher reliance on patent protection (first difference) are larger after the establishment of the CAFC (second difference). In particular, we estimate the following equation:

$$\ln(R\&D_{it}) = \alpha PostCAFC_t \times IRPP_i + PostCAFC_t \times X_i^{'}\gamma + \phi_t + \phi_i + \varepsilon_{it}, \qquad (1)$$

where the dependent variable is the log of R&D or the log of R&D effort, measured as R&D over the number of employees, of firm i in year t. The first term on the right-hand side is the DID term of interest, an interaction of IRPP and an indicator for the post-CAFC period, i.e., years from 1983 forward. The second term of the right hand side is an interaction of the post-CAFC dummy variable and pre-sample means of several firm characteristics. Finally, we control for a full set of time and firm fixed effects. The DID coefficient of interest is α. A positive and statistically significant point estimate would mean that the CAFC stimulated investments disproportionately more in firms operating in industries where patents are a more important mechanism of protection.

The CAFC triggered increases in the strength of patent protection for firms located in the five geographical circuits that we have labeled as "High increase" (i.e. the Third, Eighth, Second, First and Sixth circuits), but not so much in the remaining ones that we have labeled as "Low increase" (i.e. the Fourth, Fifth, Seventh, Ninth, Tenth and other). Accordingly, we estimate separate regressions of equation (1) for firms in "High increase" and "Low increase" circuits. We expect positive and statistically significant effects mostly for firms in the "High increase" sample. This strategy is useful to rule out possible confounding effects from similarly timed policies that might have favored R&D investments in industries where the importance of patent protection is also higher.[1] Any similarly timed policy that we are aware of was country-wide and should have affected firms in both subsamples to a similar degree. Therefore, positive effects in the sample of "High increase" but not in the sample of "Low increase" would be highly suggestive of CAFC-driven effects.

6 Results

Table 3 reports baseline estimates using the IRPP measure from Mansfield (1986). All the columns include firm fixed effects as well as circuit by year fixed effects. Estimates of α are positive and statistically significant (albeit only at a ten percent for the R&D equation) for firms located in the "High increase" group, and negative but statistically significant for firms in the "Low increase" group. Such results indicate that firms in industries with greater reliance on patent protection reacted to the establishment of the CAFC by increasing their R&D expenditures. Such effect can only be detected for firms located in geographical circuits

[1] For example, the Research and Experimentation Tax Credit, was introduced as part of the Economic Recovery Tax Act of 1981. At about the same time, the Bayh–Dole Act (the Patent and Trademark Laws Amendment of 1980) allowed universities and other non-profit institutions automatically to retain title to patents derived from federally funded R&D. Bayh–Dole explicitly recognized technology transfer to the private sector as a desirable outcome of federally financed research.

that experienced high increases in patent protection.

For the increase in R&D to be attributable to the CAFC, the $IRPP$ measure should be correlated with employment in the post-CAFC period, but not before. To determine whether there is a relationship between $IRPP$ and R&D in the years before 1982, we replace the $PostCAFC$ indicator with interactions of $IRPP$ and a full set of year dummies, using 1982 as the base category. Similarly, we also interact all the pre-sample mean controls with the full set of year dummies. Results for the yearly difference-in-differences coefficients, are displayed visually along with their 95 percent confidence intervals in Figure 3. Point estimates are statistically insignificant at conventional levels until after 1982 for firms in the "High increase" group and remain flat for firms in the "Low increase" group. The estimates turn positive and statistically significant in the post-CAFC period, with the effects becoming more pronounced over time.

