The Incentive and Welfare Effects of the European Unitary Patent*

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Abstract

The harmonization of the European patent (EP) system through the upcoming Unitary Patent (UP) is one of the largest recent changes in a major intellectual policy regime. Using a model of patent renewals and data for chemical patents granted in 2000 by the European Patent Office, we find that i) the average European patent (EP) is worth €230K; ii) essentially all inventors would have used UP had it been available; iii) private value of patents increases by 7% on average with the largest contributions coming from increased patent length and reduced fees and very little from improved quality of inventions and expanded territorial scope of patent protection; iv) private value of patents is 54-57% and consumer surplus 43-46% of total welfare; v) total welfare increases only 0-2% as consumer surplus is reduced 2-9%. There are large differences between countries in the changes induced by UP.

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1 Introduction

The establishment of the European patent system in the early 1970s was a major change in the European and global intellectual property rights regime. The European Patent Convention (EPC) in 1973 created the European Patent Office (EPO) which provides a legal framework for the granting of European patents (EPs). An EP has a single harmonised application and granting procedure but remains essentially a bundle of national patents. Over the past 50 years the European patent system has evolved with increased integration and harmonisation[1], but the implementation of a *real* European patent has remained elusive until recently. The introduction of the Unitary patent (UP henceforth) is the first major overhaul and a big step towards the original objective and, at the same time, one of the most significant changes in the global intellectual property regime this millennium. The new UP system is finally expected to be operational in 2022, creating the possibility of a single patent providing protection in several countries.[2] We analyse the incentive and welfare effects of introducing the UP.

The existing evaluations of UP (see below) and its proponents have stressed that its major benefit is the 'streamlining' of the application process and the reduction in costs by allowing inventors to apply for a single patent instead of multiple national patents, as is the case with EP. This change means that inventors save on legal and translation costs, and face a single schedule of renewal fees instead of multiple national renewal fee schedules. The fact that the introduction of UP gives inventors an option on top of the current EP regime and thereby strengthens intellectual property rights has gained far less attention. The alternative that the new UP regime offers is between taking an EP just like in the current regime and thereby tailor patent protection by country (i.e., in which countries to take out a patent, and within each country, for how long) at the cost of higher renewal fees and legal and translation costs, and the UP whereby patent protection is unified in length across all participating countries and renewal fees are lower. We quantify the private and social effects of this major institutional change, taking into account the increased cost-effectiveness of the patent protection and the effects of the change on patent quality.

We build a three-part model to evaluate the expected effects of UP. The first part is

[1]Plomer (2020) provides a full history of the transformation of the European patent system

[2]The introduction of the UP is linked to the creation of the Unified Patent Court (UPC) which will have jurisdiction over UPs and EPs. All the participating members have to ratify the UPC Agreement Act. The process took a big step forward in July 2021 when the German Federal Constitutional Court rejected to applications for a preliminary injunction against the UP.

a single-agent dynamic model of renewal decisions for the existing EPs. The second part is a patent production function linking the level of R&D to the private value of patents. The second part allows us to evaluate how the introduction of UP will affect patent quality at the intensive margin, i.e., regarding existing patents. The last part is a mapping between private value and consumer surplus. We estimate the model using renewal data for EPs applied for in 2000 in the technology area of chemicals (excluding pharmaceuticals).[3] We use the estimated parameters to simulate the counterfactual effects of the UP on the (i) length and territorial scope of patents and thereby their private value; (ii) quality of existing patented inventions (intensive margin); and (iii) surplus of European consumers.

We find that the vast majority of the inventors of chemical patents applied for in 2000 would have opted for UP, had they had the possibility. The average gain in private value is €16,803. 46% of this comes from a reduction in renewal fees, keeping geographical coverage of the patent and its length constant; 3% comes from increased geographical coverage, 45% from increased length of the patent, keeping geographical coverage constant, and the remaining 6% from a change in patent quality. We find that 62% of inventors would have invested more into R&D and thereby increased the quality of their patents, measured by the number of citations, by an average of 1.2% (+0.64 additional citations). All in all, the private value of patents increases by 7.3% on average with the introduction of UP. We then turn to the change in social value. Making different assumptions on the demand function of the consumers, we find that the welfare generated by the chemical patents applied for in 2000 increases between 0.4 to 1.9% with the introduction of UP. Consumer surplus decreases by 2.1 to 8.7%. We find that most national patent offices (NPOs) would receive significantly lower income coming from fees, with large variations across NPOs. We also find a number of new results pertaining to the value of individual EPs.

We can also shed light on how the gains from UP introduction are distributed among the participating countries. We find that the relative change in patent value due to UP is decreasing in the value of inventions under IP: thus e.g. Austria benefits by over 10% whereas Sweden and Ireland only by some 6% relative to the value of patents by the inventors of these countries under EP (under particular assumptions about the demand curve). Consumer surplus changes have a very different distribution: First,

[3] We chose chemical patents because the chemical industry relies on patents (Mansfield, 1986; Levin et al., 1987; Cohen, Nelson and Walsh, 2000) and the year 2000 because by then, due to a change in the application procedure, a large fraction of patent applications are designated to all EPC Member States and we still observe the patents to the statutory maximum term of 20 years.

the increase in consumer surplus is not linked to consumer surplus attained under EP. Second, changes are negative for all countries. Third, the differences are large, with Greek and Danish consumers losing 20%, but French, British and German consumers only a few per cent. Finally, the welfare gain is (weakly) positively correlated with the level of welfare under EP. Portugal gains the most (almost 2%), and Greece the least (1.2%).

We build on several existing literatures, the first of which has as its objective the evaluation of the effect of IPR on incentives to invent. It is generally acknowledged that this is a difficult task (e.g. Williams, 2017; Moser, 2021). Most studies use changes in patent policy as natural experiments to tackle this question (e.g. Sakakibara and Branstetter, 2001; Lanjouw and Cockburn, 2001; Lerner, 2002; Moser, 2005; Qian, 2007). Budish, Roin and Williams (2015) use variation induced by the length in clinical trials. A few papers look specifically at the implications of harmonising patent protection. Studies in this literature mostly focus on implications of strengthening patent protection for the less innovative South versus the more innovative North (e.g. Helpman, 1993; Lai and Qiu, 2003; McCalman, 2001; Bilir, Moser and Talis, 2011). Our approach differs from existing studies in that we provide an ex-ante evaluation of a forthcoming change in IPR, but note that our method could be applied ex-post, too. We are not aware of prior empirical work that would build a welfare analysis on a renewal model of patents, but e.g. Cornelli and Schankerman (1999) provide a (theoretical and) simulation analysis of the welfare effects of different patent renewal systems.[4]

Our study obviously has its limitations, among which are the following: First, our quantification of incentive effects builds on the standard incentive theory of patents according to which stronger patent protection increases incentives to invest. There are both empirical and theoretical results suggesting that this intuitive relation does not necessarily hold. For example, we abstract away from sequential innovation (Green and Scotchmer, 1995).[5] Second, we ignore the potential savings in legal and translation costs of obtaining a patent; this may bias our counterfactual estimates downwards. Third, we also ignore the effects of the UP system on litigation (see e.g. Schuett and

[3]See e.g. Todd and Wolpin (2006) for an ex-ante evaluation, albeit of a very different policy. Unlike them, we do not have access to post-treatment (=introduction of UP) data.

[4]The main interest of Cornelli and Schankerman (1999) is on the shape of the optimal renewal fee schedule.

[5]Theoretically, the effects of stronger patents in the process of cumulative innovation are often found to be negative (see, e.g. Bessen and Maskin 2009). However, the studies providing quasi-experimental evidence (Galasso and Schankerman, 2015; Sampat and Williams, 2019) find more ambiguous results on the effect of patents on follow-on invention, with differences possibly being explained by them concentrating on different fields of invention. See Williams (2017) for a discussion.

Schankerman, 2021). The change in the regime includes the establishment of the Unified Patent Court. The UPC is the only court to handle cases relating to UP, but for EP, there is a seven year transition period, after which they, too, will be handled only by the UPC. It is quite difficult to assess the effect of foregoing the incorporation of a change in how litigation is organised.[6] Fourth, we ignore any effects that UP may have outside Europe e.g. through changed incentives to invent. Fifth, we abstract away from the effects at the extensive margin, i.e., regarding the number of patents. Since the UP system makes patenting more cost effective, it is likely to increase the propensity to patent which may affect innovation and welfare adversely (see e.g. Hunt, 2006; Bessen and Hunt, 2007). However, the last problem may be mitigated by the fact that we have chosen to study chemical patents: the traditional incentive theory of patents is more likely to hold for them than in the case of more complex technologies. Finally, we exclude considerations of strategic patenting (see e.g. Choi and Gerlach, 2019, for a theoretical treatment) from our analysis.

The prior literature includes studies of the European patent system. Hall and Helmers (2019) analyze the patenting behavior of firms following the accession of 14 countries to the EPC in the last decade. Danguy and de la Potterie (2011) estimate the effect of UP on renewal fee incomes for NPOs and the EPO. They find that if the UP system fully replaces the EP system, the total income will be higher and most patent offices should be better off (except Germany). They extend this work in Danguy and de la Potterie (2014) where they simulate the effects of UP on the financial income of NPOs and EPO but now taking into account that the UP system will coexist with the EP system. Under various assumptions on the renewal fee scheme of UP - not known at that time - they find that an average UP would generate more income for patent offices than an average EP. Our results suggest that fee income would only go up if there was a significant positive effect at the extensive margin. Our work is also related to papers looking at the effects of fees on patenting behavior (De Rassenfosse and van Pottelsberghe de la Potterie, 2013, for a survey). We contribute by providing what to the best of our knowledge is the first comprehensive counterfactual analysis of a major institutional change in the patent system in Europe, taking in particular the effect of the change in fee structure into account.[7]

[6]According to Lanjouw and Schankerman (2001), the probability of a randomly drawn US patent (granted between 1978-1999) to be sued is 1.7%. Using data on West German patents applied for between 1953 and 1980, Lanjouw (1998) finds that the probability of a patentee winning a litigation trial is round 80-90%.

[7]Deng (2007*a*) compares the value of national patents from the 1970s to the value of EP patents from the 1980s and finds the latter to be much more valuable, but does not provide a counterfactual analysis.

We build on the literature on patent renewal and more specifically on a deterministic model of patent renewal introduced in Pakes and Schankerman (1984) and Schankerman and Pakes (1986*a*) and used e.g. in Bessen (2008) and Schankerman (1998). In this literature, models are based on the idea that it is costly for a patent owner to renew the patent to keep the legal protection in place. Therefore, the owner decides optimally to renew the patent as long as the expected returns from the patent exceed the renewal costs. The owner of the patent expects that the stream of returns will cover the maintenance fees through the use of technology, licensing or commercialization. The optimal solution for the patent holder has the form of a stopping rule which indicates whether to pay the maintenance fee in each period.

Pakes (1986) extends the model to include learning shocks. In other words, there is uncertainty for the patent owner regarding the sequence of returns that the patent generates if it is kept in force. Earlier research has found that most of the uncertainty related to the returns to patent protection occurs before the fifth or sixth year of the patent's life. Lanjouw (1998) refines the model to include the costs of litigation and the possibility of infringement. She also introduces a more flexible model of returns taking into account obsolescence, which happens when an invention becomes worthless. She estimates the distribution of the private value of patents for different technologies in West Germany. Other researchers found differences in private values by owners and patent characteristics in Europe (Schankerman, 1998) and the US (Bessen, 2008). Serrano (2018) allows for the possibility of trading patents, measured by the re-assignment of patents. Renewal decision models have been applied in different countries and contexts including patents granted in France using a binomial tree approach (Baudry and Dumont, 2006), in Australia (Wang, 2012) and in Great Britain and Ireland between 1852 and 1876 (Sullivan, 1994). In an important precursor to our work, Deng (2011) extends the framework to the context of EPs. We follow Bessen (2008) in modeling patent value using individual level data and several patent characteristics: patent family size, the nationality of the applicant, the number of forward citations, the number of patent claims and IPC classes.

