The Responsiveness of Inventing: Evidence from a Patent Fee Reform

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Abstract

Inequality leads to a misallocation of talent when individuals are credit constrained. This paper studies such misallocation by tracing the effects of a large reduction in the cost of patenting on innovation. I exploit a patent fee reform in the United Kingdom in 1884 to investigate the responsiveness of inventors, and create a novel dataset on 54,000 inventors and their patent renewals. The reduction in the cost of inventing leads to a considerable and persistent rise in the quantity of lower- and high-quality ideas patented. Inventors respond strongly by delaying to patent lower-quality ideas before the reform and by bunching patents just after the reform. Innovation, as proxied by high-quality patents, increases in the longer run with an elasticity of 1.25. To test for the presence of credit constraints I generate two proxy measures of wealth using inventor names and addresses, and find a larger innovation response for poorer inventors. These results indicate efficiency gains from decreasing the cost of inventing and in addition, from relaxing credit constraints.

Keywords: innovation incentives, inventing elasticities, patent quality, credit constraints

JEL classification: J22, J24, L26, O31, O33

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1 Introduction

Technological progress is a fundamental driver of growth and one of the most effective ways for combating challenges from diseases to climate change. Despite their pervasive relevance, we know little about the incentives and constraints that individual inventors face. Do inventors respond to reductions in the cost of inventing? Inventors are high-skilled individuals who may be particularly responsive to such financial incentives. In such a case high costs for inventing diminish inventing efforts similar to a tax on effort. Yet, inventors differ from other workers in many ways and could be motivated purely by scientific achievement and reputation rather than by monetary payoffs. Inventing may also be unresponsive if capital-intensive inputs cannot easily be modified and prerequisite skills are acquired over years. This paper studies empirically whether inventors adjust their efforts in response to an incentive change by tracing the effects of a reduction in the patent fee in the United Kingdom in 1884 for 54,000 inventors.

In contrast to the production of other goods, invention is a risky process in which output cannot be perfectly predicted from the inputs (Arrow, 1962). Inventing activities and the ideas produced are difficult to assess, and information about their quality is asymmetric. In the resulting imperfect market for ideas inventors cannot easily sell on their ideas, nor raise funds to gain protection for their intellectual property if they are credit constrained. In such an imperfect market for ideas the relative wealth of inventors matters. Resource allocation may be closer to optimal for wealthy inventors who are not credit constrained, and the inventing talent of poor inventors is misallocated. This analysis provides new evidence for such misallocation effects.

While many countries such as the United States, China, South Korea and Singapore currently have policies in place to subsidise patent filing fees, these reductions in the cost of inventing also share characteristics with numerous other policies that aim to propel innovation. Understanding the effectiveness of such policies is key as new inventions can be transformative, and large sums of money are spent on innovation. For example, the US spent nearly US$ 500 billion on research and development (R&D) in 2018, and average R&D expenditures in high-income countries account for around 2.6 percent of GDP.

A main contribution of this paper is to provide new insights on the responsiveness of inventing based on microdata. A large patent fee reduction in the United Kingdom in 1884 serves as a quasi-experimental change in financial incentives at a time when inventing was less reliant on formalised education and large upfront capital investments in equipment. The patent reform in 1884 reduced fees by 84 percent from a high initial level, and lead to a considerable and persistent rise in the quantity of lower- and high-quality ideas patented. To study the responses to this reduction in the cost of inventing, I create a comprehensive new dataset of UK patenting for a ten-year window around the fee change. This data includes detailed information on the names, addresses and occupations of 54,000 British inventors who applied for UK patents from 1879-1888 and obtained patent grants. In addition, I compile renewal information for the patents of these inventors from over 60 volumes of printed journal publications of the UK Patent Office to construct a measure of patent quality. Renewed patents are valuable because inventors only pay expensive renewal fees if the expected benefit exceeds their cost[1], and patent renewals are widely used in the literature to gauge patent quality (Schankerman and Pakes, 1986; Griliches, 1990; Lanjouw et al., 1998)[2]. The cumulative fees for renewing a UK patent remained constant over the reform period in the 1880s.

I provide a stylised framework that accounts for the short-run delays in patenting lower-quality ideas before the reform and the marked bunching of patents just after the fee reduction. To analyse this shifting of patents observed in the months around the reform, I adapt the bunching approach developed by Kleven and Waseem (2013) and Best and Kleven (2017) for notched discontinuities in tax and duty schedules to the case of the downward patent fee notch in January 1884. The short-run effect on patenting quality shows that patent quality is not simply a function of the total number of granted patents. Inventors can assess the quality of their ideas and choose the optimal timing to patent and for inventing efforts accordingly. Innovation, as proxied by high-quality patents, increases in the longer run with an elasticity of 1.25. Similar to the effects of cost reductions for supplying labour, these results point to efficiency gains from decreasing the cost of inventing.

A second main contribution of this study is to show evidence for strong relative responses to the fee reduction by inventors with lower wealth. Poorer inventors respond more strongly to the cost reduction for inventing than rich inventors, which is indicative of entry barriers due to credit

[1]Another possibility is to construct quality measures from patent citations in contemporaneous publications (Nuvolari and Tartari, 2011; Hanlon, 2015) but to my knowledge a continuous publication with this information does not exist for 1879-1888. A frequently used measure for more recent patent quality are citations by later patents but only few British patents from the 1880s appear in later citation data.

[2]For example, Brunt et al. (2012) adjust nineteenth-century agricultural patents in Britain for quality by using renewal information. Hanlon (2015) employs renewal data on UK textile patents to assess the effects of input prices on the direction of technological change in the 1860s.

constraints when the pre-reform fee is high. To investigate this misallocation of talent, I create two proxy measures for inventor wealth. The first wealth measure makes use of the probabilistic share of inventor surnames at the county level among high-wealth individuals that were probated at death. This strategy of imputing rank from the likelihood of a surname appearing in high socio-economic status groups follows Clark (2014) and Clark and Cummins (2015), and the resulting wealth measure is independent of individual ability and effort as well as of local education levels. I construct a second wealth measure from information on the employment of servants in inventor households. Information on the number of servants employed by household is available in the 1881 Census of Population, and I uniquely match a subsample of inventors in the census data by using full inventor names and addresses. In addition to efficiency gains from decreasing the cost of inventing, the reform of 1884 improved the allocation of talent by relaxing credit constraints for poorer inventors.

This paper contributes to a recent empirical literature on the responsiveness of inventors and researchers to incentives. University researchers in Norway decreased patenting and entrepreneurship by 50 percent after their rights to innovation proceeds were reduced by more than half (Hvide and Jones, 2018). In work by Lerner and Wulf (2007) the number of high-quality patents increases in firms in response to longer-run compensation incentives for research personnel, and Lach and Schankerman (2008) find that scientists in universities respond to stronger royalty incentives by increasing the quality rather than the quantity of inventions. Akcigit et al. (2022) show that innovation declines with rising income and corporate taxes, and Akcigit et al. (2016a) and Moretti and Wilson (2017) document significant geographical mobility of inventors in response to taxes.

My investigation of inventor responses by wealth forms part of the broader empirical work on misallocation. Existing microevidence focuses on the association between parental income and the likelihood of becoming an inventor. Using administrative data on 1.2 million US inventors, Bell et al. (2018) show that children growing up in low-income households are ten times less likely to become inventors, even when maths test scores are held constant, due to differences in in human capital investments. Work by Aghion et al. (2017) for Finland controls for education and the IQ of inventors and also finds that parental income matters for inventing. Using a macro approach, Hsieh et al. (2019) estimate that improvements in the occupational allocation of women and men contributed between 20 and 40 percent of growth in aggregate US output between 1960 and 2010. Related papers in macroeconomics show that the number of entrepreneurs is determined by the tightness of borrowing constraints (Evans and Jovanovic, 1989; Holtz-Eakin et al., 1994; Cagetti and De Nardi, 2006), and that the propensity of becoming a business owner is increasing in wealth (Hurst and Lusardi, 2004). When credit constraints are present, a reduction in wealth inequality can foster growth by allowing constrained individuals to invest in good ideas (Banerjee and Newman, 1993; Aghion and Bolton, 1997). In work by Akcigit et al. (2016b), imperfections in the market for ideas lead to a misallocation of ideas in equilibrium.

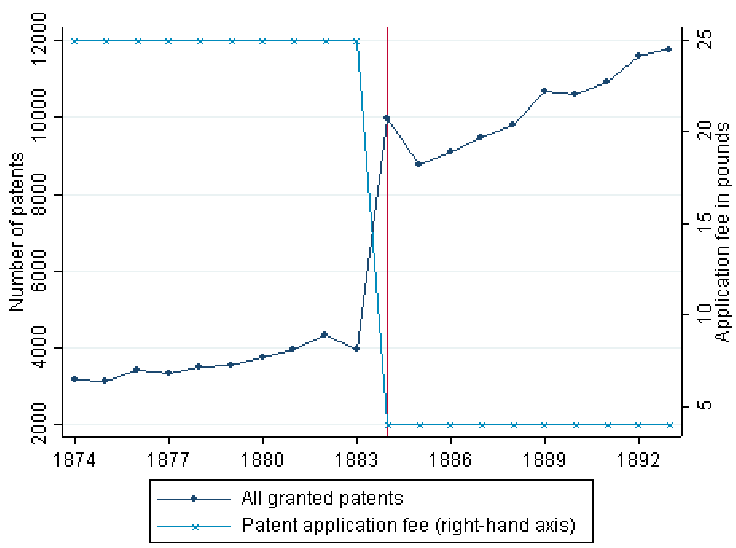
This paper also has implications for the effectiveness of innovation policies, which include direct R&D grants, R&D tax credits, patent boxes, university incentives or human capital investments. Bloom et al. (2019) provide a summary of these policy tools. For example, Bloom et al. (2002) show that R&D tax credits are an effective innovation policy with a long-run elasticity of around unity. In an analysis of a R&D tax credit reform in the UK in 2008, Dechezleprêtre et al. (ming) estimate an elasticity of R&D spending of around 2.6 in response to a cost reduction for smaller firms that are more likely to be financially constrained. In the analysis of a change in Canadian tax law, Agrawal et al. (2020) document R&D elasticities of small private firms above unity. In a quasi-experimental evaluation of R&D subsidies of a large-scale grant programme by the US Department of Energy, Howell (2017) finds stronger effects of R&D subsidies for more financially constrained firms. In one of the only papers on patent fee elasticities, de Rassenfosse and van Pottelsberghe de la Potterie (2012) estimate a patent fee elasticity of around -0.30 in recent cross-country data, compared to an elasticity of overall patenting of -1.68 found in this study. To my knowledge, Nicholas (2011) carries out the only previous study of the effects of the UK patent reform in 1884, by using a 20-percent annual sample of granted patents for 1878-1888. The main focus of his analysis is the geographic and sectoral composition of the longer-run increase in patents, which is evenly distributed. The work presented in this paper differs from the study by Nicholas by assessing the effects of the fee change on the inventing effort of individuals with detailed data extracted from all patents by date of their application.