The estimated effects are economically significant. The point estimate in column 1 indicates that, relative to firms with an IRPP at the twenty-fifth percentile (0.01), firms with an IRPP at the seventy-fifth percentile (0.15) increased their R&D investments by 0.12 log points $(0.824 \times (0.15 - 0.01))$. It is also possible to calculate the implied change in R&D in levels for firms with an IRPP at the seventy-fifth percentile, relative to firms in the 25th percentile, as $\exp(\widehat{\alpha}(IRPP_{75th} - IRPP_{25th}) + \mu + \frac{\sigma^2}{2}) - \exp(\mu + \frac{\sigma^2}{2})$, where μ and σ are the mean and standard deviation of $\ln(R\&D)$ in the pre-CAFC period.[2] According to this expression, the implied relative increase in R&D due to the CAFC was of \$21.48M. This represents a 15% increase with respect to an average R&D expenditure of \$143M in the pre-CAFC period. Using the point estimate in column 3, the implied relative increase in R&D effort obtained with the same expressions is of 0.13 log points and \$0.66M, which again represents a 15% increase with respect to an average R&D effort of \$4.5M per employee in the pre-CAFC period.

Tables 4, 5 and 6 report estimates using the IRPP measures from Levin *et al.* (1987), Cohen *et al.* (2000) and Arundel & Kabla (1998) respectively. The results in these tables are consistent with the baseline results obtained with Mansfield's measure. An interesting aspect of these other surveys is that they report IRPP measures for product and process

[2] Note that we are using properties of the lognormal distribution.

innovations. For the IRPP measure in Levin *et al.* (1987) we can only detect positive effects for product innovations. For Cohen *et al.* (2000) and Arundel & Kabla (1998) we detect positive responses to the CAFC when using both the product and process based measures of IRPP. However, both measures are strongly correlated as shown in Figure 2. When both measures are simultaneously included in the regressions, only the product measure enters with a statistically significant sign (such results are not shown in the tables). Therefore, it seems that firms are responsive to stronger patent protection when they operate in industries with high reliance on patent protection for product innovations.

7 Conclusion

The main contribution of our study is to showcase that in order to detect incentive effects from patent laws, researchers should account for differences in IP protection strategies across firms. Empirical designs aimed at estimating average effects seem inappropriate given that, as indicated by seminal innovation surveys, the average firm does not rely on patents as an appropriation mechanism. We use survey-based measures of reliance on patent protection to study if responses to stronger patent protection can be found where they are to be expected, that is in firms that rely on patents as a protection mechanism. We leverage the formation of the CAFC, one of the most significant pro-patent shifts in the U.S. over the last decades, as the focal reform of interest. Using a difference-in-differences approach we find that the establishment of the CAFC did encourage research investments disproportionately more in firms operating in industries that rely on patents. Such effects are economically significant and only arise in the post-CAFC period for firms located in geographical circuits that experienced high increases in patent protection.