We contribute to the patent renewal literature by first, allowing a free parameter to capture the correlation of the initial value of patents between any two countries.[8] Second, to be able to estimate the ensuing large number of parameters (169), we introduce the composite marginal likelihood method to this literature (for an overview, see Varin, Reid and Firth, 2011). Third, we use the private patent value estimates from the re-

[8]Deng (2011) models the correlation between two countries as a function of their geographical distance.

newal model in a model of inventive investments. Fourth, prior work has concentrated on estimating the private value of patents without extending the analysis to social value. To do so, we extend the approach of Schuett and Schankerman (2021) whose welfare analysis builds on a linear Cournot model. By utilizing so-called ρ-linear (see Anderson and Renault, 2003) demand functions we provide a more flexible method and execute the welfare calculations using several different parameterizations.

The rest of the paper is organized as follows. We present the European patent system in more detail and discuss the distinction between EP and UP in section 2. In section 3 we describe the data source and provide some descriptive statistics. We introduce the theoretical framework in section 4. Section 5 is reserved for us presenting our main estimation and counterfactual results. We offer conclusions in section 6.

2 Institutional background

The new European patent system will include three layers: national patents, EPs and the upcoming UPs. We focus on the decisions between EPs and UPs.

2.1 European patents

Since 1977, the EPO has offered a unified patent application and examination procedure for all signatory States to EPC. In 1978, only seven members were contracting States and 3,572 patents were filed. In 2019, 38 countries were contracting States[9] and 181,479 applications were filed. The terminology "European" is misleading because the European dimension exists only at the examination stage of the patent application: EP does not provide supranational protection, but rather a bundle of national patents. In fact, an EP is subject to national patent law, including the payment of renewal fees in States where the patent is in force. This fragmented and complex post-grant procedure

[9] Contracting States to the EPC (with dates of entry into force): Belgium (1977), Germany (1977), France (1977), Luxembourg (1977), Netherlands (1977), Switzerland (1977), UK (1977), Sweden (1978), Italy (1978), Austria (1979), Liechtenstein (1980), Greece (1986), Spain (1986), Denmark (1990), Monaco (1991), Portugal (1992), Ireland (1992), Finland (1996), Cyprus (1998), Turkey (2000), Bulgaria (2002), Czech Republic (2002), Estonia (2002), Slovakia (2002), Slovenia (2002), Hungary (2003), Romania (2003), Poland (2004), Iceland (2004), Lithuania (2004), Latvia (2005), Malta (2007), Norway (2008), Croatia (2008), Republic of Macedonia (2009), San Marino (2009), Albania (2010), Serbia (2010).

results in a more expensive patent system than in the US or in Japan (van Pottelsberghe de la Potterie and François, 2009). It is one of the arguments raised in the long-lasting debate as to why Europe should introduce a harmonised patent system. Notice though that a potential advantage of this system, also from a welfare point of view, is that the (successful) applicant can tailor the patent protection by choosing the countries where the patent is validated (see below) and for how long the patent is kept in force through renewal decisions.

Application and Examination. In the first stage, the applicant files an application for an EP in one of the three official languages (English, French or German). At the time of the application, the applicant pays a standard filing cost including a European search fee and an examination fee. Within twelve months after the filing date, the applicant is free to choose the Member States in which to seek for protection and pays per-country designation fees. Since 1999, all countries are designated by default, so most applicants decide to designate the full set of EPC Member States.[10] Moreover, the designation fee scheme encourages applicants to seek protection in the full set of States as the per-country designation fees are identical for each country up to a maximum of seven, after which additional designation countries are free of charge. The period of examination lasts usually two to six years. During the examination period the EPO conducts a formality check and then produces a search report describing the state of prior art. The patent examiners evaluate if the EPO requirements for patentability (novelty, inventive step and industrial application) are met. The search report and the application are published in the EPO Bulletin 18 months after the priority date of the patent application. The applicant may request the examination within six months after the publication of the application. Not requesting the examination is equivalent to withdrawing the patent.

Validation and renewal decisions. After the examination period, the patent is approved or denied. Traditionally, the EPO grants 60-65% of the patent applications, refuses 5%, and 30-35% are withdrawn by the applicant during the search and examination process (Lazaridis and de la Potterie, 2007). If the patent is granted, the assignee decides whether to pay an extra cost (mainly translation costs for extension/validation) to be able to validate and then transfer the granted patent into national laws in a given (member) country. We call these costs validation costs. In practice, applicants do

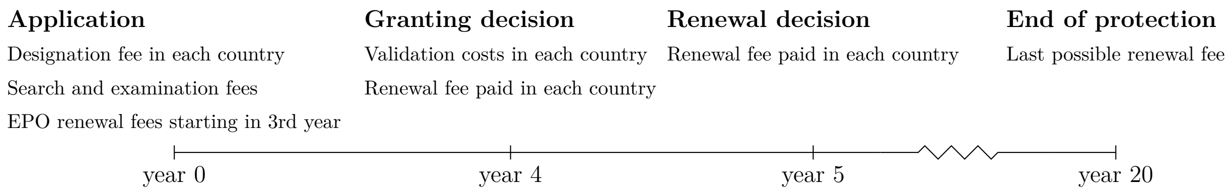
[10] In reality, some applicants decide to opt-out from some States for litigation reasons. In the first approximation, we ignore these cases.

not validate in all designated states. The validation costs differ between countries and patents. For instance, some translations, notably Danish, Swedish and Finnish, are more expensive. The translation service is usually provided by a local attorney and depends on the size of the patent (number of pages) and the patent characteristics. Since the London Agreement in 2008, translation costs have decreased. Signatory countries to the London Agreement do not require that the applicants obtain a full translation of the patent into the local language; only the claims of the EP are required to be translated. We ignore this as we focuse on patents applied for in 2000. Moreover, some States do not require a translation at all (Austria, Belgium, France, Germany, Ireland, Luxembourg, Monaco, Switzerland or United Kingdom). According to Harhoff et al. (2009), translations are not required in 60% of validation cases. Also other administrative validation costs differ by country. Some countries have additional validation costs (fee) whereas others do not charge a fee (Belgium, Luxembourg,Monaco, Switzerland and the United Kingdom). Some countries charge an additional page-based fee when the patent document is longer than a certain size (Austria, Denmark, Finland, Spain and Sweden) (Harhoff et al., 2009).

Once the patent is validated in a given country, it gives the same right as the national patent and is valid for up to 20 years from the filing date. Thereafter, the national patent laws apply, including the requirement to pay a yearly patent maintenance fee in order to keep the patent in force. The fee scheme and varies across countries (see appendix A.1 for renewal fees for the patents in our sample). Renewal fees are collected by national patent offices which retrocede half of the revenue to the EPO. Harhoff et al. (2009) shows that the level of renewal fees, validation costs as well as translation costs have an impact on the validation and renewal decisions. Our model includes this trade-off in the choice of validation countries. Note that the payment of renewal fees starts on the third year from the filing date. Therefore, a patent application can be still under examination when the first renewal decisions are taken. Following the approach of Deng (2007*b*), we model renewal decisions starting from the grant date.

Figure 1 is a simplified presentation of the patent lifetime (the timeline is indicative). In practice different routes exist such as first and second filings, and PCT applications. Guellec and Van Pottelsberghe de la Potterie (2007) provides an thorough description of the different filing procedures at the European Patent Office. We focus on validation and renewal decisions once the patent is granted; this usually happens 4 to 5 years after the patent application.

Figure 1: Lifetime and costs of a European patent (example)



2.2 The unitary patent

Principle. The unitary patent system is expected to start in 2022 and will become an additional option alongside the current national patents and EPs. As mentioned, it has been discussed in one form or another for more than four decades. The centralised pre-grant phase described above will remain the same under the new regime. Thus, there won't be any difference in the quality of the search and examination conducted by the EPO for EPs and UPs. The difference with the EP will be in the post-grant procedure with the introduction of a unique procedure, currency, deadline and no obligation to use a representative. Once the EP is granted, the applicant will be allowed to "request for unitary effect" at the EPO. This request will be free of charge and must be filed in the month following the publication of the grant in the European Patent Bulletin. Moreover, a condition to be eligible for the unitary effect is that the EP has to be granted in at least the same set of States covered by the UP system. After the request, the EP will become a UP. Whereas the EP is validated and renewed separately in each State, the UP will be renewed once a year in the full set of States covered by the new regime and will have its own renewal fee schedule.

Scope of UP. The UP intends to give protection in up to 25 EU Member States (EU27 except Spain and Croatia) which are part of the enhanced cooperation in the creation of unitary patent protection. Note that the UK government stepped out of the project in July 2020 after ratifying the UPC in April 2018. According to the EPO, it is very likely that other countries will join the Unitary Patent System in the following years. The territorial scope of UP is then likely to increase but the UP will have a fixed coverage based on the date of registration of the patent. In other words, multiple generations of UPs with different coverage are expected to be in force at the same time. This point is important as different combinations of EP and UP will be possible. Even with a Unitary patent, it will still be necessary to go through validation or extension in EPC states that are not in the UP system. For simplicity, we look at EPs granted in 2000 in 15 countries and our counterfactual policy focuses on these 15 countries (including the UK). We thereby rule out the possibility of a combination between EP and UP in our model, as well as a combination between national patents and European patents. A possible consequence of the co-existence of these systems is an increasing number of duplicate patent filings simultaneously at different patent offices. Double patents at the national and European levels already exist (von Graevenitz and Garanasvili, 2018).

Costs of UP. UP system will significantly decrease the cost of patenting compared to EP because the validation costs will be decrease and the (unique) renewal fees will be lower. Similarly to EP, if renewal fees are not paid on time, the UP will lapse.[11] The renewal fee scheme is set to be equal to the sum of EP renewal fees in the four most popular countries in 2015 for EP patent protection (Germany, France, the UK and the Netherlands). According to the EPO, it costs €170,000 to obtain a EP for ten years in the 25 states covered by the UP, whereas it will cost only approximately €35,000 to obtain the same coverage with a UP. In the long run, a UP will not require the translation of the patent (translation fees are a major reason for the high cost of EP; see van Pottelsberghe de la Potterie and François, 2009). Nevertheless, in a six-year transitional period (which may be extended to up to 12 years), translation will still be required; we therefore ignore (differences in) translation costs in our counterfactual exercise. UP, similar to EP, will have to be filed in the so-called procedural languages: English, French or German. Patents in English will need to be translated into one of the other procedural languages. French and German language patents will be translated in English. To compensate applicants for the added cost during the transitional period, the EPO will launch a scheme to cover costs related to the translation of the patent application for EU-based SMEs, natural persons, non-profit organizations and universities that are resident in a contracting Member State.

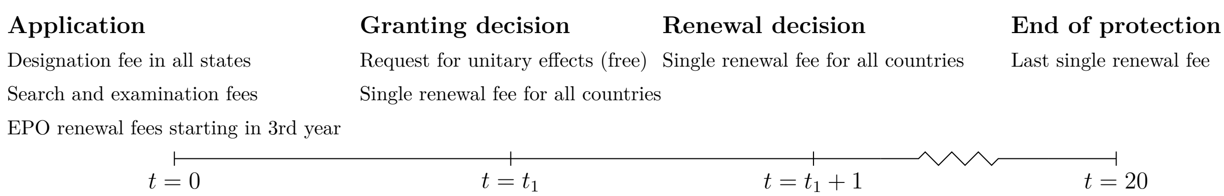
Unified Patent Court. The new regime is linked to the creation of the Unified Patent Court. The UPC will have jurisdiction on both EP and UP and we therefore assume in our counterfactual that there are no differences in the litigation practices

[11] Nevertheless, it is still possible to pay within six months of the due date with a penalty of 50% of the belated renewal fee.

of EP and UP. The creation of the UPC will have effects on litigation costs as it will provide a unified court to centralize litigation. One can expect that the creation of the Court will have an effect on the value and incentives to innovate. Also UP can be licensed in whole or part of the territories of the EU Member States. It is likely that some patent owners will take into account the future cost of litigation when they decide which route (national, EP, UP) to choose. The fact that UP can be revoked in a single action in all participating countries may also reduce the appeal in respect of high-value patents. In contrast, a standard EP could only be revoked on a national basis, one State at a time.