This paper is organised as follows. Section 2 provides an overview of the Patents, Designs and Trade Marks Act of 1884 and describes the procedures involved in obtaining a patent in the UK in the second half of the nineteenth century. A stylised model of patenting around a patent fee reduction is presented in Section 3, which distinguishes between a mechanical quality effect that increases patent numbers, and increased inventing efforts in response to the fee reduction. Section 4 describes the archival data sources, the creation of the inventor dataset, and how the wealth proxy measures are generated. Section 5 presents the estimation and results, and Section 6 concludes.

2 Context of the Patent Reform in 1884

The Patents, Designs and Trade Marks Act of 1883 took effect on January 1 1884 and significantly lowered the patent application fee from a high initial level of £25 to £4. The reduction in fees is reflected in pronounced increases in total granted and renewed UK patents, as shown in Figures 1 and 2.

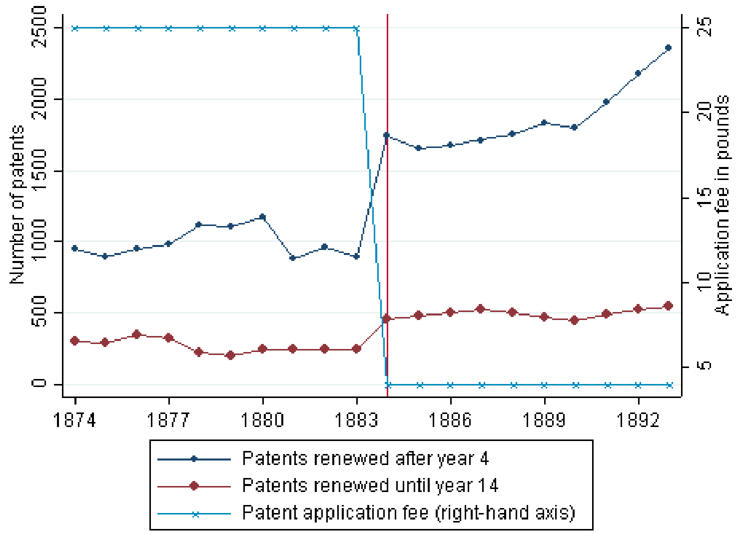
Figure 1: Number of UK patents 1874-1893



These yearly aggregate numbers are sourced from the Annual Reports of the Patent Office and include patents for British and for foreign residents. Before the reform, the costs involved in patenting in the UK were high in terms of average local living costs and impeded inventive activities (MacLeod et al., 2003). The pre-reform fee of £25 is approximately equivalent to £13,000 in 2020, when deflating by average earnings.[3] To relate the fee to the wages of middle-class employees, the yearly salary of a clerk employed in the UK Patent Office was £177 in 1883 and that of a Patent Office draughtsman was £131. When introducing the new patent bill in 1883 Joseph Chamberlain, then the president of the Board of Trade, called the initial patent fee

[3]This approximation was calculated on www.measuringworth.com. The present value varies by the method of conversion, and £25 are equivalent to about £2,600 in 2020 in terms of purchasing power.

Figure 2: Number of UK renewed patents 1874-1893



of £25 'an insurmountable obstacle in the way of the poorest inventors'.[4] In addition, cumulative renewal fees of £150 had to be paid to keep the patent in force until a full patent term of 14 years. By contrast to the UK, the patent fee in the US in the 1880s was equivalent to only £7 for a full patent term of 17 years, and patenting fees were also lower than in the UK in several other European countries. Frank Grierson, a naval architect, told the Society of Engineers in 1880 that a patent in the US 'is within the reach of every mechanic; in England it is a venture for a capitalist'.[5] One reason for the high patent fee was the explicit intention to deter patent applications for low-value inventions, so that the system could be self-policing (MacLeod et al., 2003). Overall, only a small proportion of inventions were patented in the UK in the second half of the nineteenth century (Brunt et al., 2012; Moser, 2005; Moser and Nicholas, 2013).

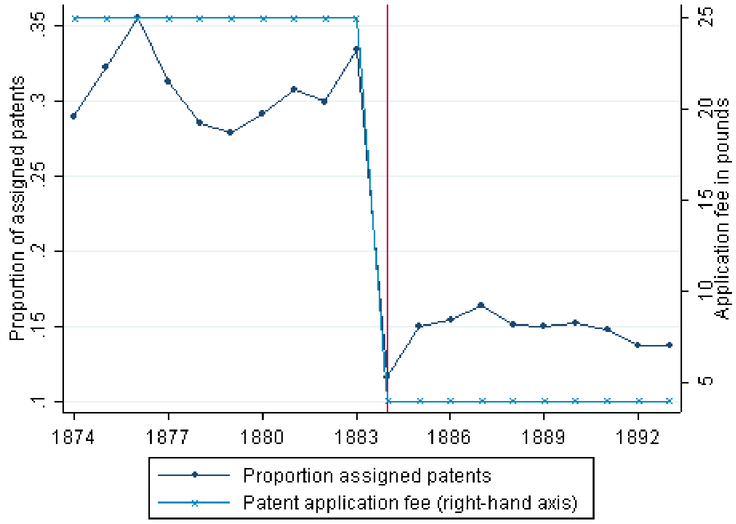
Figure 3 shows the marked fall in the proportion of assigned and licensed patents in the UK from around 30 to 14 percent after January 1884.[6] Assignment information is one data source that gives some indication about credit constraints. In the presence of credit constraints, one option for constrained inventors is to obtain protection for their idea and then sell on their patent right in the form of an assignment or a license. Assignment data for this period is only available

[4] *Hansard*, 16 April 1883, col. 354, as cited in MacLeod et al. (2003).

[5] Frank Grierson (1880), A Paper on the National Value of Cheap Patents, *Transactions of the Society of Engineers*, as cited in MacLeod et al. (2003).

[6] Annual aggregate numbers of assigned and licensed patents are sourced from the Annual Reports of the UK Patent Office.

Figure 3: Proportion of assigned UK patents 1874-1893



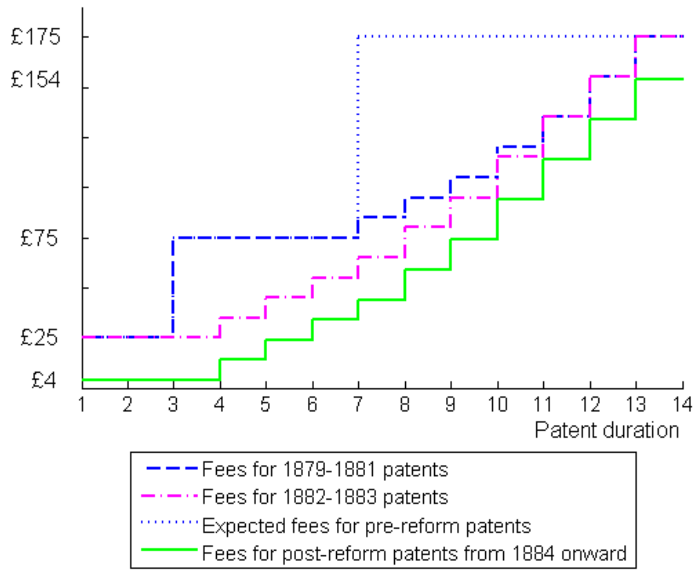
in the form of yearly aggregate data but not for individual patents.

The cumulative amount required to keep a patent to the full term of 14 years was £150 and remained the same before and after the reform in January 1884. Figure 4 provides a detailed overview of the renewal fee schedule before and after the reform. The cumulative amount of renewal fees remained the same after the reform in 1884, but the timing of renewal fee instalments changed so that patents that were applied for in 1879-1881 faced a different fee schedule.

The date of a patent refers to the date of application, after which a patent was granted within three to ten months on average. For renewals before 1884 a renewal fee of £50 had to be paid to keep the patent in force after the first three years. A payment of an additional £100 was required after seven years to maintain the patent until the full term of 14 years. For renewals of patents after the reform, the first renewal fee for patents applied for after January 1881 was only due from the fourth year onward and post-reform payments could be made annually. For estimating longer-run responses, I compare patents that were applied for in 1882 and 1885, for which the same fees were due for renewals between four and 14 years after the initial application.

The reduction in the patent fee by 84 percent in January 1884 followed several decades of public debate about the patenting system, which included pressure to abolish patents entirely. The British patent system was first reformed in 1852 as a result of the system being both 'enormously cumbersome and prohibitively costly' (Boehm and Silberston, 1967). The reform in 1852 reduced

Figure 4: Application and renewal fees payable by years of patent term



Notes: Cumulative renewal fees for keeping a patent in force to the maximum term of 14 years were £150 and remained the same after the reform in January 1884. Renewal fees payable for patents with application dates in 1882-1883 were the same as renewal fees after the reform, and only patents from 1879-1881 faced a different fee schedule for renewals before year 11. Until the reform was announced, the expectation was that renewal fees of £50 had to be paid after year 3 of patent term and of £100 in year 7. Patents from 1879-1881 that had paid the renewal fee of £50 in year 3 before the patent reform could be renewed in yearly instalments after year 7 from August 1 1884 onward.

the initial costs of obtaining patent protection from about £300 to £25, created a single UK patent to replace the separate patents of England, Scotland and Ireland, and established the UK Patent Office. These changes did not satisfy critics and the patent system met severe opposition during the 1860s and 1870s, so that some even expected the collapse of the system (Machlup and Penrose, 1950). Between 1878 and 1883 eleven bills of patents for invention were discussed in Parliament that proposed a range of changes to the patenting procedure, including a lengthening of the patent term from 14 to 26 years. The Patents for Inventions Bill proposed in February 1883 mentioned a patent fee change. The Patents, Designs and Trade Marks Act of 1883 was eventually passed in August 1883 as primary legislation that included the decrease in the patent fee from £25 to £4. The ensuing increase in patent applications from January 1884 on was unprecedented so that Boehm and Silberston (1967) describe the first eighty years of the nineteenth century as 'the age of the patentless invention'.

In this paper I focus on the patent reform that took effect in 1884. A significant patent reform was also passed in 1852 but patent renewal fees were only introduced after this reform in 1852. Comparing patent renewals before and after the reform of 1852 is thus not possible. The patent reform in 1884 was also implemented with more institutional continuity, and a greater number of inventors already participated in the patenting system in the 1880s. After the Patent Office earned a profit of two million pounds between 1850 and 1880, a tenet of the reform was that the Patent Office should no longer operate at surplus income, and that operating costs would mainly be covered with revenue from renewal fee payments. In addition to the patent fee reduction, the Patent Act of 1883 reduced the administrative steps necessary for obtaining a patent from nine to six steps, extended the period from the application date to filing a full specification from six to nine months, and slightly extended the examinations of patent applications. After the reform, the Patent Office had to establish that a patent application contained only a single invention and that the invention was properly described, but the procedure still did not entail any examination for the novelty of an invention. Fewer administrative steps and a longer time for filing the full patent specification were further positive incentives for patenting. Extended examinations are likely to have dampened the incentive of inventors to file patents somewhat. While the Patent Act of 1883 was thus a reform package, the decrease in the patent fee was the main reform component affecting incentives to patent and to invent.