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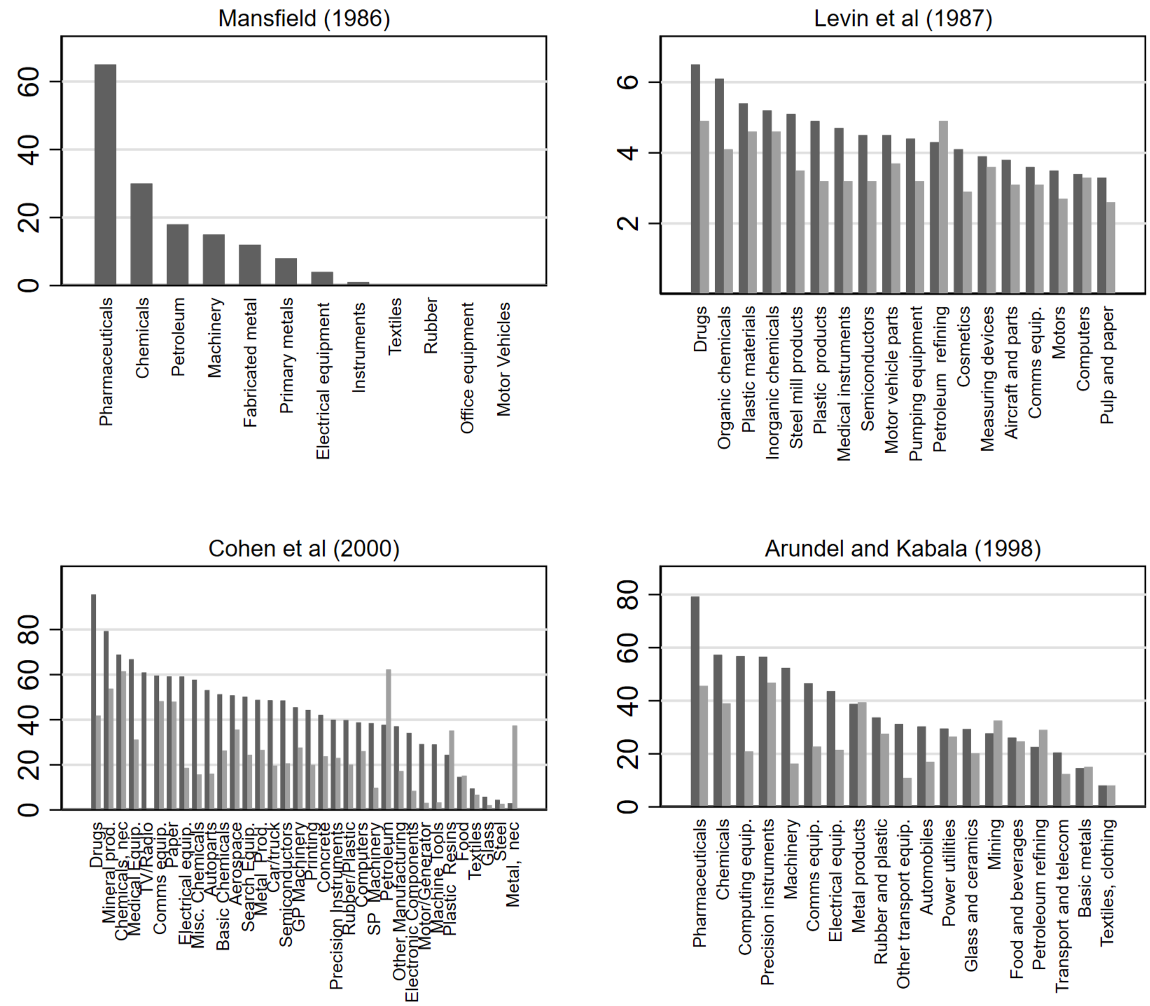
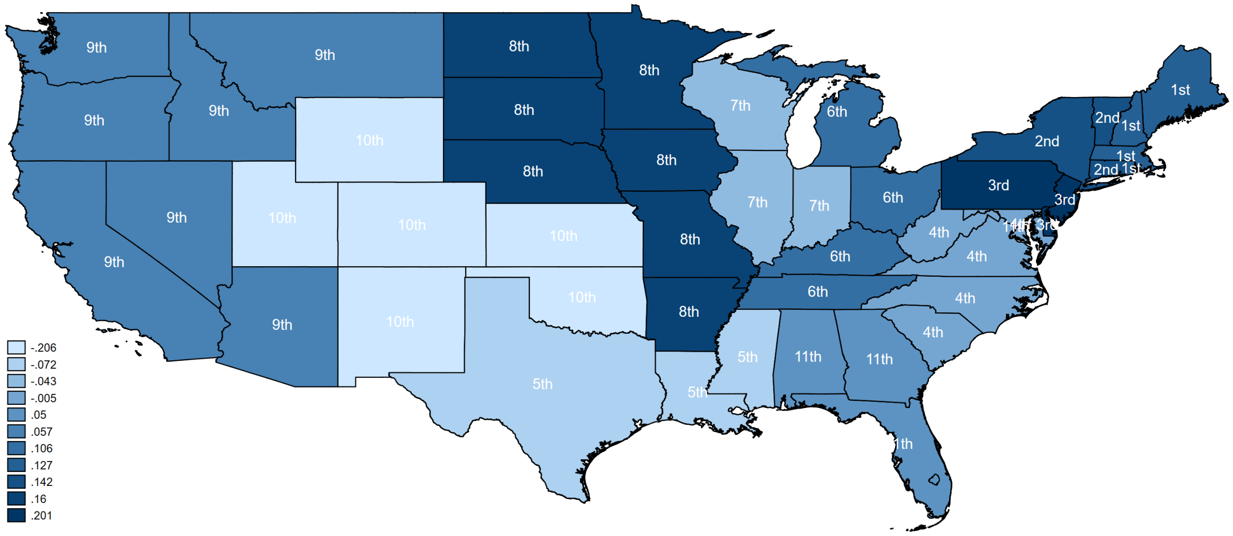
Figures and tables