Figure 2 is a simplified presentation of the patent lifetime under the UP

Figure 2: Lifetime and costs of a Unitary Patent



3 Data

3.1 Patent data

The patent data come from the EPO PATSTAT database (spring 2021) and record all EP applications and granted EPs. The data include information on the designation (decision at the time of the application) and validation (decision at the time of the grant) decisions as well as the full renewal history. PATSTAT also provides patent characteristics that are relevant for the returns: The number of forward citations, the number of inventors/applicants, the number of claims, IPC classes and patent family size. Our sample consists of all EPs applied for in 2000 in the field of chemistry (excluding pharmaceutical patents), and designated in the set of 15 Member States[12]. 26% of chemistry patents were designated in the 15 countries in 1995 and 86% in 2000. As previously mentioned, the reason of this rise is that the designation fee scheme changed in the end of the 1990's to encourage applicants to seek protection in the full set of States.

We focus on patents granted in 2000 for two reasons. First, we are able to observe the full life for these patents. Second, in contrast to earlier years, most of the patents in 2000 cohort have the same coverage: 86% of the 16,492 patents are designated in 15 countries.

We focus on chemical patents (excluding pharmaceuticals) because this is an industry that make intensive use of intellectual property. To isolate patents in the technology area of chemistry we use the ISI-OST-INPI classification updated by Schmoch (2008) and included in PATSTAT. We define a patent as belonging to a technology area if at least one IPC code of the patent belongs to this technology area.

3.2 Renewal fee schemes

Renewal fees for each country are extracted from EPO's reports "National Law relating to the EPC"[13] for each relevant year. Fees are expressed in 2010 euros using the Harmonized Indices of Consumer Prices (HICP) of Eurostat and reported in Table A.1. Note that there exist other costs for EPs such as representation costs (attorney fees, other service providers), translation costs incurred for validation and/or publication. In the model, we only take into account renewal fees.

Figure 3 shows the total fee paid in each country for a full term (20 year) EP. The total cost in 15 countries for the full term is more than €100,000 in renewal fees, but there is considerable variation between countries, from more than €15,000 in Germany to less than €3,000 in Portugal.

[12] Austria (AT), Belgium (BE), Switzerland (CH), Germany (DE), Denmark (DK), Spain (ES), France (FR), Great Britain (GB), Greece (GR), Ireland (IE), Italy (IT), Luxembourg (LU) the Netherlands (NL), Portugal (PT), Sweden (SE). We removed three States that joined the Convention during the period we are studying: Finland (1996), Cyprus (1998), Turkey (2000) as the number of EPs in these countries is very low in 2000. The proportion of patents designated in the 15 countries increased over time.

[13] https://www.epo.org/law-practice/legal-texts/national-law/archive.html

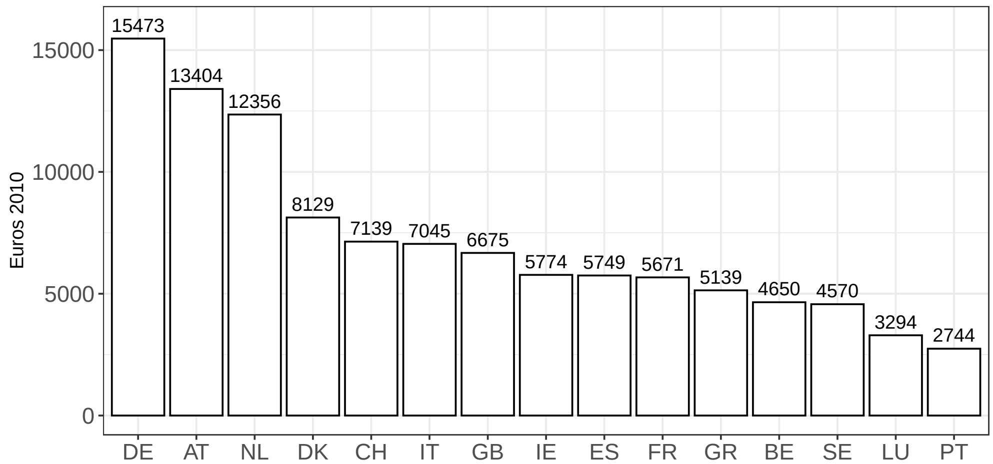


Figure 3: Total renewal costs for a 20-year protection in a given country, in euro 2010

The renewal fee structure for UP is already known and published. To take into account the fact that in 2000 the territorial scope was narrower than today, we compute the "equivalent" renewal fee scheme for UP in the counterfactual, by keeping the same ratio of renewal cost between EP and UP. The renewal fee structure used for the counterfactual is displayed in Table 1. The actual fees for 2021, covering 38 countries, are displayed in columns 2 and 3; in the fourth column we display their ratio in per cent; and our adjusted fee schedules are presented in columns 5 and 6.

Table 1: Renewal fees UP - real and counterfactual

Period	Fees EP 2021	Fees UP 2021	UP fee/EP fee, %	Fees EP 15 countries	Fees UP 15 countries
1	2,506	315	12.57%	1,400	176
2	3,250	475	14.62%	1,839	269
3	3,861	630	16.32%	2,203	359
4	4,615	815	17.66%	2,660	470
5	5,554	990	17.82%	3,113	555
6	6,463	1,175	18.18%	3,643	662
7	7,526	1,460	19.40%	4,205	816
8	8,655	1,775	20.51%	4,865	998
9	9,854	2,105	21.36%	5,676	1,213
10	11,028	2,455	22.26%	6,485	1,444
11	12,189	2,830	23.22%	7,254	1,684
12	13,569	3,240	23.88%	8,272	1,975
13	14,912	3,640	24.41%	9,343	2,281
14	16,166	4,055	25.08%	10,277	2,578
15	17,729	4,455	25.13%	11,491	2,887
16	19,227	4,855	25.25%	12,720	3,212

3.3 Variables

Renewal decisions. We use the legal status information in PATSTAT to construct the renewal variable. This variable indicates the number of years the patent is renewed. It ranges from 0 which means the patent is granted in a country but not validated, to 16 years which means that the patent is renewed every year up to the statutory limit, i.e., 20 years after filing date. Only a minority of patents are renewed for more than 16 years. This situation happens when the examination period is shorter than 4 years. In these cases, we code them as being renewed for 16 years. We thus assume that the examination period is equal to four years for all the patents in our sample.

We use two sources of information to construct the renewal variable: Information on lapsing and information on renewal. In some countries, the grace period after lapsing for non-payment of renewal fees can be quite long. A lapse event coded in PATSTAT does not necessarily mean that a patent expired. On the other hand, renewal information in PATSTAT is not fully reliable. We follow Harhoff et al. (2009) who write: "Following the advice of an EPO expert, information on patent lapses were preferred over renewal information, in case both databases contained conflicting results".

As can be seen from Table 2, there is significant variation in renewal over countries: the longest patents are found in Germany (mean 10 years) and the shortest in Luxembourg, Greece, Denmark and Portugal (all less than 5 years on average). There are also considerable differences in the distribution, with more than a quarter of patents being renewed for at least 15 years in Germany and 14 years in France and Great Britain. In Luxembourg and Greece, a quarter of patents is renewed for at least 5 years.

Validation decisions. As noted by Hall and Helmers (2019), it is not easy to determine from PATSTAT whether a patent has been validated in a country after being granted by the EPO. The legal status of PATSTAT do not provide directly this information because not all the national patent offices record the payment of validation fee. Moreover, some countries do not charge a validation fee. We again adopt the approach of Harhoff et al. (2009). We assume that non-validation is indicated by a lapse of the patent in the 365 days following the grant of the patent. Table 2 reveals (Nb country validated) that on average, a chemical EP applied for in 2000 is validated in 6 countries and 25% in at least 8 of the 15 countries we consider. As shown in Table A.2 in the appendix, there is a significant variation in validation across countries: from 20.8% in Luxembourg to 89.1% in Germany for EPs in our sample. These validation and maintenance rates are in line with those obtained by Danguy and de la Potterie (2011) who consider a larger sample of EPs.

Number of forward citations. The number of citations is often used to proxy for the value of patent and the scientific contribution of an invention. Many studies find a positive association between forward citations and the value of patents (e.g. Trajtenberg, 1990; Lanjouw and Schankerman, 2004). The descriptive statistics for the number of citations 3 years, 5 years and 10 years after patent application are shown in Table 2. On average, a patent in the sample receives 3.0 citations in the first 10 years after the patent application date. As is clear from the table, European patents do not receive many citations.

Number of claims. The claims define in technical terms the scope of the protection. The number of claims is sometimes used as a measure of the patent scope (e.g. Marco, Sarnoff and Charles, 2019). The higher is the number of claims, the broader the scope of the patent Og et al. (2020). The relationship between the number of claims and patent value is not necessarily linear and excessive claims can be associated with lower returns. As shown in Table 2, the average number of claims in the sample is 14.8.

IPC classes. We follow the existing literature and use the number of IPC (International Patent Classification) subclasses (e.g A101B) for each patent as a measure of the technological breadth of the invention (Lerner, 1994). The IPC subclasses are assigned by the examiner. The average number of IPC classes is 5.4 with a quarter of patents having more than 7 classes.

Patent family size According to the EPO, a simple patent family (DOCDB patent family in PATSTAT) is a "collection of patent documents that cover a single invention" and therefore all members of a patent family will have exactly the same priorities. In PATSTAT, the priorities taken into account are the first filings, the provisional first filings and the equivalents to first filings. Continuation and divisions are considered to cover the same content as the parent application and are therefore in the patent family regardless of the priorities they claim. Putnam (1996) is one of the first to use the size of patent family as a proxy for the value of patents. In our sample, chemical patents have an average of 11.83 members in their patent family.

3.4 Descriptive statistics

The cost of patent validation and renewal decisions is the reason why not all the patent holders choose to validate a granted patent in all the designated countries. A large proportion of patents is not renewed for the full patent term. Tables 2 and A.2 provide some evidence of differences in the set of validated countries and renewal decisions, as well as differences in total cost of renewal across countries. A patent in the sample is validated on average in 5.9 countries. Germany, Great Britain, France and Italy are the countries with the highest validation rates and renewal rates. There is a substantial number of countries for which the average validation rate is relatively low.

Table 2: Descriptive statistics chemical EPs granted in 2000

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Patent characteristics							
Citations 3y	16,492	1.460	6.276	0	0	1	448
Citations 5y	16,492	1.911	7.919	0	0	1	623
Citations 10y	16,492	3.004	11.169	0	0	3	783
Nb of IPC classes	16,492	5.385	4.107	1	3	7	45
Nb of applicants	16,492	1.092	0.344	1	1	1	8
Nb of inventors	16,492	3.185	2.120	1	2	4	24
Nb of claims	16,492	14.772	10.921	1	8	19	247
Patent family size (docdb)	16,492	11.833	9.079	1	7	14	126
Renewal and validation decisions							
Germany	16,492	9.918	4.956	0	6	15	16
France	16,492	8.938	5.156	0	5	14	16
Great Britain	16,492	8.773	5.168	0	4	14	16
Netherlands	16,492	5.548	4.883	0	2	8	16
Austria	16,492	4.602	4.375	0	1	7	16
Italy	16,492	7.116	5.158	0	3	11	16
Spain	16,492	6.173	5.041	0	2	9	16
Sweden	16,492	4.616	4.422	0	1	7	16
Switzerland	16,492	5.242	4.811	0	1	8	16
Belgium	16,492	5.253	4.720	0	2	8	16
Denmark	16,492	4.168	4.193	0	1	6	16
Luxembourg	16,492	3.597	3.685	0	1	5	16
Greece	16,492	3.689	3.760	0	1	5	16
Portugal	16,492	3.843	3.887	0	1	5	16
Ireland	16,492	4.181	4.204	0	1	6	16
Nb of countries validated	16,492	5.949	4.205	0	3	8	15

4 Theoretical framework

Renewal decisions at the EPO are complex. We do not attempt to provide an exhaustive model of renewal and validation decisions, but concentrate to what to our understanding are the key decisions.