3 The Decision to Patent Close to a Fee Reduction

The stylised model in this Section describes the decision of an inventor to patent in the context of a patent fee change. An inventor chooses to patent an idea when the patent value exceeds the value of not patenting, and a fall in the patent fee has two main effects. On the one hand, a cheaper fee lowers the quality threshold at which it is profitable to patent an idea. On the other hand, inventors can respond to the fee drop by exerting more inventing effort because of higher net payoffs.

3.1 A Negative Selection Effect Due to a Lower Quality Threshold

An anticipated fall in the patent fee induces a trade-off between a lower patent fee in the future and the value decline of an ageing idea that is not patented when it is conceived. While a cheaper fee is always desirable for the inventor, a delay in patenting an idea is costly. If an idea is not patented for a long time, it can be imitated. An inventor maximises his utility from patenting an idea, which is a function of the quality of the idea q, the time when the idea is conceived s, and the time at which the idea is patented t, and $t \geq s$,

$$U(q, s, t) = (1 - \delta)^{t-s} M(q) - F(t). \tag{1}$$

The decay rate δ captures the hazard rate of imitation for an idea that is left unpatented. The proportion of the value that decays increases exponentially with the time delayed for patenting $t-s$. $M(q)$ is the immediate utility of an idea, which is a monotonically increasing and unbounded function of q, with $M(0) = 0$. I assume that the inventor has perfect information about the quality of his idea, that other costs of inventing are abstracted from, and that discounting is constant with a zero discounting rate. The reservation utility of not patenting is set equal to zero.

The optimal timing of a patent depends on the decay rate of an idea and the profile of patenting fees $F(t)$. In the case of a sudden and anticipated fee drop at time t^*, the profile of fees can be written as $F(t) = F^H$ for $t < t^*$, and $F(t) = F^L$ for $t \geq t^*$ with $F^H > F^L$. In this case, it is only ever optimal to patent at time s or at t^*. Either the inventor patents in the current period, or waits the minimal amount of time before patenting at the lower fee. When the latter occurs an idea is patented at t^* and thus contributes to the bunching at the fee notch. The evolution of patent numbers P is illustrated in Figure 5.

The corresponding value function of an idea of quality q conceived at time s is given by

$$V(q, s) = \max_{t} U(q, s, t). \tag{2}$$

To explain bunching of patents at t^*, I first consider when it is optimal for an idea to be patented at time t^*. This is equivalent to maximising the value function above at $t = t^*$. If an idea conceived at time $s < t^*$ is delayed from patenting until t^*, the utility of patenting at time t^* must exceed the reservation utility of zero. For each s, this defines a minimum quality of an idea $\underline{q}(s)$. For an idea to be delayed, it must be the case that $q \geq \underline{q}(s)$. This is summarised by

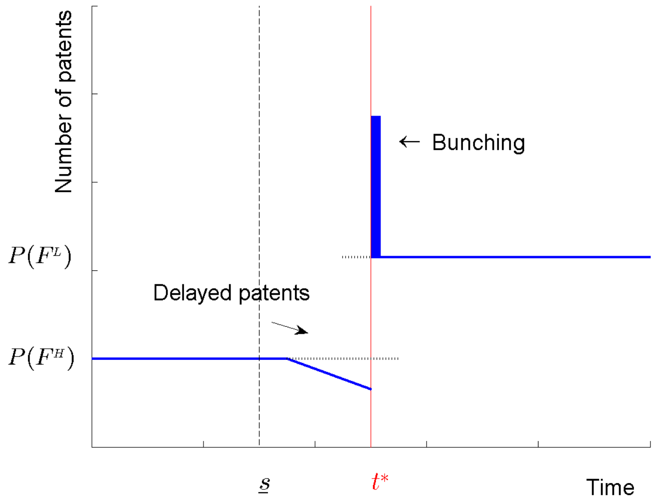
$$q(s) \geq M^{-1}\left(\frac{F^L}{(1-\delta)^{t^*-s}}\right), \tag{3}$$

such that the lower bound of the quality of an idea worth delaying is

$$\underline{q}(s) = M^{-1}\left(\frac{F^L}{(1-\delta)^{t^*-s}}\right). \tag{4}$$

As M is monotonically increasing and unbounded, M^{-1} is well-defined and also monotonically increasing. The minimum quality threshold $\underline{q}(s)$ is a decreasing function of s because a higher

Figure 5: Delayed patenting before a patent fee drop



Notes: This Figure shows the evolution of patent numbers P as a function of the fee regime over time with a patent fee drop at time t^*. The earliest time when it can be profitable to delay a patent to t^* is given by $\underline{s}$. Depending on the quality of an idea, some patents are delayed between $\underline{s}$ and t^*, and the missing mass given by the triangle below a counterfactual distribution is a lower bound for mechanically delayed patents in period t^*.

s represents a smaller delay time $t^* - s$. This means that an idea of lower quality is still worth patenting at time t^* if s is higher.

In addition, for an idea to be delayed optimally it must be the case that the inventor receives a higher utility for patenting at time t^* than at time s. This implies

$$(1-\delta)^{t^*-s} M(q) - F^L \geq M(q) - F^H, \tag{5}$$

which after rearranging leads to the following condition for the quality of an idea that is delayed

$$q(s) \leq M^{-1}\left(\frac{F^H - F^L}{1-(1-\delta)^{t^*-s}}\right). \tag{6}$$

This condition defines an upper bound to the quality of an idea delayed from time s

$$\bar{q}(s) = M^{-1}\left(\frac{F^H - F^L}{1-(1-\delta)^{t^*-s}}\right). \tag{7}$$

For an idea to be worth delaying, it must be the case that the idea is not too good. If an idea were of very high quality, then the decay of the idea is so costly that it is not worth delaying. In particular, $\bar{q}(s)$ is an increasing function of s. For greater s the amount of time needed for delaying is shorter, therefore the relative decay $(1-\delta)^{t^*-s}$ is smaller, and hence an idea needs to be of higher quality not to be worth delaying.

The above two bounds for the quality of an idea worth delaying solve the optimisation problem of the inventor. Whenever it is the case that $\underline{q}(s) \leq q \leq \bar{q}(s)$, then an idea is delayed for patenting until time t^*. There is a minimal time $\underline{s}$, before which an inventor would never want to delay patenting. The upper quality bound is an increasing function of s and the lower bound is a decreasing function of s. Defining $\underline{s}$ by $\underline{q}(\underline{s}) = \bar{q}(\underline{s})$, then for periods $s < \underline{s}$ it is the case that $\underline{q}(s) > \bar{q}(s)$. It is thus never optimal for the inventor to wait until t^* with patenting an idea conceived before $\underline{s}$. Such an idea would need to be both of very high quality for it to be still worth patenting at the later time of t^*, and yet still not be so good that one would prefer to simply patent it in the current period. It is impossible for both to occur for $s < \underline{s}$, and this establishes the earliest time at which a fee change can affect patenting decisions.

Knowing the optimal decision of when to patent an idea, it is possible to describe the size composition of bunching at time t^*. I assume that for each instantaneous moment in time, there is a continuum of measure 1 draws from a quality distribution of ideas. Suppose that the quality distribution of ideas follows a Pareto distribution, with a density function $\gamma(q)$ and a cumulative distribution $\Gamma(q)$. As there is a continuum of measure 1 of draws, the proportion of ideas drawn matches exactly that of the distribution.

Using this assumption, I can derive the exact measure of draws that is chosen to be delayed at each moment in time. For an idea to be delayed from time s, it must be the case that $\underline{q}(s) \leq q \leq \bar{q}(s)$. It follows that the measure of draws to be delayed must equal

$$d(s) = \Gamma(\bar{q}(s)) - \Gamma(\underline{q}(s)), \tag{8}$$

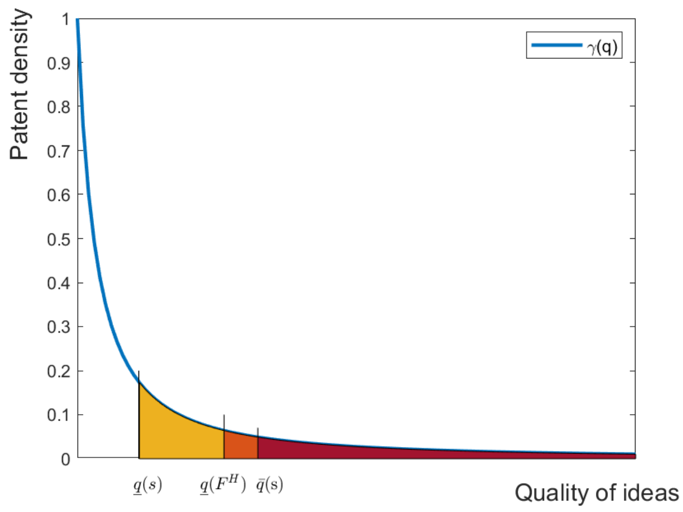
which includes previously viable ideas with quality above $\underline{q}(F^H)$ and ideas that are only viable when the fee is low. These ideas that appear in the bunch are laid out be the orange and yellow areas in Figure 6 respectively.

Finally, the size of the bunch is the accumulation of the above measures of draws,

$$B = \int_{\underline{s}}^{t^*} d(s)ds. \tag{9}$$

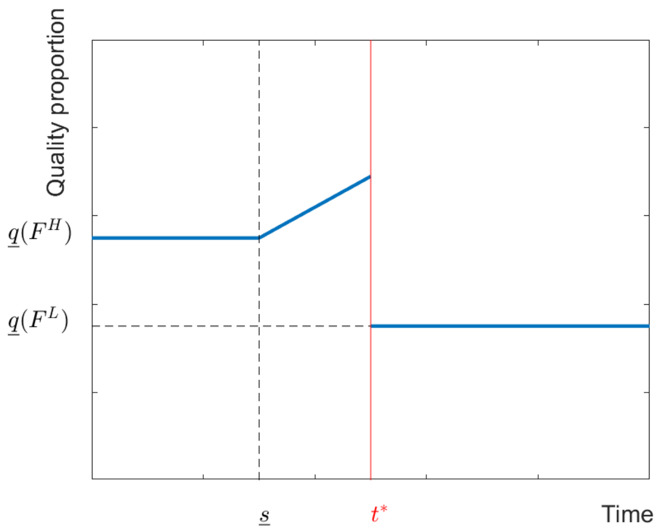
As shown in Figure 7, the minimum quality of an idea is higher before the fee reduction. It increases in periods $t > \underline{s}$, when patenting of some ideas is delayed, and falls to $\underline{q}(F^L)$ after the fee reduction in period t^*.

Figure 6: Delayed patents that contribute to bunching



Notes: The distribution of the quality of ideas is denoted by Pareto density $\gamma(q)$. Ideas of age s are delayed if their quality falls between the minimum quality threshold $\underline{q}(s)$ and the upper quality bound $\bar{q}(s)$ for an idea of age s. The red area represents ideas of very high quality above $\bar{q}(s)$ that are not bunched. Ideas in the orange are are lower-quality ideas above $\underline{q}(F^H)$ whose patenting is delayed until after the reform, and ideas in the yellow area are only viable after the fee is reduced and also contribute to bunching.