Figure 1. Industry reliance on patents protection



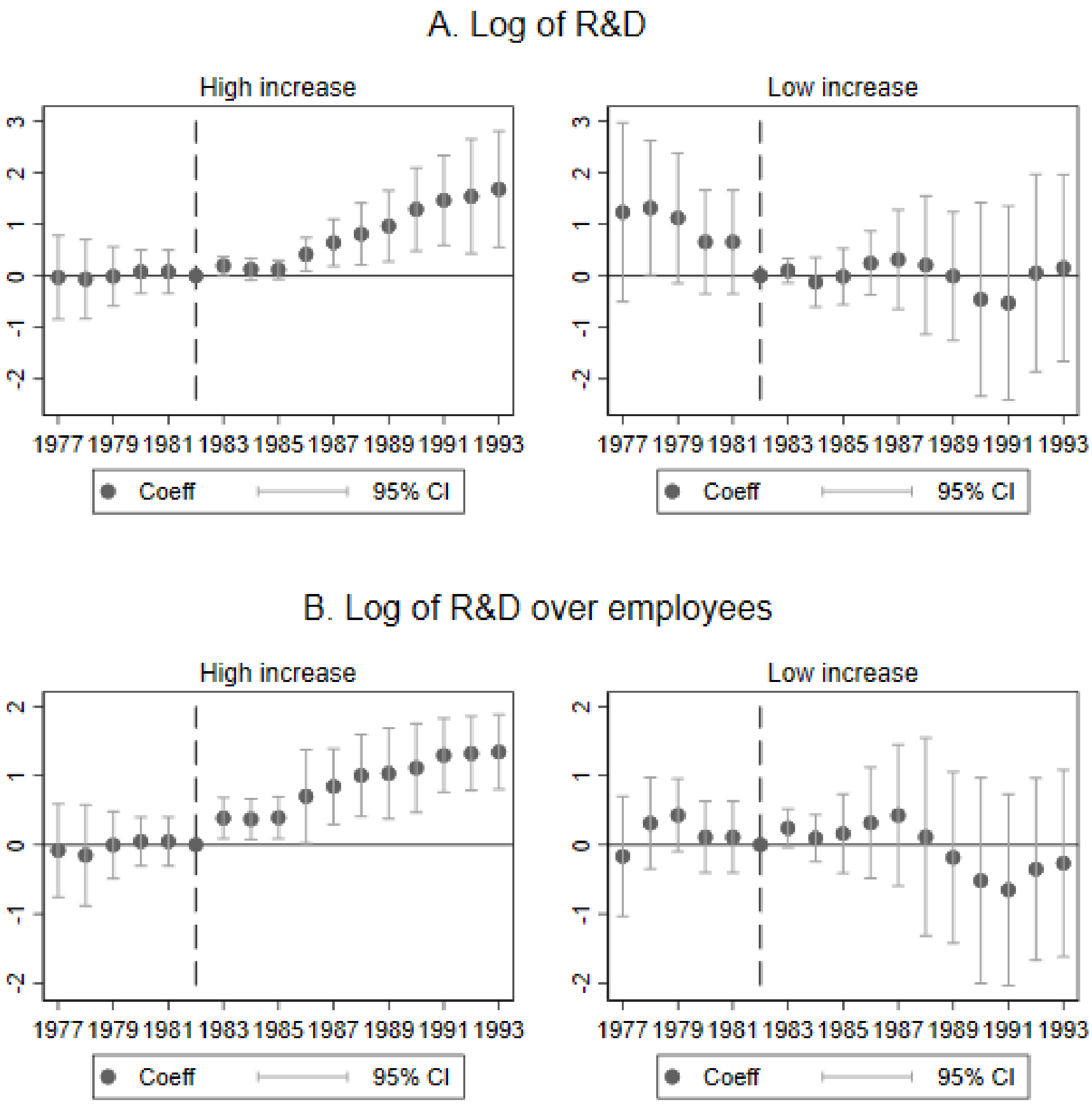
Notes: This figure graphs the measure of industry reliance on patent protection (IRPP) as an appropriation mechanism as reported in several innovation surveys. Dark bars refer to product innovations while light bars refer to process innovations. Mansfield (1986) does not distinguish between product and process innovations.