4.1 The renewal decision model

4.1.1 Private value of EP

The main assumption of the model is that patent holders decide on validation and renewal strategies by comparing the expected returns with the renewal costs, following the deterministic approach of Pakes and Schankerman (1979); Schankerman and Pakes (1986*b*) and Bessen (2008). Consider an inventor seeking to validate and renew an EP in multiple countries. The granted patent protects a single invention i indexed by $i = 1, \ldots, I$ in country j, indexed by $j = 1, \ldots, J$. The return to invention i in country j in period $t = 1, \ldots, \overline{T}$ is defined by R_{ijt} where $\overline{T}$ is the statutory maximum duration of the patent.

The model is deterministic in the sense that the inventor knows perfectly the full sequence of returns from the time the patent is granted. We assume that returns for patents in a country j depreciate every period at the constant rate $\delta_j \in (0, 1)$ known by the patent holder and to be estimated. Patent return for invention i in country j in period t is then:

$$R_{ijt} = \delta_j^{t-1} R_{ij1} \quad \text{where } R_{ij1} \text{ is the return in the first period}$$

The renewal cost C_{jt} in a country j in period t is known for the full life of the patent. The private value of patent protection is the value to the owner of the patent. This information is not observed by the researcher but is observed by the patent holder. Following Putnam (1996) and Deng (2011) who analyze patent renewal in an international context, the private value of a EP covering an invention i in a country $j \in 1, \ldots, J$ is:

$$V(R,T) = \sum_{j=1}^{J} \sum_{t=1}^{T_j} \max_{T_1,\ldots,T_J} \beta^{t-1}(\beta R_{ijt} - C_{jt}) \tag{1}$$

The owner decides in each country j how many periods $T_j \in [0, 1, 2, \ldots, \overline{T}]$ she will renew the patent, balancing patent returns with costs. Note that $T_j = 0$ means that the patent is not validated in country j because the patent holder decides not to pay the first renewal fee. Costs are paid at the beginning of each period whereas returns are received at the end of each period. Returns are discounted by the discount factor β which is assumed to be known and, following the literature, fixed to 0.95.

4.1.2 Renewal and validation decisions

We can use an assumption of our model and a feature of the renewal data to come up with a way of characterizing the renewal and validation decisions. The assumption of the model is that revenues are (weakly) decreasing over time and the institutional feature is that renewal fees are strictly increasing over time. Together, the above assumption and the feature of the data mean that $\beta R_{ijt} - C_{jt}$ is decreasing in time (patent age) and the optimal length of a patent is determined by the the last period where $\beta R_{ijt} - C_{jt} \geq 0$ holds.

The patent holder renews a patent i in country j in period t as long as:

$$\beta R_{ijt} \geq C_{jt} \Longrightarrow R_{ij1} \geq \frac{C_{jt}}{\beta \delta_j^{t-1}} \tag{2}$$

We take the log of these expressions and define $r_{ijt} = \log(R_{ijt})$ and $c_{jt} = \log(C_{jt})$. The number of years a patent is renewed in a country j is denoted y_{ij}. y_{ij} is linked to the unobserved returns r_{ij} by

$$y_{ij} = \begin{cases} 0 \quad \text{if} \quad -\infty < r_{ij0} \leq c_{j1} - \log \beta \\ 1 \quad \text{if} \quad c_{j1} - \log \beta < r_{ij0} \leq c_{j2} - \log \delta_j - \log \beta \\ \ddots \\ \overline{T} \quad \text{if} \quad c_{j\overline{T}} - (\overline{T} - 1) \log \delta_j - \log \beta < r_{ij0} < +\infty \end{cases} \tag{3}$$

The log of the initial return in a country j (r_{ij}) is a latent variable assumed to be determined by a linear model with a deterministic observed part and a random part unobserved by the researcher:

$$r_{ij1} = X_{ij}^{'} \gamma_j + \epsilon_{ij} \tag{4}$$

where $X_{ij}^{'}$ is a K dimensional vector of observed covariates that include patent characteristics which affect the quality of the invention. The covariates are the forward citations 10 years after filing, family size (= the number of countries in which the invention has been protected, with EPO countries counting as one), the number of claims, the number of IPC classes, and dummies for the applicant being from country $j = 1, .., J$. γ_j is a vector of parameters to be estimated that measure the "source of returns". ϵ_{ij} is a random component assumed to follow a multivariate normal distribution with mean $\mu \in \mathbb{R}^J$ and covariance matrix $\Sigma \in S_{++}^J$ where S_{++}^J is the space of symmetric positive definite $J \times J$ matrices. Unobservable (to the econometrician) parts of return to a patent may be correlated across countries. We further assume that model satisfies the exogeneity condition $E(X_{ij}\epsilon_{ij}) = 0 \quad \forall j$. The assumption that the logarithm of returns is normally distributed is supported by surveys showing that the distribution of patent value is highly right skewed (Gambardella, Harhoff and Verspagen, 2008).

$$(\epsilon_{i1}, \ldots, \epsilon_{iJ}) \sim N \left[\begin{pmatrix} \mu_1 \\ \mu_2 \\ \vdots \\ \mu_J \end{pmatrix}, \begin{pmatrix} \sigma_1^2 & \rho_{12} & \cdots & \rho_{1J} \\ \rho_{12} & \sigma_2^2 & \cdots & \rho_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{1J} & \rho_{2J} & \cdots & \sigma_J^2 \end{pmatrix} \right]$$

The correlations between ϵ_{ij} allow us to capture the degree of to which patent value is correlated between any pair of countries. due to e.g. correlated demand. Estimating the parameters of the covariance matrix for J-countries imply the estimation of $\frac{J(J+1)}{2}$ parameters. In our case $J = 15$, making the estimation of the covariance matrix parameters computationally challenging.

4.1.3 Estimation and Identification

The parameter vector to be estimated is $\theta = (\mu, \Sigma, \delta, \gamma)$ where γ is a $K = 19$ dimensional vector of estimates for covariates, μ is a J = 15 dimensional vector of mean initial returns, δ is a J-dimensional vector of decay rates and Σ is a $\frac{J(J+1)}{2}$ dimensional vector of all error variances-covariances stacked.

Let us define a series of thresholds in (3) using (4) as

$$
\begin{aligned}
&\kappa_{ij}^{0}(\theta) = -\infty \\
&\kappa_{ij}^{1}(\theta) = c_{j1} - \log\beta - X_{ij}'\gamma_j \\
&\kappa_{ij}^{2}(\theta) = c_{j2} - \log\delta_j - \log\beta - X_{ij}'\gamma_j \\
&\ldots \\
&\kappa_{ij}^{k}(\theta) = c_{jk} - (k-1)\log\delta_j - \log\beta - X_{ij}'\gamma_j \\
&\ldots \\
&\kappa_{ij}^{\overline{T}}(\theta) = c_{j\overline{T}} - (\overline{T}-1)\log\delta_j - \log\beta - X_{ij}'\gamma_j \\
&\kappa_{ij}^{\overline{T}+1}(\theta) = +\infty
\end{aligned}
$$

Note that for a given invention i in a country j, the unknown thresholds satisfy the condition: $\kappa_{ij}^{0}(\theta) < \kappa_{ij}^{1}(\theta) < \ldots < \kappa_{ij}^{\overline{T}+1}(\theta)$ because the renewal fees are increasing over time.

Let $\phi_{\mu,\Sigma}(\epsilon_{i1}, \ldots, \epsilon_{iJ})$ be the multivariate probability density function with:

$$(\epsilon_{i1}, \ldots, \epsilon_{iJ}) \sim \mathcal{N}(\mu, \Sigma)$$

The likelihood function for an invention i that is renewed m_1 period(s) in country 1, m_2 period(s) in country 2, ..., m_J period(s) in country J is

$$
\begin{aligned}
L_i(\theta) = \;& Pr(y_{i1} = m_1, y_{i2} = m_2, \ldots, y_{iJ} = m_J) \\
= \;& \int_{\epsilon_{i1}=\kappa_{i1}^{m_1}(\theta)}^{\epsilon_{i1}=\kappa_{i1}^{m_1+1}(\theta)} \int_{\epsilon_{i2}=\kappa_{i2}^{m_2}(\theta)}^{\epsilon_{i2}=\kappa_{i2}^{m_2+1}(\theta)} \ldots \int_{\epsilon_{iJ}=\kappa_{iJ}^{m_J}(\theta)}^{\epsilon_{iJ}=\kappa_{iJ}^{m_J+1}(\theta)} \phi_{\mu,\Sigma}(\epsilon_{i1}, \ldots, \epsilon_{iJ}) d\epsilon_{i1}, \ldots, d\epsilon_{iJ}.
\end{aligned}
$$

The likelihood involves the computation of a J-dimensional integral for each invention which is computationally difficult for large J. To circumvent this issue, we use the composite marginal likelihood (CML) method described below.

Composite marginal Likelihood (CML). The composite likelihood methods were first introduced by Besag (1975) under the term of pseudo-likelihood and then popularised by Lindsay (1988) as composite likelihood methods. The approach consists of constructing a likelihood object based on the likelihood of marginal or conditional events. Paleti and Bhat (2013) compare simulated maximum likelihood (SML) with the use of a composite marginal likelihood (CML). They show that using SML is cumbersome and prone to simulation errors. Furthermore, they find that CML recovers parameters as well as the SML estimation approach and with a substantially reduced computational cost (see also Bhat, Varin and Ferdous (2010)). This method has been applied widely in statistics but has gained little attention in economics and econometrics. Mullahy (2016) propose a composite marginal likelihood approach to estimate multivariate probit models with bivariate probit. In our setting, the approach requires us to replace the full likelihood function by a surrogate likelihood constructed from pair-wise bivariate ordered probits. Therefore, the full pair-wise approach of CML requires to evaluate $J \times (J-1)/2$ pairs.

The standard pairwise CML likelihood function for invention i is:

$$L^i_{CML}(\theta) = \prod_{j=1}^{J-1} \prod_{j'=j+1}^{J} Pr(y_{ij} = m_j, y_{ij'} = m_{j'}) \tag{5}$$

where the probability that an invention i is renewed m_j periods in country j and m_k periods in country k is:

$$\begin{aligned} Pr(y_{ij} = m_j, y_{ik} = m_k) =& Pr\left(\kappa_{ij}^{m_j} \leq \epsilon_{ij} \leq \kappa_{ij}^{m_j+1} \quad \cap \quad \kappa_{ik}^{m_k} \leq \epsilon_{ik} \leq \kappa_{ik}^{m_k+1}\right) \\ =& \Phi_2\left(\frac{\kappa_{ij}^{m_j+1} - \mu_j}{\sigma_j}, \frac{\kappa_{ik}^{m_k+1} - \mu_k}{\sigma_k}, \rho_{jk}\right) - \Phi_2\left(\frac{\kappa_{ij}^{m_j} - \mu_j}{\sigma_j}, \frac{\kappa_{ik}^{m_k+1} - \mu_k}{\sigma_k}, \rho_{jk}\right) \\ & - \Phi_2\left(\frac{\kappa_{ij}^{m_j+1} - \mu_j}{\sigma_j}, \frac{\kappa_{ik}^{m_k} - \mu_k}{\sigma_k}, \rho_{jk}\right) + \Phi_2\left(\frac{\kappa_{ij}^{m_j} - \mu_j}{\sigma_j}, \frac{\kappa_{ik}^{m_k} - \mu_k}{\sigma_k}, \rho_{jk}\right) \end{aligned}$$

Φ_2 is the bivariate standard normal cumulative distribution with covariance ρ.