Figure 7: Selection affecting the proportion of higher-quality patents



Notes: Only patents of higher quality are patented between periods $\underline{s}$ and t^* because these incur a higher cost of decay if delayed. The quality threshold for ideas declines from $\underline{q}(F^H)$ to $\underline{q}(F^L)$ at t^*.

One measurement of the quality of an idea in the data is based on the decision to renew a patent. Unlike the fee for patenting the fees to renew a patent did not change at the threshold t^*. Therefore, a patent is renewed if the original idea is of a quality greater than the lower-quality bound for renewals, which does not vary across time. Based on this framework I can make the following prediction using renewals as a measurement of quality.

Prediction 1. The proportion of renewals among patents submitted at time s is increasing in s, where $\underline{s} \leq s < t^*$, because it is more and more costly to delay patents of higher quality between $\underline{s}$ and t^*. The patents that appear in the bunch at the fee notch at t^* have a smaller proportion of renewals compared to the proportion of renewed patents that are submitted between $\underline{s}$ and t^*.

3.2 An Incentive Effect Due to Increased Inventing Effort

So far, only the optimal time to patent existing ideas is considered. For a given time period, an important choice also arises with respect to the amount of inventing effort to exert. With increased effort innovation can occur. To allow for an increase in inventions in the model, individuals choose inventing effort to obtain a larger quantity of draws from the quality distribution of ideas. For this purpose I endogenise the size of the measure of draws. Instead of a measure 1 of draws from the same quality distribution of ideas, the measure of draws can now be generalised to d. Drawing more ideas is costly as, for example, research time is required to develop new ideas. I model this cost by introducing an effort function $e(d)$, where $e'(d) > 0$ is unbounded and $e''(d) > 0$. These two conditions ensure an interior solution, as the marginal cost of an additional draw is so high eventually that the number of draws is finite.

A representative inventor chooses d at time s to maximise the utility of patenting from a measure of d draws,

$$\max_{d} E_q d\,[V(q,s)] - e(d), \tag{10}$$

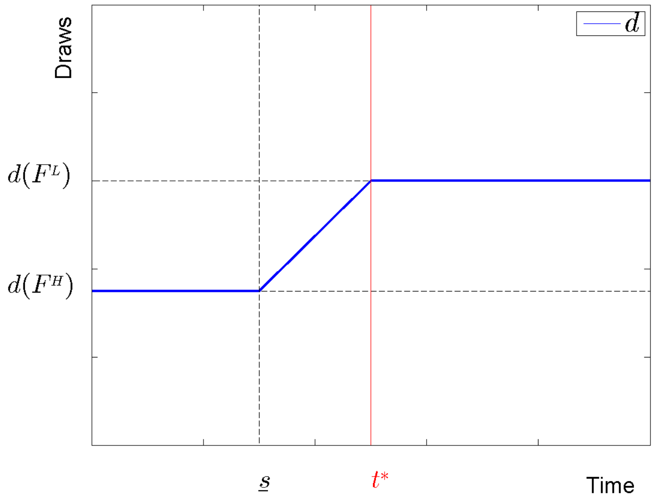
which generates the following first-order condition with respect to d,

$$E_q\,[V(q,s)] = e'(d). \tag{11}$$

As effort is increasing in d, the optimal choice for d is increasing in the expected value function $E_q\,[V(q,s)]$. This expression can be used to analyse the effect of the fee change on innovation. As the number of patents renewed is the proxy measure for innovation, a higher rate of inventing corresponds to more ideas that exceed the minimum quality threshold for renewals. More frequently exceeding the minimum quality threshold happens when d is higher.

The fee reduction incentivises higher d, as shown in Figure 8. At the initial steady-state when $s < \underline{s}$, ideas have no additional value despite the option to delay. As s increases beyond $\underline{s}$, the value of an idea increases due to the increasingly less costly option of delaying. This causes the optimal level of d to increase. From t^* on, there is a new steady-state, where the value of an idea is at the new higher value. The optimal level of d is constant at this new higher level. The increases in d are reflected in a greater absolute number of high-quality patents, and hence a greater rate of inventing. Thus, the fee reduction has an effect of incentivising more inventions and innovation.

Figure 8: The incentive effect of a fee drop on effort exerted



Notes: The overall payoff from patenting increases after the fee falls to F^L, which incentivises inventors to exert more effort and take more draws from the quality distribution of ideas.

Prediction 2. When effort increases, the absolute number of renewals after the fee change at t^* is higher than at the initial steady-state when $s < \underline{s}$.

3.3 Credit Constraints

Furthermore, I allow for the possibility that the effect of a fee change is not homogeneous across the population of inventors. Inventors who are credit constrained are likely to respond more strongly to a fee reduction than those who are unconstrained. To account for constraints in the model, I introduce a credit limit c for each inventor such that the inventor cannot patent whenever the fee $F(t)$ is greater than c.

The optimal behaviour of an inventor subject to a credit constraint c depends on the relation of c to F^H and F^L. When $c > F^H > F^L$, the inventor is unconstrained and thus behaves as described above. When $c < F^L < F^H$, the inventor can never patent. In the case when $F^L < c < F^H$, the inventor cannot patent when the fee is high before the reform but is able to patent under the cheaper fee. Therefore after t^*, this inventor behaves the same as an unconstrained inventor. Before t^*, the constrained inventor can also delay ideas to patent in the bunch at t^*. The delaying behaviour of the constrained inventor differs from that of the unconstrained inventor because his decision to delay is not constrained by equation (5). There is a minimum quality for patenting but an upper bound as for the unconstrained inventors does not apply, so that only condition (3) is relevant. The proportion of draws that gets delayed for patenting is now

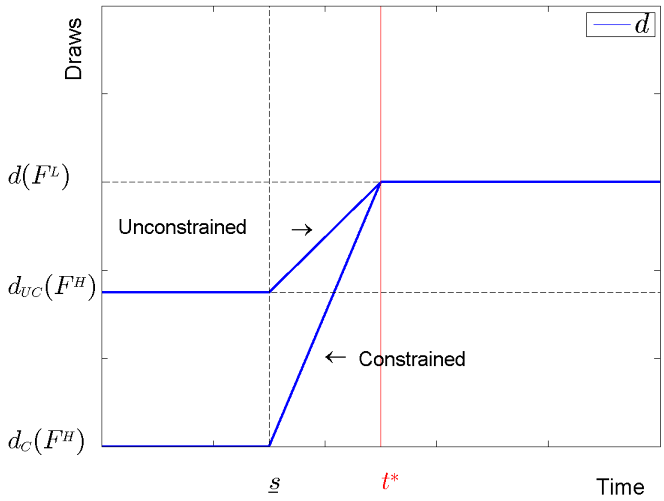
$$d_C(s) = \Gamma(\bar{q}(s)). \tag{12}$$

Before period $\underline{s}$ the expected value of an idea is zero, and hence the optimal measure of draws for a constrained inventor is zero. As s increases beyond $\underline{s}$, the optimal measure of draws increases at a rate faster than that of the unconstrained inventor, which is illustrated in Figure 9. At t^*, the optimal measure of draws is the same as that of the unconstrained inventor at the new higher level. From t^* onwards, unconstrained and constrained inventors exert the same amount of effort if credit constraints are fully relaxed.

The data only contains imperfect measurements of when an inventor is constrained, and the categories of constraints correspond to different distributions of c. The constrained group of inventors in the data are individuals with a lower distribution of c and hence are on average more likely to be constrained. Using this measure of constraints, the following prediction follows from the model.

Prediction 3. The innovation response, measured by the percentage increase in renewed patents, is stronger for the constrained group.

Figure 9: The effort increase for constrained and unconstrained inventors



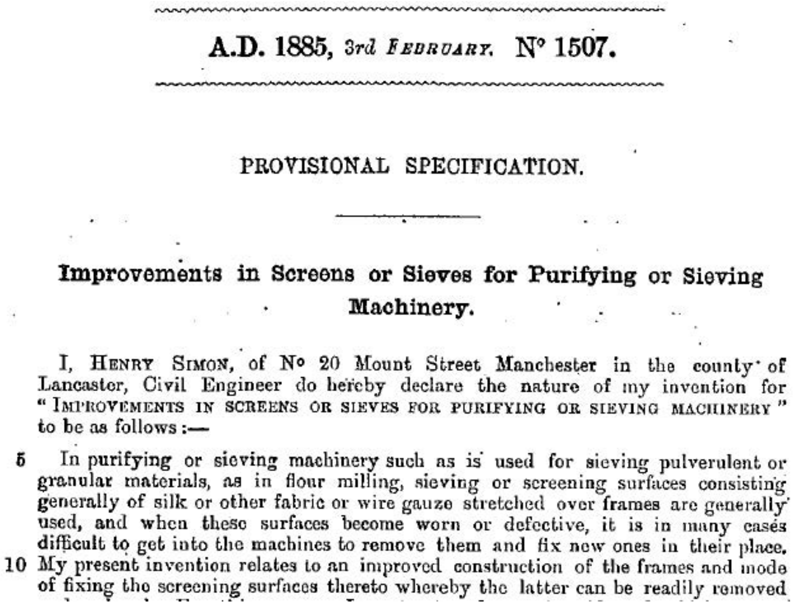
Notes: Inventors who are credit constrained during the high fee regime exert zero effort before period $\underline{s}$, and increase draws faster than unconstrained inventors after $\underline{s}$. If constraints are fully relaxed as a result of the fee drop, effort exerted by the constrained catches up with that of the unconstrained inventors in period t^*.

4 Data

The data used in this paper contains information on individual patentees, who are inventors that were granted a patent, and the date of their patent application. The patent dataset generated includes British patentees between 1879-1888, a ten-year window around the decrease in the patent fee on January 1 1884, and is composed of 54,000 British patentees who were granted a total of 42,500 patents. Information on the patent date, name of the patentee, their address and, where available, their occupation were extracted from individual patent specifications. Figure 10 shows an example abstract of a 1885 patent that includes the patentee's name, address and occupation, which were typically provided in patent abstracts.

In addition, I digitised and compiled renewal information on the life cycle of patents with application dates between 1879-1888 from over 60 volumes of the Patent Office journal for 1879-1902. Information on whether a patent was granted and renewed at different years of term is only available in printed volumes of the Patent Office journal, which is called *Commissioners of Patents' Journal* until 1884, *Official Journal of the Patent Office* for 1884-1888, and *Illustrated Official Journal (Patents)* from 1889 onwards. To generate a second quality measure for patents,

Figure 10: Specification extract for patent number 1507 of year 1885



A.D. 1885, *3rd February.* **N° 1507.**

PROVISIONAL SPECIFICATION.

Improvements in Screens or Sieves for Purifying or Sieving Machinery.