Figure 2. CAFC-driven changes in strength of patent protection



Notes: This figure graphs the increase in patent protection (probability that a patent is found valid and infringed as reported in Table 1 of Henry and Turner, 2006) after the establishment of the CAFC, by regional circuit.

Figure 3. Interaction terms - Mansfield (1986)



Notes: This figure reports coefficients and 95 percent confidence intervals for the estimated coefficients of the interaction terms version of the DID equation reported in Table 3. The base category is the year 1982 in which the CAFC was established.

Table 1. Survey-based measures of reliance on patent protection

	Mansfield (1986)	Levin et al. (1987)	Cohen et al. (2000)	Arundel and Kabala (1998)
Period covered	1981-1983	1981-1983	1994	1990-1992
Country	U.S.	U.S.	U.S.	UK, DE, IT, NL, BE, ES, DK, FR
Coverage	100 manufacturing firms	650 individuals representing 130 lines of business of R&D-doing publicly traded manufacturing firms	1,165 large R&D doing manufacturing firms	604 respondents of a 1993 survey targeted at EuropeŠs largest R&D performing industrial firms
Measure of industry reliance on patent protection (IRPP)	Percent of developed inventions that would not have been developed if patent protection could not have been obtained	Effectiveness of patents in preventing duplication for new or improved processes and products, evaluated on a seven point scale (1=not at all effective; 7=very effective)	Mean patent propensity rates for product and process innovations, measured as the percentage of product and process innovations that are patented	Sales-weighted patent propensity rates for product and process innovations, measured as the percentage of product and process innovations that are patented
Source within article	Column 1 in Table 1	Columns 1 and 2 of Table2	Columns 4 and 6 of Table A1	Columns 3 and 4 of Table 1
Number of industry groups	12	18	34	19

Table 2. Descriptive statistics

	A. High-increase circuits						B. Low-increase circuits					
	Firms	Obs.	Mean	S.D.	Min	Max	Firms	Obs.	Mean	S.D.	Min	Max
R&D	214	3,638	178.76	613.12	0.00	8,617.05	138	2,346	102.99	222.24	0.01	2,637.91
R&D over employees	214	3,638	6.01	6.20	0.02	67.75	138	2,346	7.24	8.81	0.06	98.96
Post-CAFC	214	3,638	0.65	0.48	0.00	1.00	138	2,346	0.65	0.48	0.00	1.00
IRPP - Mansfield (1986)	186	3,162	0.14	0.17	0.00	0.65	126	2,142	0.09	0.13	0.00	0.65
IRPP - Levin et al. (1987)	102	1,734	4.50	0.98	3.30	6.50	68	1,156	4.16	0.67	3.30	6.50
IRPP - Cohen et al. (2000)	196	3,332	0.47	0.20	0.03	0.95	116	1,972	0.47	0.14	0.03	0.95
IRPP - Arundel and Kabala (1998)	202	3,434	0.47	0.15	0.08	0.79	133	2,261	0.46	0.13	0.08	0.79
Capital, pre-CAFC mean	214	3,638	1,045	3,291	0.03	33,328	138	2,346	562	1,874	0.24	12,910
Sales, pre-CAFC mean	214	3,638	5,338	16,898	1.74	149,471	138	2,346	2,770	7,050	5.06	57,861
Labor, pre-CAFC mean	214	3,638	26.43	71.42	0.01	742.00	138	2,346	12.77	21.81	0.04	119.02
R&D, pre-CAFC mean	214	3,638	107.69	365.62	0.05	3,815.10	138	2,346	47.38	93.90	0.09	600.43
Patent flow, pre-CAFC mean	214	3,638	39.19	90.11	0.00	819.67	138	2,346	20.65	46.16	0.00	361.33