The pairwise marginal likelihood function is then:

$$L_{CML}(\theta) = \prod_{i=1}^{I} L^i_{CML}(\theta)$$

Identification. The renewal fees provide information on scaling of the latent variable in models of patent renewal. Therefore, unlike in the standard ordered probit, no restriction on variance parameters is needed. In essence, as the renewal fees are measured in euros, it follows both that no coefficient is needed and that one obtains a natural interpretation of other variables and their coefficients in monetary terms. Furthermore, we assume X_i does not contain a constant term so the standard normalization $\mu = 0$ becomes unnecessary in this case.

Standard Errors. Standard errors are computed using a bootstrap with 200 replications.

5 Estimation results

Figure 4 shows mean initial (log) returns of patents in a given country on the x- and decay rates on the y-axis. The highest initial returns are earned in Germany (i.e., for patents giving protection in the German market), Great Britain, The Netherlands and France. The differences across countries are large: The mean initial return to a patent in Germany is five times that of the lowest in Greece, for patents having identical characteristics. It is also noticeable that the initial return for patent protection in The Netherlands is on par with that in France and higher than in Italy or Spain despite the Netherlands being a smaller country. We also estimate large differences in decay rates. Three of the four countries with the highest initial returns also have the highest decay rates, meaning that patents in Germany, Great Britain and France lose value more slowly than in other countries. Figure 4 shows that Germany, Italy, Spain, France and Great Britain have the highest variation in initial returns, i.e., more heterogeneity in the quality of inventions. The differences across countries in heterogeneity of returns is also sizeable, with Germany having a 40% higher standard deviation of returns than Denmark. Figure 5 further shows that the association between mean initial returns and standard deviation is weaker than that between initial returns and the decay rate, as some countries such as The Netherlands have relatively high mean initial returns but a low standard deviation. The estimation results are displayed in Table A.3.

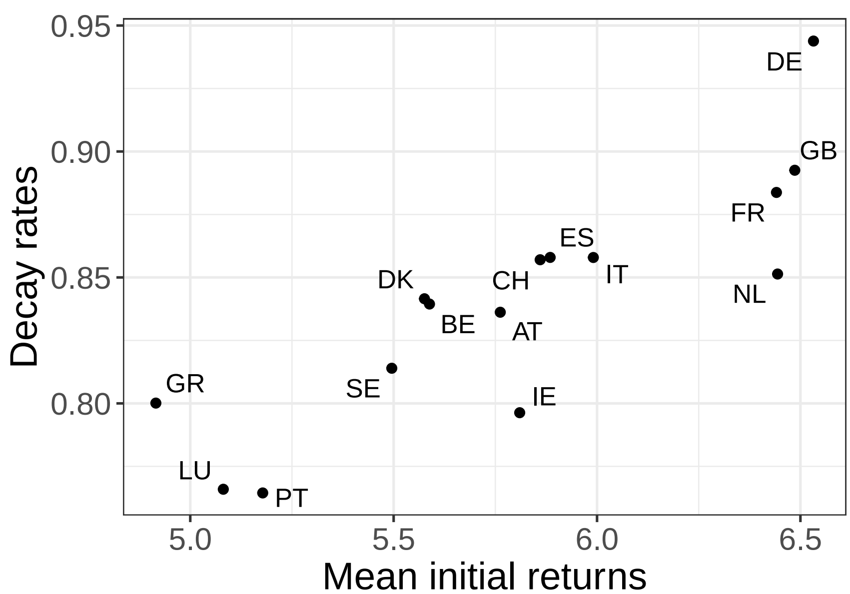


Figure 4: Mean initial return and decay rate

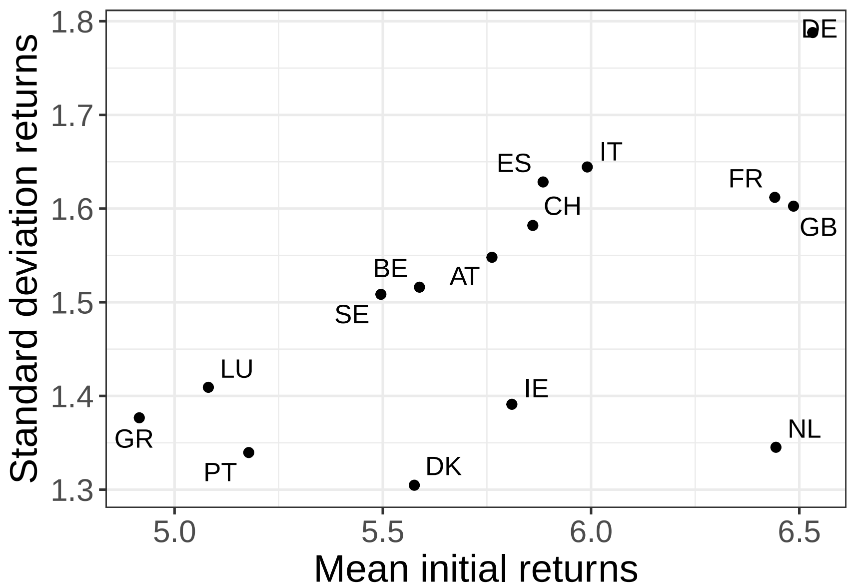


Figure 5: Mean initial return and its standard deviation

The left part of Figure 6 shows that *Family size*, forward *Citations* at 10 years and the number of *IPC classes* are positively associated with the initial returns. The coefficients can be interpreted as semi-elasticities. For instance, a one country increase in family size is associated with a 4.3% increase in the return in the first period. The coefficient for the number of *Claims* is negative.

The right part of Figure 6 shows coefficients measuring the effect of applying for a patent in the country of the applicant. In most countries, patent holders receive a higher initial return in their countries of residence: The effect is largest for German inventors. For Luxembourg and Greece, this positive association does not exist.

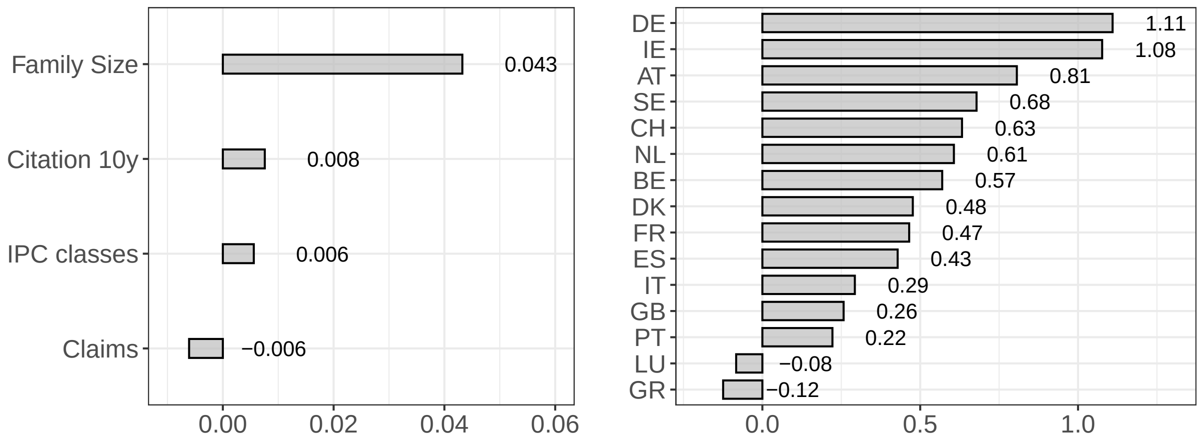


Figure 6: Coefficients for Family Size, Citation 10y, IPC classes, claims and nationality with country interaction

In Figure 7 we show the correlation of returns across countries. Prior work has either assumed that country-specific returns are uncorrelated, or that the correlation is a function of physical distance between the countries (Deng, 2011). We find that correlations are not dictated by distance alone: For example, the correlation between the returns to a given patent in Germany and Spain is higher than the correlation between the returns to the same patent in Germany and neighboring Belgium. All in all, the variation in the correlations is substantial, reaching from a high of 0.9 between Portuguese and Greek returns to a low of 0.4 between German and Luxembourgish returns.

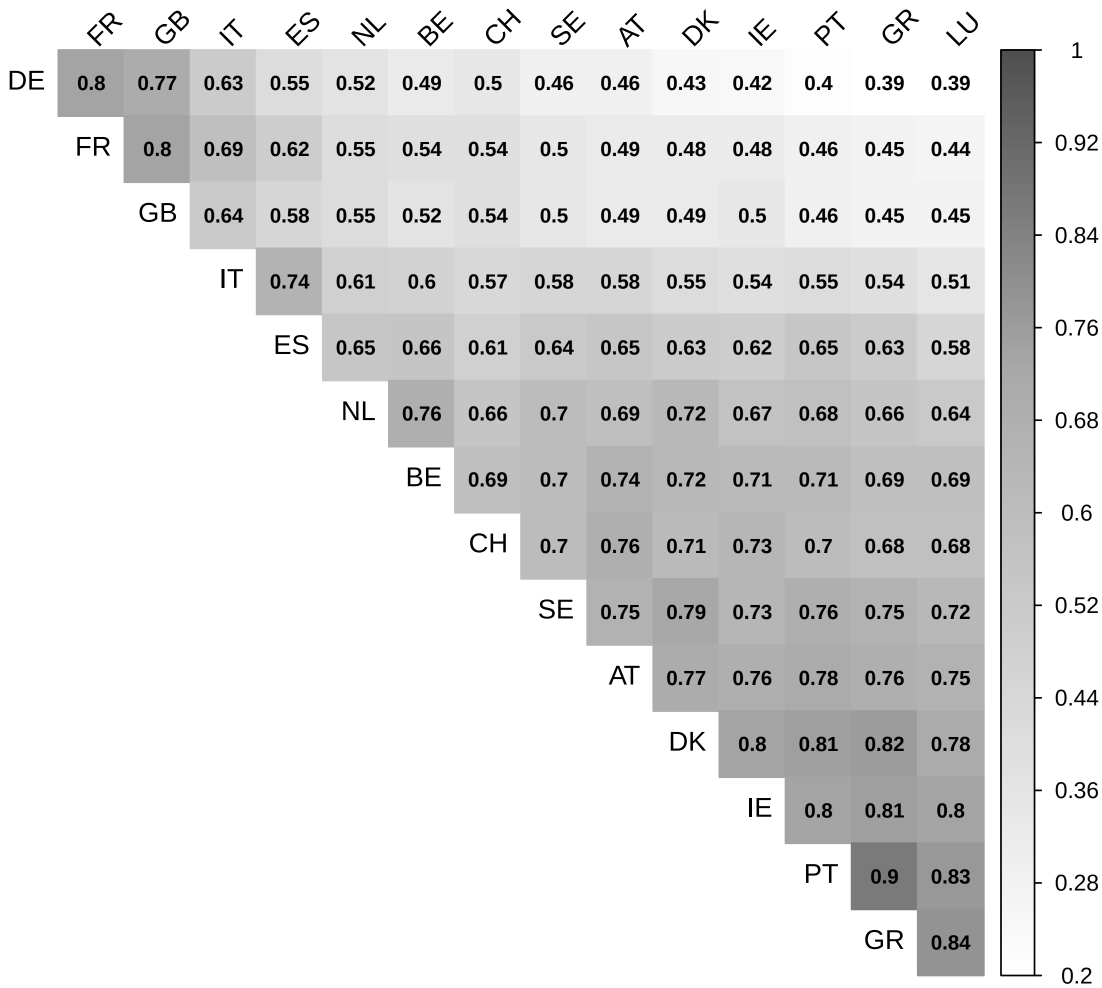


Figure 7: Correlation in initial value ϵ_{ij}

6 Counterfactual analysis

In this section we first present the formulae for calculating the private value of a patent in the EP and UP regimes. The counterfactual proceeds then in three steps: First, in subsection 6.2 we keep the patent quality constant and study i) what fraction of patent holders would opt for UP instead of EP, had it been available in 2000 and ii) how the gain in value is correlated with the value under EP. In the second step in subsection 6.3, we introduce a model of knowledge production which allows us to interpret the observed patent quality under EP as the outcome of profit maximization. We can then evaluate by how much the quality of the patent would have improved, had the UP regime already been in place at the time the developers of the chemical patents applied for in 2000 made their R&D investments. In subsection 6.4 we decompose the change in value to the effects of i) changed territorial scope of the patent; ii) changed duration of the patent; iii) change in renewal fees; and iv) change in patent quality. In the third step (subsection 6.5), we utilize the fact that we estimate the private value of the monopoly right to utilize the invention underlying the patent. We develop a method that allows us to estimate the consumer surplus of a given patent (in a given country-year-cell) during the period the patent is in force, and after it has been allowed to lapse.