I, Henry Simon, of N° 20 Mount Street Manchester in the county of Lancaster, Civil Engineer do hereby declare the nature of my invention for "Improvements in screens or sieves for purifying or sieving machinery" to be as follows:—

In purifying or sieving machinery such as is used for sieving pulverulent or granular materials, as in flour milling, sieving or screening surfaces consisting generally of silk or other fabric or wire gauze stretched over frames are generally used, and when these surfaces become worn or defective, it is in many cases difficult to get into the machines to remove them and fix new ones in their place. My present invention relates to an improved construction of the frames and mode of fixing the screening surfaces thereto whereby the latter can be readily removed

I matched patents that were granted in the United States to British residents with the British patent data. By using information from the American *Annual Report of the Commissioner of Patents* for years 1879-1890, on average 230 UK patents per year pre-1884 and 430 patents per year from 1884 onward can be identified as British patents that also received patent protection in the US.

To test for credit constraints, I create two proxy measures for inventor wealth by using precise information on inventor names and addresses. Subsections 4.1 and 4.2 describe how the two proxy wealth measures are generated. Table 1 shows summary statistics of the number of patentees and types of patents. Over 60 percent of patents were granted to a single patentee, and the remaining 39 percent were patentees named on patents granted to more than one inventor. Of all patents applied for, 55 percent were granted.

To analyse responses under the same incentive conditions, I focus on patentees who were resident in Britain, referred to as British patentees in this paper. The demographic information compiled from patent specifications enables distinguishing between foreign and British patents, and around two thirds of all UK patentees were British.[7] Data did not previously exist that

[7] A distinction is drawn between foreign residents and British residents who both obtained patent protection in the UK. The patent data also includes around one percent of patentees resident in Ireland, who are not included in the sample of British patentees. Census data is not available for Ireland for the 1880s and wealth proxy measures

Table 1: Summary statistics for British patentees and patents

	1879-1888	1879-1882	1885-1888
Number of British patentees	53,873	11,114	31,354
Number of patents by British patentees	42,474	8,822	24,456
Proportion of single inventors	0.61	0.62	0.59
	(0.49)	(0.49)	(0.49)
Average number of patentees if team	2.26	2.26	2.27
	(0.57)	(0.57)	(0.59)
Proportion of patentees with more than one patent	0.55	0.52	0.55
	(0.50)	(0.50)	(0.50)
Average number if multiple patents per patentee	4.90	4.73	5.04
	(6.85)	(5.96)	(7.24)
Proportion renewed at four years	0.31	0.35	0.30
	(0.46)	(0.48)	(0.46)
Proportion of patents renewed at 14 years	0.07	0.06	0.07
	(0.25)	(0.25)	(0.25)
Proportion of patents patented in the US	0.06	0.09	0.06
	(0.25)	(0.28)	(0.23)

Notes: British patentees are patentees who were resident in Great Britain. Multiple patentees named on a single patent are referred to as team. Standard deviations are reported in parentheses.

allows identifying granted patents of British residents only, who are likely to be more responsive to a UK fee change than foreigners who patent in the UK. Previously, patent data for this period was mainly available in the form of printed publications of the UK Patent Office, with only yearly aggregate data on patents applied for, granted patents and renewed patents. In the Annual Reports of the Patent Office from 1884 onwards, aggregate yearly figures are provided separately for patent applications by foreigners and by British residents but this breakdown is not available before 1884, nor for granted or renewed patents.

4.1 Ranking Inventor Surnames by Wealth

I use inventor surnames to construct a proxy measure of wealth, by making use of the relative probate frequency of an inventor's surname by county compared to the general frequency of the surname in a county. This approach follows Clark (2014), Clark and Cummins (2015) and Clark et al. (2015) who develop surname-based measures for estimating intergenerational wealth mobility. Olivetti and Paserman (2015) apply a similar strategy by indexing the relative occupational status of first names in the US over the last two centuries.

can thus not be generated for patentees resident in Ireland.

Probate was legally required for any estate value at death equal to £10 or above, and on average only 15 percent of adults in England had their estate probated at death between 1858-1887 (Clark and Cummins, 2015). Probate information is available in the records of the National Court of Probate for years after 1858, and was accessed through the genealogy website www.ancestry.co.uk to create a ranking of inventor surnames by county. While the National Probate Calendar indexes testators with information on full names, county, value of estate, and sometimes occupation, I only use county average occurrences of a surname among those being probated at death for the rank measure. This approach has the advantage of making the resulting wealth measure independent of individual achievement or talent, and of education levels in a county. The surname measure is constructed as the ratio of county frequencies,

$$\frac{Share\ of\ surname\ z\ probated\ in\ county\ j\ at\ T \pm 10}{Share\ of\ surname\ z\ in\ county\ j\ in\ the\ 1881\ census}.$$

To approximate the age cohort of the inventor, the time range for the surname probate likelihood is defined as a 21-year range around T, the patenting year plus eleven years. With an average inventor age of 36, and accounting for the fact that inventors are likely to have an average life expectancy that is higher than the British population average of 43 years in the 1880s, this gives an average inventor age range of 37 to 57 for which corresponding probate years are searched. As the median patent in the sample is filed in 1886, I restrict the census surnames to individuals between the ages of 21 and 41 in the 1881 census. An example of relative counts and the corresponding ranking of inventor surnames for the county of Yorkshire is provided in Table 2.

Using this surname ranking, it is possible to match around 83 percent of inventor surnames with probated surnames in the county of an inventor's residence. Figure 11 shows the evolution of the proportion of inventors with a high socio-economic surname rank from 1879-1888.

Around nine percent of inventor surnames can be uniquely matched with a probate surname within a county and time period. I do not use unique matches, however, as a unique match does not necessarily include the inventor in question because the probate data only contains the small population subsample that was probated at death.

4.2 Census Information on the Employment of Servants

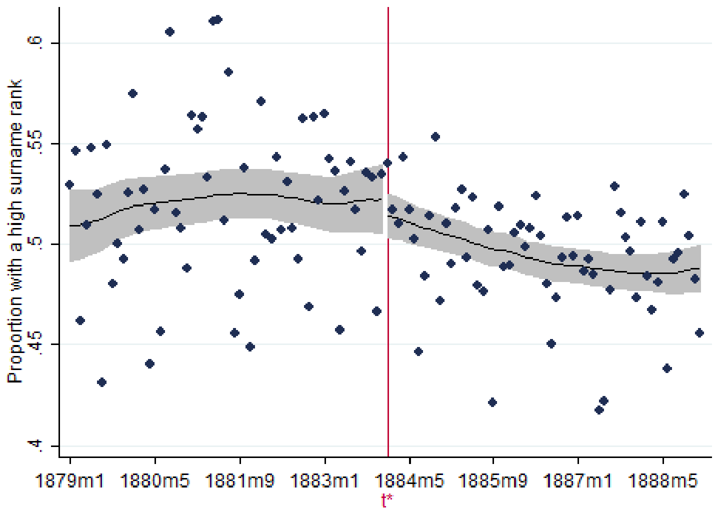
The 1881 Census of Population contains information on the number of servants employed in each household. I use this information on servants to construct a second proxy measure for wealth

Table 2: Surname ranks for county Yorkshire

Lowest ranked surnames:			Highest ranked surnames:		
Surname	Probated N	Census N	Surname	Probated N	Census N
Hemmingway	1	107	Micklethwait	11	7
Maskell	1	37	Reffitt	4	3
Mullin	1	34	Mclintock	5	3
Griffin	5	194	Whytehead	5	3
Beesley	1	31	Qualter	4	2
Balls	1	30	Cordeaux	4	2
Dodd	5	151	Middlemost	4	2
Duffy	8	232	Gallwey	2	1
Case	1	28	Bamlett	2	1
Sturgeon	1	28	Pollit	6	3
Average county N	122,565	885,509	Average county N	122,565	885,509

Notes: The frequency of surname occurrence within a county is denoted by N. Probated N refers to the number of surnames probated in a county over a 21-year period that is chosen to approximate a patentee's age cohort. Lowest ranked surnames are shown for non-zero ranks.

Figure 11: Proportion of patentees with high wealth ranking



Notes: Surnames are classified as high-rank if the probabilistic share of an inventor's surname being probated at death exceeds that of its frequency in the 1881 census at the county level. A 95-percent confidence interval is shown for polynomials fitted before and after the patent fee change at t^* in January 1884.

by merging the data on inventors with the 1881 census. The 1881 census includes full names and demographic information of each individual, and the 100-percent sample of the 1881 census with individual names was accessed through the North Atlantic Population Project.[8] I match the data on inventors with census data based on an algorithm using the full names and addresses of inventors. Due to the increased digital availability of historic census data, studies that use similar matching of historical records with census data as implemented in this paper have become more frequent over the last years.[9]

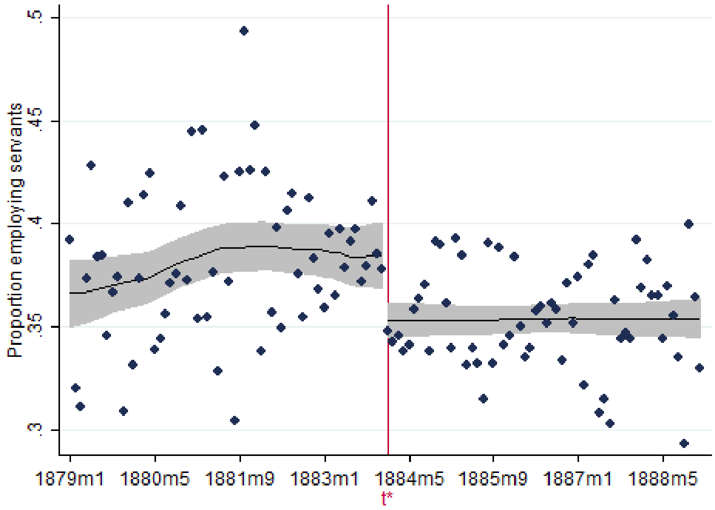
By using data on names and addresses around 34 percent of patentees can be uniquely matched in the census data. While nearly all patentees have a match in the census data, many of these matches are not unique. The resulting sample of uniquely matched patentees is not random and is likely to reflect socio-economic selection based on less frequent names and lower geographic mobility between the date of the 1881 census and the date of patenting. To locate patentees in the census data, I impose a labour force age range of 16 to 60 for each year of patenting and a corresponding age cohort in the 1881 census. For example, an inventor who patented in 1888 was on average younger in 1881 than one who patented in 1879, and is more likely to have moved from the county of residence since the census year.

The wealth proxy constructed from census data used in this paper is whether a patentee household employed servants or not. On average, 36 percent of matched patentees employed servants in their household compared to around 19 percent of the male census population aged between 16 to 60 years. The measure of servants employed in a household thus indicates that patentees are a subsample of the population with comparatively high wealth. Figure 12 plots the proportion of matched patentees who employ at least one servant, showing a small downward shift after the patent fee reduction in January 1884. For an inventor household that employs servants, the average number of servants is 1.17 before 1884 and 1.09 from January 1884 onwards.