NOTE. This table reports summary statistics of the variables used in the regressions for firms located in circuits that underwent high increases (Panel A) and low increases (Panel B) in patent protection (i.e. probability that a patent is found valid and infringed) after the establishment of the CAFC. Values are in 2010 $ million.

Table 3. Difference in differences results - Mansfield (1986)

	A. $\ln(\text{R\&D}_{it})$		B. $\ln(\text{R\&D/emp}_{it})$	
	High	Low	High	Low
	(1)	(2)	(3)	(4)
Post × IRPP_i	0.824*	-0.790	0.910***	-0.107
	(0.398)	(0.850)	(0.168)	(0.351)
Post × $\ln(\text{Capital}_{i,1977})$	0.002	-0.014	0.005	-0.118
	(0.164)	(0.127)	(0.099)	(0.089)
Post × $\ln(\text{Employees}_{i,1977})$	0.092	-0.215	0.333***	0.012
	(0.100)	(0.233)	(0.081)	(0.146)
Post × $\ln(\text{Sales}_{i,1977})$	-0.243	0.081	-0.223*	0.141
	(0.194)	(0.229)	(0.119)	(0.172)
Post × $\ln(\text{R\&D}_{i,1977})$	-0.005	0.069	-0.161**	-0.034
	(0.042)	(0.141)	(0.053)	(0.066)
Post × $\ln(\text{Patents}_{i,1977})$	0.103**	0.017	0.084***	0.032
	(0.044)	(0.096)	(0.025)	(0.077)
Firm and circuit×year FE	Yes	Yes	Yes	Yes
Impact in ln points	.12	-.11	.13	-.01
Impact in millions	21.48	-12.53	.66	-.09
R^2	0.96	0.94	0.87	0.86
Firms	186	126	186	126
Observations	3,162	2,142	3,162	2,142

NOTE. This table reports OLS coefficients for the estimated difference-in-differences (DID) regressions. The dependent variable is the log of R&D (Panel A) or the log of R&D over employment (Panel B) as indicated at the top of the table. The explanatory variable of interest is the interaction of IRPP and the post-CAFC indicator. The controls include post-CAFC indicator interacted with the log of the average pre-sample value (between the years 1977 and 1975) of several firm characteristics (captial, employment, sales, R&D and number of patents). ***, ** and * indicate significance at a 1%, 5% and 10% level respectively. Standard errors are clustered at the industry level used to measure IRPP.

Table 4. Difference in differences results - Levin et al. (1987)