6.1 Private value of EPs and UPs

The discounted private value of invention i under the EP regime is the discounted sum of the country-year-specific returns for all the years in a given country that the EP is renewed:

$$V_i^{EP}(R;\theta) = \sum_{j=1}^{J} \sum_{t=1}^{T_j^*} \beta^{t-1}(\beta\delta_j^{t-1} R_{ij1} - C_{jt}^{EP}) \tag{6}$$

where

$$T_j^* = \max_t \sum_{k=1}^{t} \beta^{k-1}(\beta\delta_j^{k-1} R_{ij1} - C_{jt}^{EP}) \;\; s.t. \; t \leq \bar{T}$$

The discounted private value of an invention i under the UP regime is calculated similarly, but now the patent covers all countries by design, and is renewed for the same number of years in each country:

$$V_i^{UP}(R;\theta) = \sum_{t=1}^{T^*} \quad \beta^{t-1}\Big(\beta \sum_{j=1}^{J}(\delta_j^{t-1} R_{ij1}) - C_t^{UP}\Big) \tag{7}$$

where

$$T^* = \max_t \quad \sum_{k=1}^{t} \beta^{k-1}(\beta \sum_{j=1}^{J} \delta_j^{k-1} R_{ij1} - C_k^{UP}) \;\; s.t. \; t \leq \bar{T}$$

As the UP is an option that the patent holder can exercise, while the EP is the default protection, the private value in the current EP and the new UP regimes are then:

$$V_i^{current}(R;\theta) = V_i^{EP} \tag{8}$$

$$V_i^{new}(R;\theta) = \max\Big\{V_i^{UP}, V_i^{EP}\Big\} \tag{9}$$

6.2 Private value of patents keeping patent quality constant

Using the parameter estimates, we simulate 100 times each of the 16,492 year 2000 chemical industry patents and compute the net private value under the current and new regimes while keeping patent quality constant. Figure 8 gives the mean values of EP patents by country: German patents (i.e., patents yielding protection in Germany) are the most valuable and more than twice as valuable on average as British and French patents. At the other end of the spectrum, Greek and Luxembourgish patents are on average worth less than €3,000. Using these figures, a patent taken out in all countries and having the mean value of each country would be worth over €200,000.

Figure 9 gives the mean value of EPs by country of applicant. EPs granted to applicants from Ireland, Sweden and Portugal are of higher value on average.

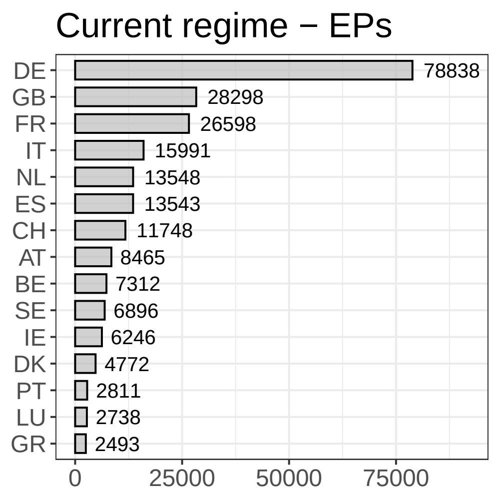


Figure 8: Mean value of EPs by country

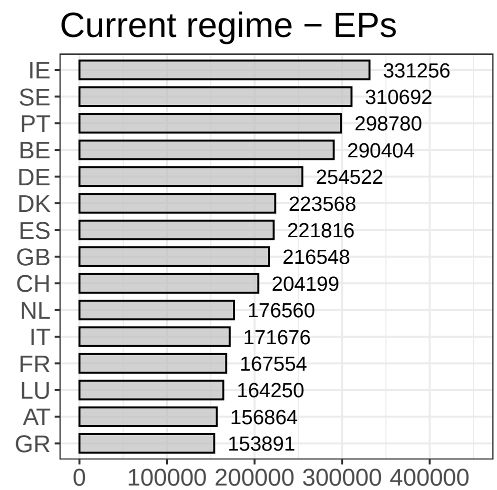


Figure 9: Mean value EPs by country of applicant

Table 3 reports key findings of our first counterfactual exercise. The mean value of a patent increases by €15,656 from the introduction of UP. Further, we see that the distribution of patent value is quite similar under EP and UP. The change in value at the 10^{th} percentile is less than €6,000, while at the 90^{th} percentile it is €27,000. The largest gains happen at the top of the distribution. The UP option turns out to be almost universally valuable even keeping patent quality constant as we find that only 0.1% of patent holders would prefer EP instead of UP.

Table 3: Counterfactual effects on private value of patents, keeping quality constant

Statistics	$\mathbf{V^{current}}$	$\mathbf{V^{new}_{cf1}}$	$\mathbf{V^{new}_{cf1} - V^{current}}$
Q. 10 %	12,379	19,459	5,841
Q. 25 %	30,518	40,919	9,358
Median	76,900	91,880	14,435
Q. 75%	185,122	205,788	20,864
Q. 90%	407,600	432,808	27,352
Q. 95%	663,300	690,907	31,211
Q. 99%	1,838,672	1,869,236	38,006
Mean	229,659	245,306	15,656
Min	0	0	0
Max	7.2 Bn	7.2 Bn	45,263
N	1,649,200	1,649,200	1,649,200

Figure 10 shows the monetary gains from shifting to the new system given a private value of EP on the x-axis, keeping patent quality constant.

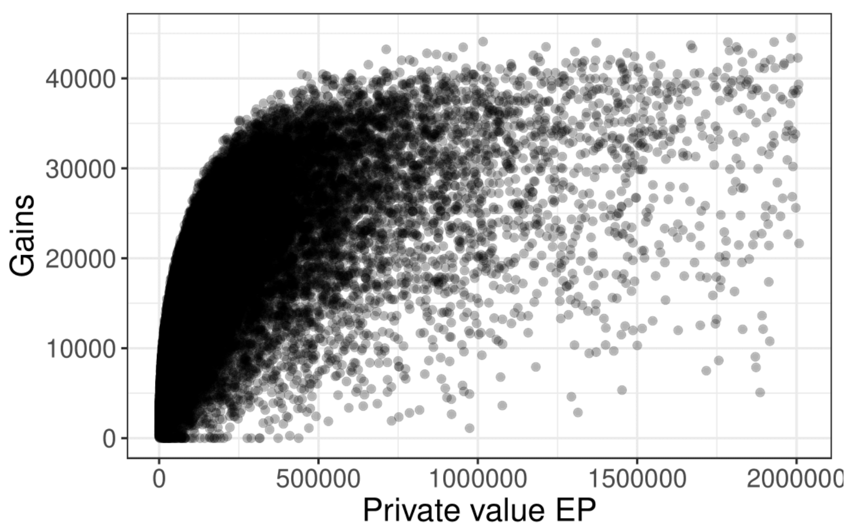


Figure 10: Gains from UP, keeping patent quality constant - Random sample of 50,000 patents

6.3 Private value of patents with endogenous patent quality

6.3.1 Patent production function

A theoretical model of patent production. The renewal decision model presented above allows us to calculate the private value of patent i under both regimes: $V_i^{current}$ and V_i^{new}. Nevertheless, the model does not take into account the effect of the new regime on the incentives to invent. In other words, V_i^{new} is computed under the assumption that the quality of the invention remains constant. To capture the change in patent quality for those patents in our data (the intensive margin), we assume that the profits V from a patent is a function of citations Y (keeping other patent characteristics constant). Each potential inventor is capable of at most one invention, and can affect the value of the invention by investing in R&D (R). The profits for an inventor are:

$$\pi = V(Y(R)) - wR - K, \tag{10}$$

where $V(.)$ is the private value or profit of patenting an invention and relates the quality of the patent Y with the private (expected discounted) value of the patent. $Y(R)$ is the knowledge production function relating a measure of patent quality (number of citations) with the level of R&D investment R, measured by the number of inventors. w is the per-unit cost of R&D and K is a fixed cost.

The first order condition for profit maximization is given by:[14]

$$\frac{\partial \pi}{\partial R} = \frac{\partial V}{\partial Y}\frac{\partial Y}{\partial R} - w = 0$$

We assume that the marginal cost of R&D is not affected by the intellectual property regime. When the inventor faces one or the other IPR regime, only $V(Y)$ changes, meaning that the following holds:

$$w = \frac{\partial V^{current}}{\partial Y}\frac{\partial Y}{\partial R} = \frac{\partial V^{new}}{\partial Y}\frac{\partial Y}{\partial R} \tag{11}$$

Equation (11) shows that at the counterfactual optimum, the inventor will equate the marginal improvement in patent value with its factual value. We depict the situation in Figure 11 where the inventor faces a situation where $V^{new}(R)$ lies everywhere above $V^{current}(R)$, and has a larger derivative w.r.t. R. In such a case, moving from the current

[14]The second order condition is $\frac{\partial^2 V}{\partial Y^2}\left(\frac{\partial Y}{\partial R}\right)^2 + \frac{\partial V}{\partial Y}\frac{\partial^2 Y}{\partial R^2} < 0$

to the new regime leads to higher R&D investments, higher quality, and therefore higher private value.

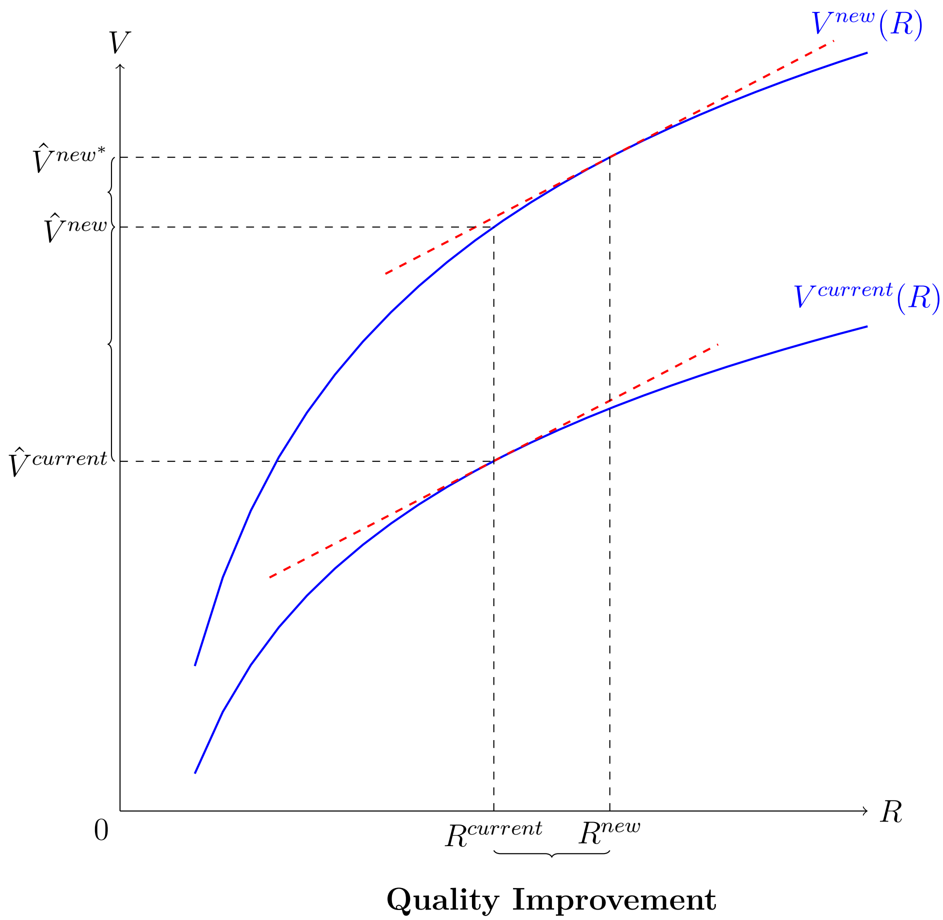


Figure 11: Example of quality improvement due to UP

6.3.2 Estimations of $V(Y)$ and $Y(R)$

To operationalize the above model, we project the logarithms of the value of patent i in the two regimes and onto a second order polynomial of the number of 10-year citations. We present the results in Table 4. We find that patent value is convex in the number of citations, and the parameters of the two polynomials are different from each other. This suggests indeed that inventors will adjust their R&D investments to the IPR regime they face. Figures 4 show graphically the results of the linear regressions.