[8]The North Atlantic Population Project provides access to 1881 Census data for Great Britain, by K. Schürer and M. Woollard, *National Sample from the 1881 Census of Great Britain* [computer file], Colchester, Essex: History Data Service, UK Data Archive [distributor], 2003.

[9]For example, such matched census data is used in work on intergenerational mobility in the US and in Britain (Long and Ferrie, 2007, 2013), on intercontinental migration to the US (Abramitzky et al., 2012), or for analysing the cultural effects on language imposition in the US (Fouka, 2019).

Figure 12: Proportion of patentee households employing at least one servant



Notes: Information on servants employed is available for inventors that can be uniquely matched in the 1881 census. A 95-percent confidence interval is shown for polynomials fitted before and after the patent fee change at t^* in January 1884.

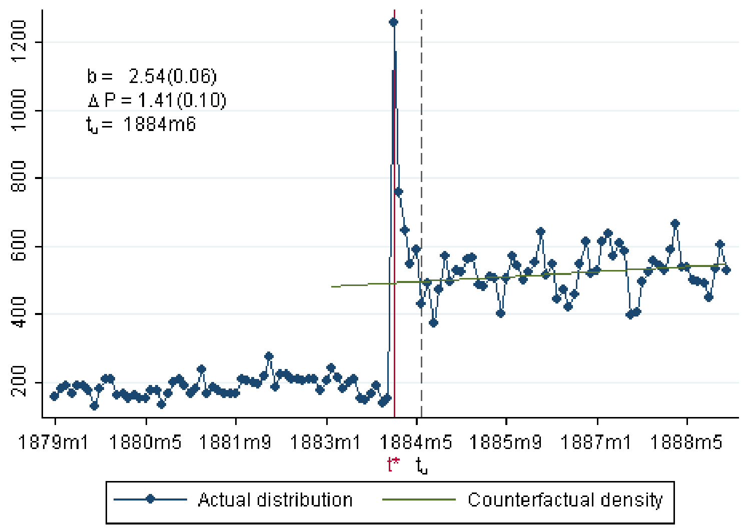
5 Estimation

The total number of patents increased strongly after the fee drop on January 1 1884, with significant bunching at and after the fall in the fee as depicted in Figure 13. In this section, I first estimate the excess bunching observed in the months after the fall in the patent fee. The short-run responses are then compared to longer-run elasticities for periods from 1879-1888 that are not affected by the short-run shifts of patenting activity.

5.1 Bunching and Longer-run Elasticities

The downward notch in the patent fee in January 1884 introduces a discrete fall in patenting costs that leads to short-run bunching of patents. As described in Section 3, it is profitable to delay patenting in the periods just before the patent fee drops when the value of waiting exceeds the value of patenting before the fee change in t^*. Kleven and Waseem (2013) and Best and Kleven (2017) develop a bunching approach that uses the discontinuities in the choice sets of individuals created by the presence of a notch for identifying the reduced-form elasticity of an outcome variable in response to a tax or duty change. I apply this bunching strategy to analyse the short-run response to the fall in the patent fee in the months from January 1884 onward.

Figure 13: Number of British patents granted



Notes: The x-axis plots the application date of patents. Excess bunching over the counterfactual density after the fee reduction at t^* in January 1884 is denoted by b, and ΔP refers to the percentage change in average monthly patent numbers between years 1885 and 1882. Period t_U marks the upper bound for the months affected by bunching. Bootstrapped standard errors are reported in parentheses.

Excess bunching in response to the fee drop is estimated as the total number of patents over a counterfactual density of patents. The counterfactual is here approximated by fitting a predicted linear trend in patenting numbers from the months exceeding the upper bound to the periods affected by bunching, $t > t_U$, to the months affected by bunching, $t^* \leq t \leq t_U$, and using bins of one month's width. The counterfactual is thus obtained from the predicted values of the regression

$$\hat{c}_t = \beta t P_t + \sum_{i=t_0}^{t_U} \gamma_i \, \mathbf{1}[P_t = i] + v_t, \tag{13}$$

when omitting the dummies in the excluded range, $t \leq t_U$, and excess bunching b is given by

$$b(t_U) = \frac{\sum_{i=t^*}^{t_U} (c_t - \hat{c}_t)}{\sum_{i=t^*}^{t_U} \hat{c}_t}. \tag{14}$$

The upper bound t_U of the exclusion range is relatively sharp in the data, so that it can be chosen as the point marking the upper bound of the patents that are bunched. In Figure 13, a vertical dashed line indicates t_U in June 1884. Instead of one spike at t^* only, patents are bunched until several months after the fee notch, which is likely due to frictions in the processing of applications and in the application timing by inventors. For the estimates in this paper, I extend the exclusion range for estimating the counterfactual distribution to all months before t_U, instead of fitting a polynomial to both sides of the bunching period $t^* \leq t \leq t_U$. This avoids bias from behavioural responses affecting the alternative counterfactual distribution in the months before t^* because bunching at the fee notch can be a result both of delayed patents and increased effort in anticipation of the fee change. Standard errors for the bunching estimators are bootstrapped in a procedure following Chetty et al. (2011). Standard errors for the other parameters are obtained by pairwise bootstrapping.

The fee notch produces pronounced short-term shifting of patents to the periods after the fee drop when $t^* \leq t \leq t_U$. The magnitude of excess bunching b for British patents of all durations is 2.54. The corresponding short-term elasticity of patent numbers in response to the fee change is given as the ratio of excess bunching over the percentage change in the patent fee,

$$e_{SR} = \frac{b}{\Delta F}, \quad (15)$$

where ΔF is equal to $(F^H - F^L)/F^L$. The short-run elasticity for British patents of all durations corresponds to -3.02 and is reported in Table 3.

Table 3: Patent number responses to the 1884 patent fee reduction

	b	e_{SR}	ΔP	ε_{LR}
All patent types	2.54	-3.02	1.41	-1.68
	(0.06)	(0.07)	(0.10)	(0.13)
Granted only	2.67	-3.18	1.62	-1.92
	(0.06)	(0.08)	(0.13)	(0.08)
Renewed after four years	2.24	-2.67	1.05	-1.25
	(0.05)	(0.06)	(0.10)	(0.06)
Renewed for 14 years	1.53	-1.82	1.13	-1.34
	(0.08)	(0.10)	(0.19)	(0.13)
Patented in the US	7.42	-8.83	0.34	-0.41
	(0.34)	(2.04)	(0.17)	(0.20)

Notes: Short-run excess bunching is given by b, e_{SR} denotes the reduced-form elasticity estimated from bunching, $\Delta P = (P_{1885} - P_{1882})/P_{1882}$ is the percentage change in the monthly average number of patents in 1885 compared to 1882, and ε_{LR} gives the longer-run elasticity. Standard errors are reported in parentheses.

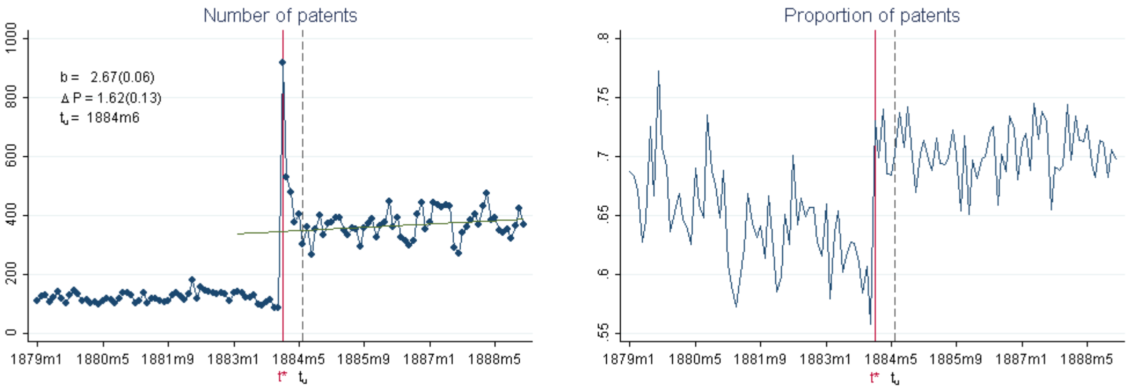
This short-run elasticity measures the combined response of existing delayed patents and patented new ideas in response to the fee reduction. Just before the fee notch patenting numbers show some decline, and this small area of missing mass to the left of the fee drop is a lower bound to all delayed patenting. In the absence of delays, this reduced-form elasticity would measure a Frisch elasticity.

The data includes information on whether a patent was granted only, granted and renewed at four years, or granted and renewed for years up until the full term of 14 years. Figure 14 decomposes the aggregate patent number into three quality types according to renewal status. In line with Prediction 1, higher-quality renewed patents exhibit less excess bunching, and excess bunching is smallest for the highest quality patents that are renewed for the full term of 14 years. The graphs in the right column of Figure 14 show the proportion of patents by renewal type and the increasing quality of patents just before the fee notch confirms Prediction 1. It is more costly to delay high-quality patents, so that high-quality patents are patented even if the cheaper fee is imminent. The proportion of renewed patents exhibits a pronounced fall at the fee notch to a new lower steady-state level. The precise fall in quality proportions at the fee notch indicates that individuals know about the quality of their patented ideas and optimise the timing of patenting. The average quality of ideas patented reaches a new lower equilibrium level in period t^*.

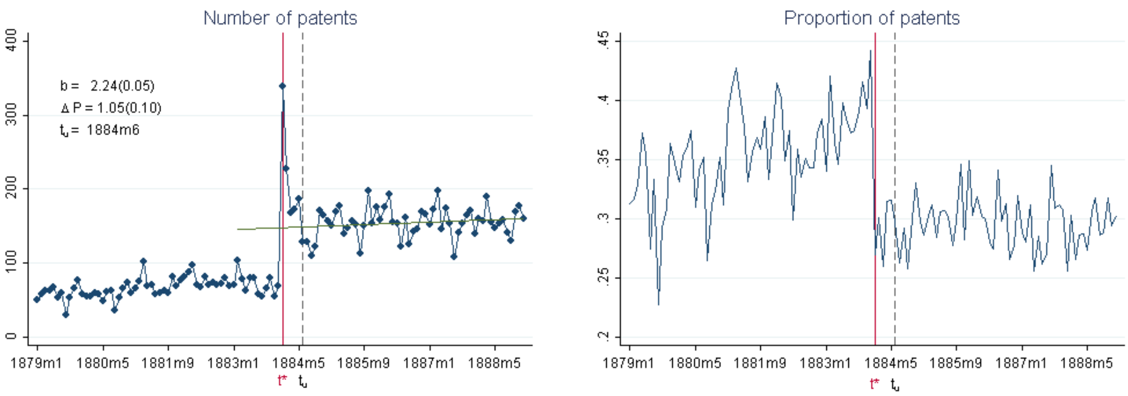
In the longer run, monthly rates of patenting shift upward to a new steady-state, and to analyse this response average monthly percentage changes between 1885 and 1882 are compared. These years are close to the fee reduction but are not affected by bunching, and for these two years the renewal fee regime is the same. The percentage change in average patenting rates in 1882 compared to 1885 is denoted by ΔP and is equal to 1.78. As described in the framework in Section 3, this longer-run effect reflects increased effort and investments from inventors who take more draws from the quality distribution of ideas after the fall in the patent fee. At the same time, the quality threshold for patenting an idea falls so that some additional patents are of lower quality. As summarised in Prediction 2, the incentive to exert more effort results in an increased number of renewals after the fee reduction at t^*. This increase in renewed high-quality patents is equal to new innovation if the measures of patent quality capture value. Figure 14 shows that the average percentage change in patents which are renewed after four years is 1.05 and the percentage change in patents renewed until full term is 1.13. The longer-run elasticity of innovative activities in response to the fee change can be approximated by the percentage change