	Product innovations				Process innovations			
	A. ln(R&D$_{it}$)		B. ln(R&D/emp$_{it}$)		C. ln(R&D$_{it}$)		D. ln(R&D/emp$_{it}$)	
	High	Low	High	Low	High	Low	High	Low
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post × IRPP$_i$	0.168**	0.026	0.144***	-0.056	0.085	-0.272	0.160*	-0.073
	(0.069)	(0.142)	(0.040)	(0.097)	(0.161)	(0.197)	(0.092)	(0.103)
Post × ln(Capital$_{i,1977}$)	-0.180	0.001	-0.173	-0.085	-0.198	0.037	-0.191	-0.079
	(0.194)	(0.178)	(0.125)	(0.102)	(0.189)	(0.167)	(0.120)	(0.103)
Post × ln(Employees$_{i,1977}$)	-0.203	-0.148	0.106	0.076	-0.247*	-0.252	0.126	0.041
	(0.127)	(0.208)	(0.076)	(0.105)	(0.123)	(0.222)	(0.072)	(0.109)
Post × ln(Sales$_{i,1977}$)	0.171	0.029	0.133	0.035	0.190	0.065	0.104	0.061
	(0.212)	(0.204)	(0.149)	(0.148)	(0.210)	(0.124)	(0.147)	(0.123)
Post × ln(R&D$_{i,1977}$)	0.027	-0.022	-0.094	-0.024	0.064	-0.010	-0.074	-0.021
	(0.104)	(0.155)	(0.089)	(0.075)	(0.107)	(0.150)	(0.088)	(0.074)
Post × ln(Patents$_{i,1977}$)	0.128	0.084	0.028	0.033	0.137	0.142	0.036	0.034
	(0.095)	(0.097)	(0.042)	(0.090)	(0.102)	(0.095)	(0.041)	(0.089)
Firm and circuit×year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Impact in ln points	.12	.02	.1	-.04	.06	-.19	.11	-.05
Impact in millions	25.06	3.04	.57	-.29	12.26	-28.88	.63	-.38
R^2	0.96	0.95	0.86	0.89	0.96	0.95	0.86	0.89
Firms	102	66	102	66	102	66	102	66
Observations	1,734	1,122	1,734	1,122	1,734	1,122	1,734	1,122

NOTE. This table reports OLS coefficients for the estimated difference-in-differences (DID) regressions. The dependent variable is the log of R&D (Panel A) or the log of R&D over employment (Panel B) as indicated at the top of the table. The explanatory variable of interest is the interaction of IRPP and the post-CAFC indicator. The controls include post-CAFC indicator interacted with the log of the average pre-sample value (between the years 1977 and 1975) of several firm characteristics (captial, employment, sales, R&D and number of patents). ***, ** and * indicate significance at a 1%, 5% and 10% level respectively. Standard errors are clustered at the industry level used to measure IRPP.

Table 5. Difference in differences results - Cohen et al. (2000)

	Product innovations				Process innovations			
	A. ln(R&D$_{it}$)		B. ln(R&D/emp$_{it}$)		C. ln(R&D$_{it}$)		D. ln(R&D/emp$_{it}$)	
	High	Low	High	Low	High	Low	High	Low
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post × IRPP$_i$	1.165***	0.304	0.721***	0.127	1.290***	0.387	0.937**	0.688*
	(0.203)	(0.451)	(0.218)	(0.269)	(0.413)	(0.716)	(0.350)	(0.359)
Post × ln(Capital$_{i,1977}$)	-0.018	-0.124	-0.031	-0.203*	-0.139	-0.154	-0.109	-0.252**
	(0.165)	(0.218)	(0.135)	(0.113)	(0.173)	(0.232)	(0.134)	(0.111)
Post × ln(Employees$_{i,1977}$)	-0.026	-0.166	0.192**	0.065	0.030	-0.133	0.239**	0.125
	(0.126)	(0.175)	(0.091)	(0.099)	(0.139)	(0.192)	(0.102)	(0.101)
Post × ln(Sales$_{i,1977}$)	-0.061	0.043	-0.094	0.041	-0.043	0.032	-0.080	0.043
	(0.205)	(0.222)	(0.154)	(0.135)	(0.211)	(0.202)	(0.156)	(0.124)
Post × ln(R&D$_{i,1977}$)	-0.039	0.008	-0.166***	-0.082	0.025	0.010	-0.125**	-0.077
	(0.070)	(0.108)	(0.055)	(0.065)	(0.074)	(0.106)	(0.059)	(0.064)
Post × ln(Patents$_{i,1977}$)	0.036	0.002	0.044	-0.004	0.051	0.011	0.049	-0.000
	(0.066)	(0.082)	(0.042)	(0.060)	(0.068)	(0.086)	(0.039)	(0.059)
Firm and circuit×year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Impact in ln points	.22	.06	.14	.02	.24	.07	.18	.13
Impact in millions	33.68	5.89	.67	.15	37.75	7.55	.89	.84
R^2	0.96	0.94	0.87	0.87	0.96	0.94	0.87	0.87
Firms	196	116	196	116	196	116	196	116
Observations	3,332	1,972	3,332	1,972	3,332	1,972	3,332	1,972