Table 4: Estimation of $V^{EP}(Y)$ and $V^{UP}(Y)$

	Dependent variable:	
	$\log(V^{EP})$	$\log(V^{UP})$
	(1)	(2)
Citations	5.090×10^{-3} ***	4.587×10^{-3} ***
	(1.593×10^{-4})	(1.399×10^{-4})
Citations^2	7.419×10^{-6} ***	7.603×10^{-6} ***
	(3.204×10^{-7})	(2.814×10^{-7})
Constant	11.186***	11.415***
	(1.187×10^{-3})	(1.040×10^{-3})
Observations	1,649,134	1,649,196
R^2	0.004	0.005
Note:		*p<0.1; **p<0.05; ***p<0.01

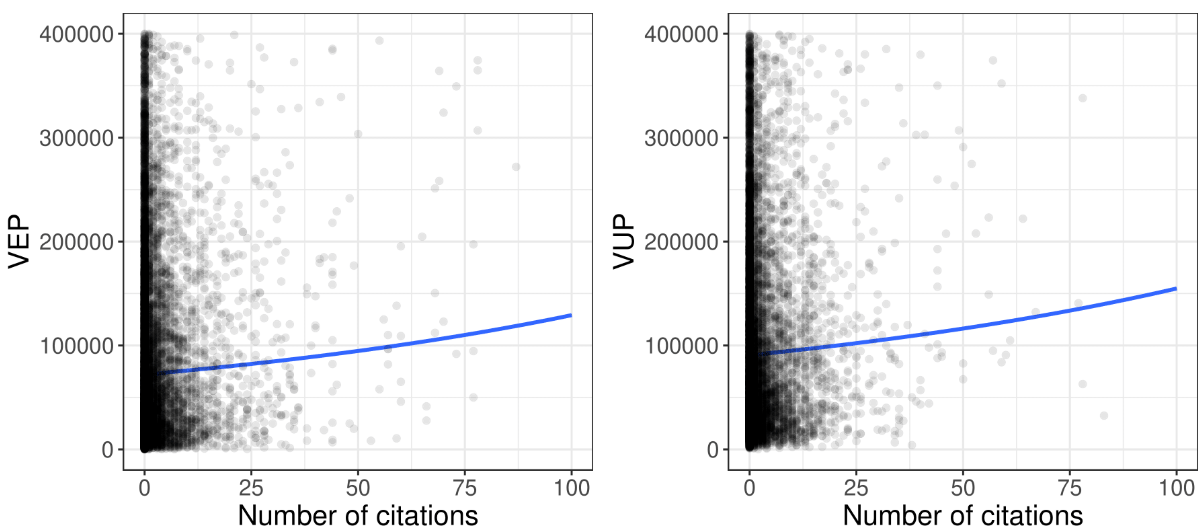


Figure 12: EP and UP private value on citations

Table 5 shows a Poisson regression where the dependent variable is the number of 10-year forward citations and the RHS variables a third order polynomial of the number of inventors. We choose a third order polynomial to ensure that the second order conditions are satisfied.

Table 5: Estimation of $Y(R)$

	Dependent variable:
	Citations
# inventors	-0.007^{***} (0.01)
# inventors^2	0.019^{***} (0.002)
# inventors^3	-0.001^{***} (0.0001)
Constant	0.902^{***} (0.017)
Observations	16,492
Note:	*p<0.1; **p<0.05; ***p<0.01

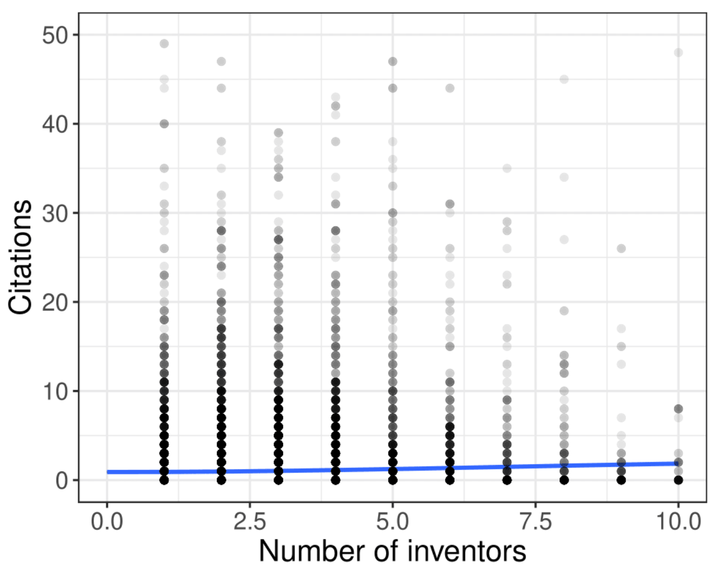


Figure 13: Projecting the number of citations on the number of inventors

Using these estimation results to numerically solve for equation (11) and then recalculating the number of citations we find that 62% of patents have an increase in the level of citations.[15]

In Figure 14 we show how the change in quality is related to the actual number of

[15]Our estimates suggest a decrease in patent quality for some of the remaining 38% of patents, but that is due to estimation error. In line with our theoretical model, we round these to zero.

citations (under the EP regime). It is clear that the lower the initial quality, the larger the absolute increase in quality.

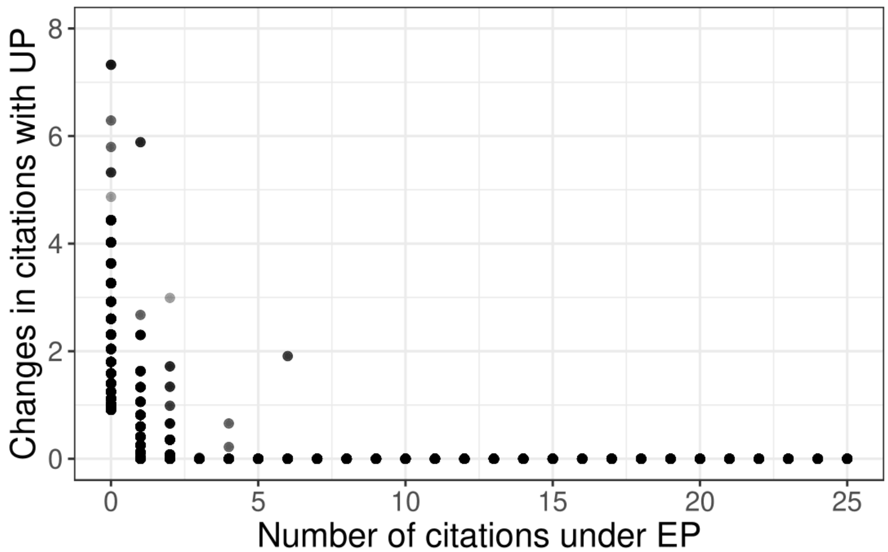


Figure 14: Change in number of citations - Random sample of 50,000 patents

6.4 Decomposition of the change in private value with endogenous quality

The introduction of UP will potentially change the scope of the patent both in terms of the number of countries that the applicant wants to cover, and the optimal length (by country) of patent protection. For some patents, in particular the most valuable ones that are taken out in all countries and renewed to the statutory maximum length, no such changes take place, but the fees needed to obtain the wanted intellectual property protection may change. Finally, as shown above, most patents would have been of higher quality had UP been in place at the time of R&D investment and this, too, will lead to a change both in the optimal patent scope and in the value of the patent. The private gain/cost of moving from EP to UP, allowing for endogenous quality of the invention, is:

$$\Delta PV = V_i^{new,cf2} - V_i^{current} = \underbrace{\sum_{j=1}^{J}\sum_{t=1}^{T_j^*} \beta^{t-1} C_{jt}^{EP} - \sum_{t=1}^{T^*} \beta^{t-1} C_t^{UP}}_{\text{Cost effect}} + \underbrace{\sum_{j=1}^{J} \sum_{t=T_j^*|T_j^*\neq 0}^{T^*} \beta^t R_{ij1}\delta_j^{t-1}}_{\text{Length effect}}$$

$$+ \underbrace{\sum_{j=1}^{J} \sum_{t=T_j^*|T_j^*=0}^{T^*} \beta^t R_{ij1}\delta_j^{t-1}}_{\text{Scope effect}} + \underbrace{V_i^{EP2} - V_i^{EP1}}_{\text{intensive margin}}$$

We present the decomposition results in Table 6. The first column gives information on the value of a patent under the current IPR regime, the second under the counterfactual regime where the inventors have the option of taking a UP and investing more in their invention, and the third the difference between these two. As can be seen, at all quantiles the new regime leads to more valuable patents than the old regime. The difference at the first decile is €7,000, at the median €15,000, at the third quartile €21,000 and at the ninth decile €29,000. Most of the change in value comes from savings through renewal fees at the high end of the value distribution and through a change in length at the low end of the value distribution. The effect of changing geographical scope is modest, as is the effect of changing quality.

Figure 15 shows graphically the decomposition of the different effects.

Table 6: Counterfactual effects on private value of patents, endogenous quality

Statistics	$\mathbf{V^{current}}$	$\mathbf{V^{new}_{cf2}}$	$\mathbf{V^{new}_{cf2} - V^{current}}$	**Quality**	**Cost**	**Scope**	**Length**
Q. 10 %	12,379	19,567	6,011	0	718	0	3,661
Q. 25 %	30,518	41,148	9,658	0	2,681	0	5,741
Median	76,900	92,370	14,996	208	5,893	229	7,893
Q. 75%	185,122	206,871	21,983	957	10,738	750	9,531
Q. 90%	407,600	435,120	29,457	2,468	17,606	1,326	10,695
Q. 95%	663,300	694,754	34,411	4,246	22,280	1,641	11,338
Q. 99%	1,838,672	1,880,094	46,283	12,470	31,541	2,177	12,412
Mean	229,659	246,456	16,807	1,112	7,727	452	7,514
Min	0	0	0	0	-8,341	0	-3,177
Max	7.2 Bn	7.2 Bn	2,387,274	2,348,175	45,263	3,883	15,395
N	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200

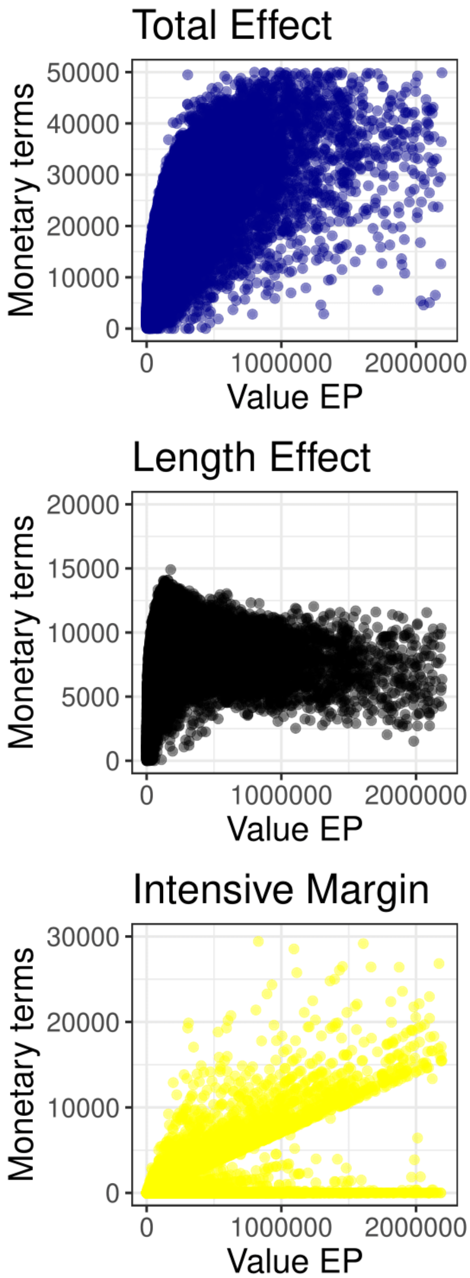


Figure 15: Gains in the second counterfactual with endogenous quality - Random sample of 50,000 patents

Figure 16 shows more specifically the gains and the decomposition of the effects by groups of patents of different value. For EPs of lower value (less than €100,000), most of the gain comes from a length effect (40-50%) and a cost effect (25%-50%). The scope effect is also non-negligible, especially for the lower tail of the distribution. For highly valuable patents, the cost effect is the main driver of the gains (more than 50%) but the quality effect is also an important dimension.