Figure 14: British patents by quality type of patent

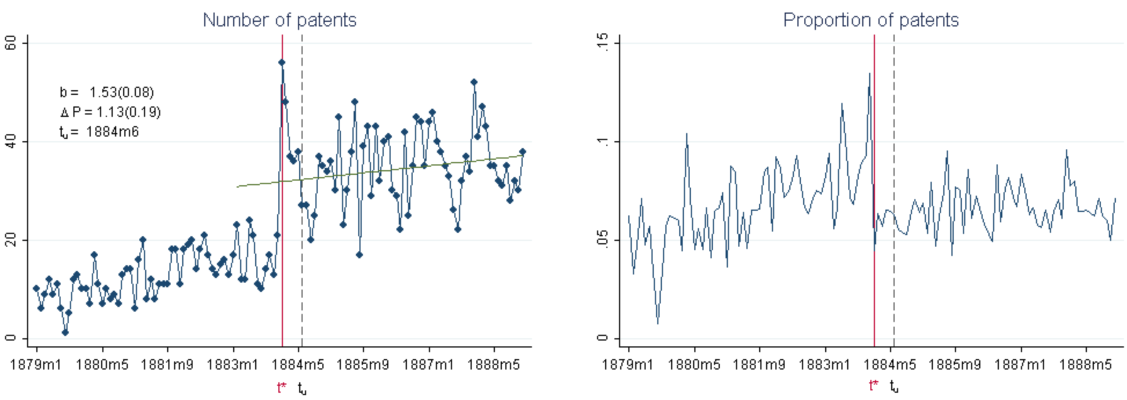
Not renewed



Renewed after four years



Renewed for 14 years



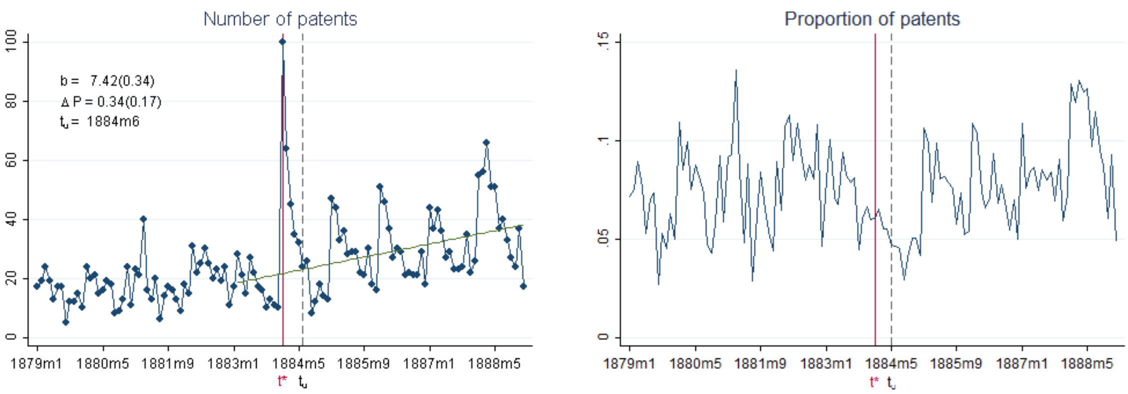
in high-quality renewed patents P_q over the percentage change in fees,

$$\varepsilon_{LR} = \frac{\Delta P_q}{\Delta F}. \tag{16}$$

These longer-run elasticity estimates are reported in Table 3 by patent quality, with the largest responses for patents that were only granted and not renewed, and the smallest responses for patents that were renewed until the maximum possible duration of 14 years.

The qualitative effect of increased innovation also holds when using British patents that received patent protection in the US as an alternative quality measure, as visible in Figure 15. While the effect is not as strong as for renewed patents, the longer-run increase in British patents in the US is 0.34. At the moment British US patents are matched by computer, which results in bias toward finding matches at the beginning of the year. In a next step matching will be carried out by hand to avoid this bias, so that the size of bunching is expected to decrease.

Figure 15: British patents that also received protection in the US



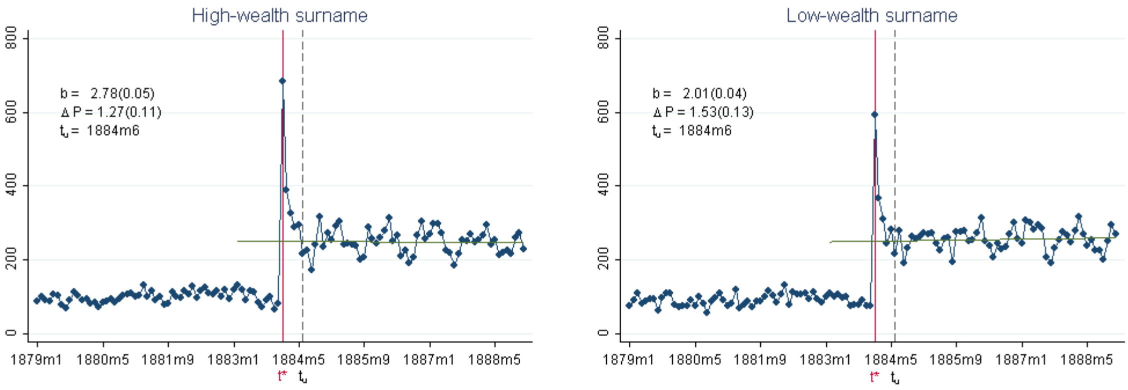
Notes: The x-axis plots the application date of patents. Excess bunching over the counterfactual density after the fee reduction at t^* in January 1884 is denoted by b, and ΔP refers to the percentage change in average monthly patent numbers between years 1885 and 1882. Period t_U marks the upper bound for the months affected by bunching. Bootstrapped standard errors are reported in parentheses.

5.2 Responses for Inventors with High and Low Wealth

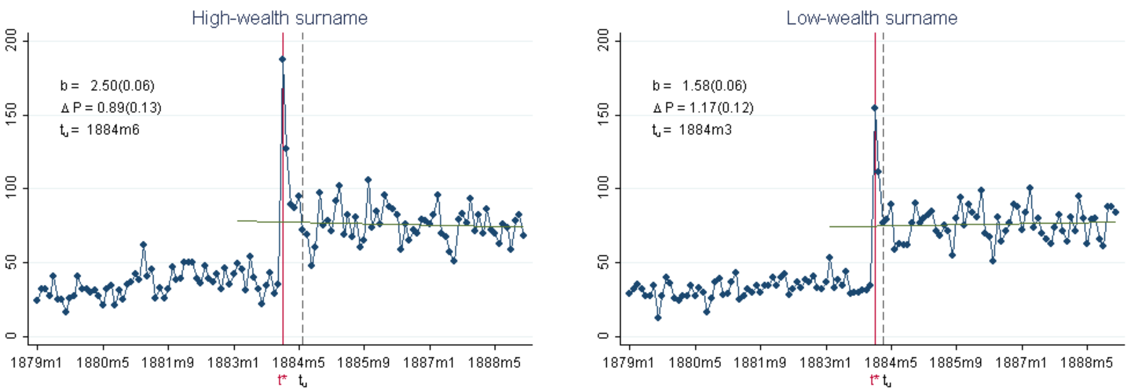
To test for the importance of credit constraints, I generate two proxy measures of wealth to distinguish between high- and low-wealth inventors. First, the overall sample of patentees is decomposed into groups with high and low surname wealth rank, as shown in Figure 16. Table 4 provides an overview of the difference in responses.

Figure 16: Number of British patents by inventor surname rank

All patent durations



Renewed after four years



Renewed for 14 years

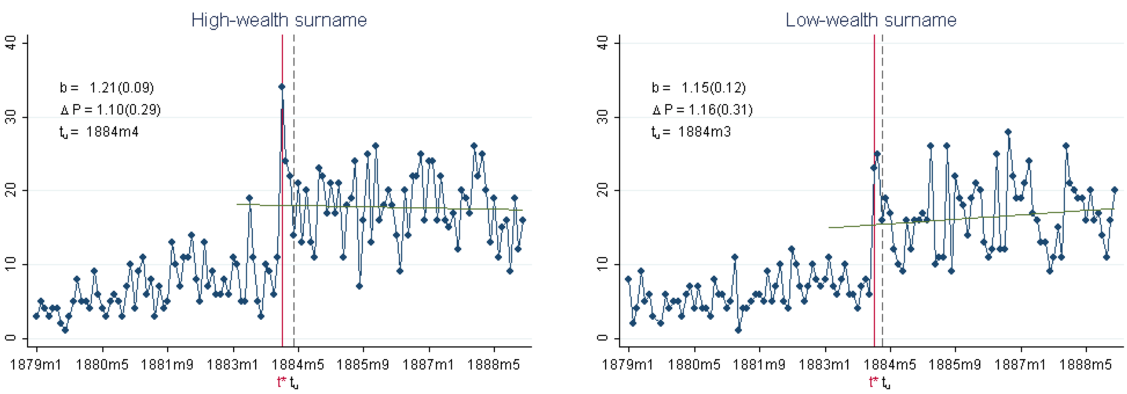


Table 4: Patentees by surname wealth rank

	b	e_{SR}	ΔP	ε_{LR}
All patent durations				
High-wealth surname	2.78	-3.31	1.27	-1.51
	(0.04)	(0.26)	(0.11)	(0.12)
Low-wealth surname	2.01	-2.39	1.53	-1.82
	(0.04)	(0.23)	(0.13)	(0.16)
Difference high - low	0.77***	-0.92***	-0.27*	0.32*
	(0.06)	(0.35)	(0.16)	(0.19)
Renewed after four years				
High-wealth surname	2.50	-2.98	0.89	-1.06
	(0.06)	(0.12)	(0.13)	(0.33)
Low-wealth surname	1.58	-1.88	1.17	-1.39
	(0.06)	(0.16)	(0.12)	(0.14)
Difference high - low	0.92***	-1.10***	-0.27*	0.33*
	(0.08)	(0.20)	(0.17)	(0.21)
Renewed for 14 years				
High-wealth surname	1.21	-1.44	1.10	-1.30
	(0.09)	(0.33)	(0.29)	(0.33)
Low-wealth surname	1.15	-1.37	1.16	-1.38
	(0.12)	(0.29)	(0.31)	(0.37)
Difference high - low	0.06	-0.07	-0.07	0.08
	(0.15)	(0.44)	(0.41)	(0.50)