NOTE. This table reports OLS coefficients for the estimated difference-in-differences (DID) regressions. The dependent variable is the log of R&D (Panel A) or the log of R&D over employment (Panel B) as indicated at the top of the table. The explanatory variable of interest is the interaction of IRPP and the post-CAFC indicator. The controls include post-CAFC indicator interacted with the log of the average pre-sample value (between the years 1977 and 1975) of several firm characteristics (captial, employment, sales, R&D and number of patents). ***, ** and * indicate significance at a 1%, 5% and 10% level respectively. Standard errors are clustered at the industry level used to measure IRPP.

Table 6. Difference in differences results - Arundel and Kabala (1998)

	Product innovations				Process innovations			
	A. ln(R&D$_{it}$)		B. ln(R&D/emp$_{it}$)		C. ln(R&D$_{it}$)		D. ln(R&D/emp$_{it}$)	
	High	Low	High	Low	High	Low	High	Low
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post × IRPP$_i$	1.402***	-0.414	1.547***	0.809**	1.515***	-0.256	1.357***	0.613*
	(0.403)	(0.660)	(0.257)	(0.280)	(0.497)	(0.812)	(0.325)	(0.307)
Post × ln(Capital$_{i,1977}$)	0.133	-0.104	0.141	-0.124	0.038	-0.090	0.026	-0.150
	(0.204)	(0.175)	(0.117)	(0.103)	(0.199)	(0.173)	(0.116)	(0.106)
Post × ln(Employees$_{i,1977}$)	0.022	-0.189	0.231**	0.006	0.065	-0.194	0.257***	0.024
	(0.114)	(0.188)	(0.092)	(0.129)	(0.110)	(0.177)	(0.081)	(0.129)
Post × ln(Sales$_{i,1977}$)	-0.051	0.049	-0.025	0.209	-0.164	0.076	-0.150	0.157
	(0.195)	(0.206)	(0.131)	(0.168)	(0.192)	(0.224)	(0.136)	(0.166)
Post × ln(R&D$_{i,1977}$)	-0.051	0.070	-0.205***	-0.080	0.021	0.058	-0.124**	-0.058
	(0.056)	(0.141)	(0.051)	(0.072)	(0.058)	(0.129)	(0.058)	(0.070)
Post × ln(Patents$_{i,1977}$)	0.037	0.023	0.024	0.047	0.046	0.022	0.040	0.048
	(0.062)	(0.090)	(0.039)	(0.063)	(0.066)	(0.093)	(0.042)	(0.066)
Firm and circuit×year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Impact in ln points	.32	-.09	.35	.19	.35	-.06	.31	.14
Impact in millions	65.13	-10.19	1.98	1.17	71.35	-6.41	1.7	.86
R^2	0.96	0.94	0.88	0.87	0.96	0.94	0.88	0.87
Firms	202	133	202	133	202	133	202	133
Observations	3,434	2,261	3,434	2,261	3,434	2,261	3,434	2,261

NOTE. This table reports OLS coefficients for the estimated difference-in-differences (DID) regressions. The dependent variable is the log of R&D (Panel A) or the log of R&D over employment (Panel B) as indicated at the top of the table. The explanatory variable of interest is the interaction of IRPP and the post-CAFC indicator. The controls include post-CAFC indicator interacted with the log of the average pre-sample value (between the years 1977 and 1975) of several firm characteristics (captial, employment, sales, R&D and number of patents). ***, ** and * indicate significance at a 1%, 5% and 10% level respectively. Standard errors are clustered at the industry level used to measure IRPP.