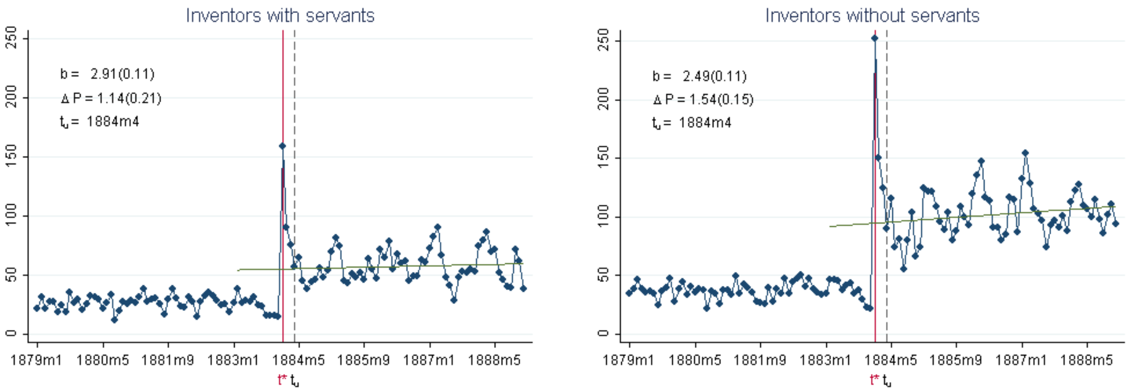
Notes: Short-run excess bunching is given by b, e_{SR} denotes the reduced-form elasticity estimated from bunching, $\Delta P = (P_{1885} - P_{1882})/P_{1882}$ is the percentage change in the monthly average number of patents in 1885 compared to 1882, and ε_{LR} gives the longer-run elasticity. Standard errors are reported in parentheses, and significance for parameter differences for patentees with high- and low-wealth surnames at the 10-percent level is denoted as *, significance at 5 percent as **, and significance at 1 percent as ***.

Longer-run elasticities for inventors with lower wealth in response to a negative fee change are higher by 0.33, and this difference is significant at the 10-percent level of significance. As for the overall sample, the proportion of patents renewed after four years falls for both wealth groups.

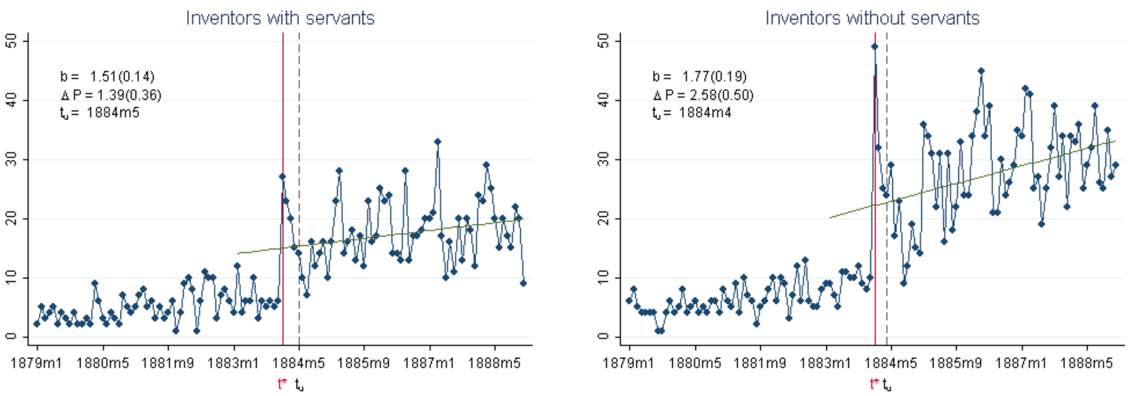
Second, matching patentees in the census enables a decomposition of the sample into inventors that employ servants in their household and those who do not have servants. Figure 17 plots the response in patent numbers after January 1884 for these two groups. The response of patentees

Figure 17: Number of British patents by employment of servants in inventor household

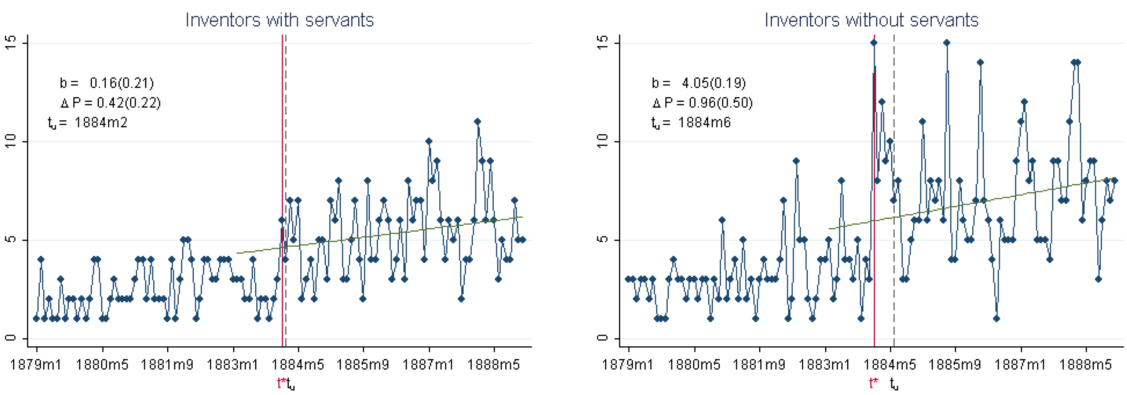
All patent durations



Renewed after four years



Renewed for 14 years



that do not employ servants is much stronger and significant in terms of total patent numbers as well as for patents renewed after four years. These findings are consistent with Prediction 3, the case when constrained inventors increase effort rapidly from very low levels once credit constraints are relaxed. If constraints continue to bind after t^*, they are likely to prevent patenting and also to interfere with the payment of renewal fees for granted patents, as pointed out by MacLeod et al. (2003). Such an effect would decrease the response of renewed patents to the fee change.

Table 5: Patentees matched in the census by employment of servants

	b	e_{SR}	ΔP	ε_{LR}
All patent durations				
With servants	2.91	-3.46	1.14	-1.36
	(0.11)	(0.13)	(0.20)	(0.23)
Without servants	2.49	-2.96	1.54	-1.83
	(0.11)	(0.13)	(0.15)	(0.18)
Difference with - without	0.42	-0.50	-0.40	0.47
	(0.15)	(0.18)	(0.26)	(0.29)
Renewed after four years				
With servants	1.51	-1.80	1.39	-1.66
	(0.14)	(0.17)	(0.35)	(0.43)
Without servants	1.77	-2.11	2.58	-3.07
	(0.19)	(0.23)	(0.49)	(0.64)
Difference with - without	-0.26	0.31	-1.18**	1.41**
	(0.23)	(0.28)	(0.60)	(0.77)
Renewed for 14 years				
With servants	0.16	-0.19	0.42	-0.50
	(0.21)	(0.26)	(0.22)	(0.26)
Without servants	4.05	-4.82	0.96	-1.14
	(0.19)	(0.23)	(0.48)	(0.57)
Difference with - without	-3.89***	4.63***	-0.54	0.64
	(0.29)	(0.34)	(0.53)	(0.62)

Notes: Short-run excess bunching is given by b, e_{SR} denotes the reduced-form elasticity estimated from bunching, $\Delta P = (P_{1885} - P_{1882})/P_{1882}$ is the percentage change in the monthly average number of patents in 1885 compared to 1882, and ε_{LR} gives the longer-run elasticity. Standard errors are reported in parentheses, and significance for the parameter differences for patentees with and without servants at the 10-percent level is denoted as *, significance at 5 percent as **, and significance at 1 percent as ***.

Similarly, constrained inventors could on average produce lower-quality inventions even after the constraints are relaxed if human capital or other investments over their life time also suffered due to credit constraints. The presence of these types of constraints would dampen the observed responses by inventors with lower wealth.

For both groups the percentage increase in renewals exceeds that of renewals in the full patent data sample. Table 5 documents correspondingly high elasticities.

The reason for larger increases in renewed patents in the matched compared to the overall sample is that the sample of unique patentee matches is not random. These estimates indicate that patentees with rare names and constant address information in their patent specifications are on average individuals who exert higher levels of effort in response to a patent fee drop. In interpreting the effects by inventor wealth group the focus is therefore placed on the relative differences between the groups.

6 Conclusion

The patent fee reduction legislated by the 1883 Patents, Designs and Trade Marks Act had stark effects on patenting activity. This paper decomposes the responses of inventors to the fee drop into increased inventing effort, and a negative selection effect due to the reduced patent quality threshold. This analysis of innovative behaviour is made possible by the creation of a new detailed dataset on 54,000 British inventors, which includes renewal information for each patent. I present a stylised framework for understanding inventor responses with predictions about short-run bunching behaviour and longer-run patent quality. The data confirms the expected short-run effects, and indicates that inventing efforts increased after the patenting cost reduction. This effort response is particularly strong for poorer inventors.

In the short run, inventors delay patenting until the fee is reduced, which gives rise to significant bunching after the cheaper fee comes into effect on January 1 1884. The increase in patent quality and the decline in the number of patents before the fee reduction show that patent renewals are a result of inventor choice and not simply a function of the number of patented draws from the quality distribution of ideas. As predicted by the framework, bunching is less pronounced for high-quality renewed patents because it is more costly to delay high-quality patents. In line with Predictions 2, innovation increases significantly in the longer run both in terms of increased renewed patents and when measured in terms of British inventions that were also patented in the US. The fee elasticity of patents that are renewed after four years is -1.25. These findings indicate that efficiency increases as a result of the reduction in the patent application fee. While these quality measures are widely used in the literature to gauge innovative activities, one aim of further research is to confirm the effect of the fee change on the amount of economically useful ideas with data that does not rely on patenting information.

To test for the importance of credit constraints, the patenting responses are compared across inventors with high and low wealth. I generate an wealth proxy from the ratio of the probate likelihood of an inventor's surname relative to its general frequency in a county. A second wealth measure is created from census information on the number of servants employed in an inventor household. Both measures show a stronger innovation response to the fee reduction from inventor groups with lower wealth. These estimates suggest that in addition to the overall effect efficiency increases as a result of relaxed credit constraints after the fee reduction. The proportion of renewed patents is somewhat lower for inventors with lower wealth, which implies that some differences either in patent quality or in the ability to pay renewal fees persist after the fee reform in 1884.

The large responses to the fall in the fixed cost for patenting highlight the potential effectiveness of innovation policies that reduce the cost of inventing. A decrease in the patenting fee is an incentive with a benefit that is conditional on effort exerted. While the findings presented in this paper are time- and context-specific, they highlight the large responses in terms of the effort and investment exerted by inventors. Nowadays, patent fees are less likely to impede inventive activities, so that the impact of subsidies and tax incentives for research and development is more relevant for the design of innovation policies. A particularly relevant area for further research are the efficiency effects of dynamic constraints in the formation of human capital.

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