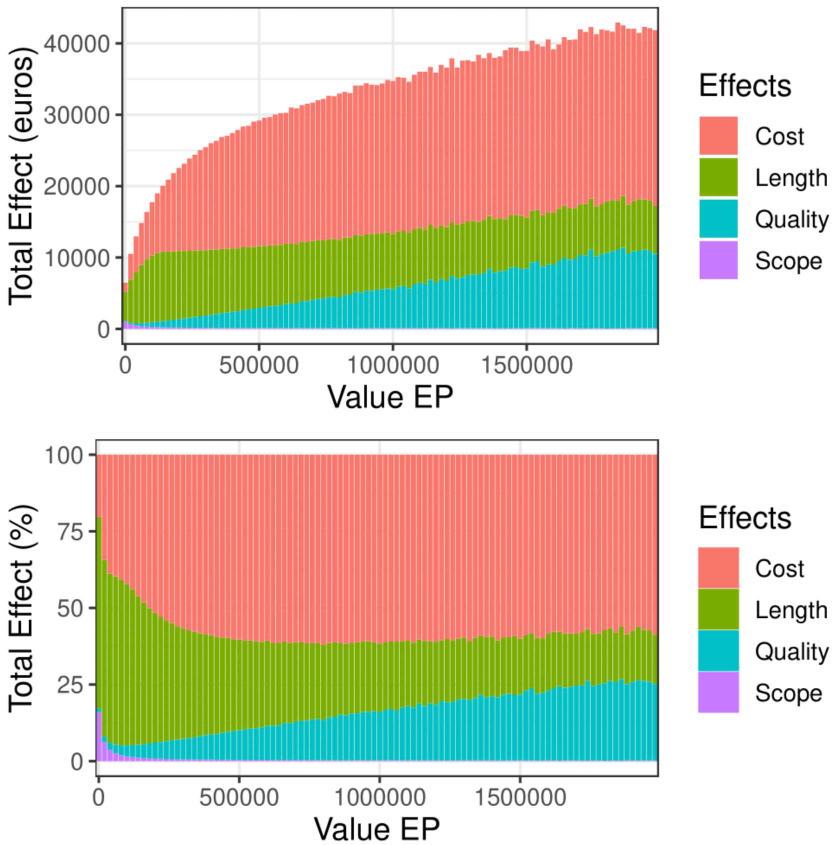


Figure 16: Gains in the second counterfactual with endogenous quality - monetary terms and percentages

6.5 From private value to social value

6.5.1 Mapping between consumer surplus and private rents

The above analysis, and the existing literature using patent renewals to infer their value, concentrate on the private value of patents. This is an obvious first step, as it potentially allows to estimate the incentive effects of a (change in) an intellectual property regime. From the point of view of planning (changes in) such regimes, one would want an estimate of the welfare effects. We now provide a welfare analysis.

Approach. Our approach is the following: Our estimates and counterfactual calculations provide us with an estimate of the (per period) monopoly profits to a given patent both in the EP and in the UP regimes. To arrive at an estimate of welfare, we need a mapping from monopoly profits to consumer surplus under monopoly for each of the periods when the patent is in force. In addition, we need an estimate of the generated welfare in the years after the patent has lapsed.

To produce the required estimates, we lean on results on ρ-linear demand functions (Anderson and Renault, 2003). We restrict our attention to ρ-linear (inverse) demand functions of the form:

$$P(Q) = A - bQ^{\rho},$$

with $\rho \in (-1, 0)$ or $\rho > 0$ (see also Spiegel, 2021). It follows directly from Corollary 1 of Anderson and Renault (2003) (as well as Corollary 1 of Spiegel, 2021) that

$$CS_M = \frac{\Pi_M}{1+\rho}, \tag{12}$$

where Π_M is the monopoly profit and CS_M the consumer surplus under monopoly. Applying Proposition 6 from Anderson and Renault (2003) to a monopoly one can show that

$$TS = \Pi_M(1+\rho)^{(1/\rho)} \tag{13}$$

where TS is total surplus, i.e., welfare under perfect competition. As an example, applying these results to the case of $\rho = 1$, i.e., linear demand, yields the familiar expressions for monopoly profit, consumer surplus under monopoly, and total surplus (with c being the constant marginal cost of production):

$$\Pi_M^{lin} = \frac{(A-c)^2}{4b} \quad ; \quad CS_M^{lin} = \frac{(A-c)^2}{8b} = \frac{\Pi_M^{lin}}{2} \quad ; \quad TS^{lin} = \frac{(A-c)^2}{b} = 2\Pi_M^{lin}$$

For the class of demand functions we consider, consumer surplus under monopoly is a decreasing function of ρ (keeping Π_M constant), and so is total surplus. In terms of estimating welfare, it is straight forward to apply equations (12) and (13) once a value for ρ has been determined and one has an estimate of monopoly profits. Regarding the latter, we assume that the computed private value of a patent is a correct proxy for the monopoly profit of a firm: thus the per period monopoly profits in the two regimes for invention i in country j in period t that are relevant for the calculation of consumer surplus are given by $\beta\delta_j^{t-1}R_{ij1}$ (i.e., gross of renewal fees). The patent-holder has a monopoly during the full life of the patent. Once the patent lapses, new firms enter the market and the equilibrium is characterized by perfect competition. We assume that the discount factor for profits and welfare are identical and the same we used in the estimation: $\beta = 0.95$. The consumer surplus for an invention i under EP and UP regimes is given by the following formulae respectively:

$$\begin{aligned} CS_i^{EP} &= \sum_{j=1}^{J}\sum_{t=1}^{T_j^*} \frac{1}{1+\rho}\beta^{t-1}\Pi_{ijt}^{EP} + \sum_{j=1}^{J}\sum_{t=T_j^*+1}^{+\infty} (1+\rho)^{(1/\rho)}\beta^{t-1}\Pi_{ijt}^{EP} \\ CS_i^{UP} &= \sum_{t=1}^{T^*} \frac{1}{1+\rho}\beta^{t-1}\Pi_{it}^{UP} + \sum_{t=T^*+1}^{+\infty} (1+\rho)^{(1/\rho)}\beta^{t-1}\Pi_{it}^{UP} \end{aligned}$$

The change in welfare of the new regime for a given patent i is then:

$$\begin{aligned} \Delta TW_i &= \sum_{j=1}^{J} V_{ji}^{UP} - V_i^{EP} + \sum_{j=1}^{J} CS_{ji}^{UP} - CS_i^{EP} \\ &= \Delta\text{Private Value}_i + \Delta\text{Consumer Surplus}_i \end{aligned}$$

To make this approach operational, a value for the demand parameter ρ is needed. As we unfortunately cannot identify it from our data. Also, as far as we know, only few reliable measures of price elasticity of demand are available in the literature for chemical products. Böcker and Finger (2017) in reviewing all works estimating the price elasticity of demand for pesticides in Europe and North America, finds a median of -0.28. Lilien and Yoon (1988) find a price elasticity for acetone between -2.48 and -1.81 during the introduction stage of the life cycle and with two different model specifications. For antibiotics, they find the price elasticity to vary between -1.23 and -0.98. Based on these scarce results, we explore more the cases $\rho = 1$ and $\rho = -1/2$ (in appendix A.5), but in our main analysis, resort to doing our welfare calculations for different values of $\rho \in \{-1/2, 1, 2\}$. $\rho = -1/2$ gives a constant elasticity demand function with a price elasticity of -2. The two other values that we apply yield a linear and a quadratic demand function; both are often used in applied work.

6.5.2 Results

Welfare calculation for different values of ρ. Results in Table 7 are based on simulations of 100 periods (=years). For values of $\rho \in \{-1/2, 1, 2, 3\}$, UP decreases consumer surplus on average by €10,000 to €13,000 per patent which is equivalent to a decrease of 2 to 9% of the consumer surplus. When ρ increases, the price elasticity of demand decreases, implying a smaller consumer surplus under the current regime. Note that the private value is unchanged and does not depend on ρ as it comes from the simulation exercise above. Following the introduction of UP, total welfare increases by €3,500 to €7,000 which is equivalent to 0.4 to 1.9% increase of total welfare.

Table 7: Welfare calculations per patent, by ρ

ρ	PV^{EP}	ΔPV	ΔPV in %	CS^{EP}	ΔCS	ΔCS in %	TW^{EP}	ΔTW	ΔTW in %
$\rho = -1/2$	229,659	16,807	+7.3%	633,499	-13,161	-2.1%	863,149	+3,645	+0.4%
$\rho = 1$	229,659	16,807	+7.3%	193,246	-11,141	-5.8%	422,896	+5,665	+1.3%
$\rho = 2$	229,659	16,807	+7.3%	142,734	-10,558	-7.4%	372,384	+6,248	+1.7%
$\rho = 3$	229,659	16,807	+7.3%	117,106	-10,182	-8.7%	346,756	+6,624	+1.9%

Linear demand case $\rho = 1$. Here we assume $\rho = 1$ (linear demand). Table 8 shows the distributions of private value (V), consumer surplus (CS), total fees collected ($Fees$) and total welfare (TW) for both the current EP regime and the new UP regime. The last column, ΔTW gives the distribution of the total gains per patent from the new system. On average, UP increases total welfare by €5,665 per patent, but reduces total welfare for at least 25% of the patents. Consumer surplus per patent decreases (€193,246 in the current system and €182,104 in the new system) as UP increases the geographical scope and patent length of most patents and thereby the number of country-period-combinations where a monopoly prevails. Interestingly, the fees collected per patent will be significantly reduced with UP. The average renewal fees collected per patent under UP are €9,675, around half the fees collected in the current EP system (€17,358). Note that our calculations do not include the external margin, i.e., new patented inventions due to UP that would generate more renewal fees. These new patented inventions could increase the total income obtained from fees as suggested by Danguy and de la Potterie (2014).[16]

A similar table (Table A.4) for $\rho = -1/2$ can be found in Appendix A.5.

[16]Notice though that these marginal new patents would be low value, i.e., they would be renewed for a shorter amount of time than the current least valuable patents. Thus, the extra renewal fee income generated by them is likely to be low.

Table 8: Welfare calculation ($\rho = 1$)

Statistics	$\mathbf{V^{current}}$	$\mathbf{CS^{current}}$	$\mathbf{Fees^{current}}$	$\mathbf{TW^{current}}$	$\mathbf{V^{new}_{cf2}}$	$\mathbf{CS^{new}_{cf2}}$	$\mathbf{Fee^{new}_{cf2}}$	$\mathbf{TW^{new}_{cf2}}$	$\mathbf{\Delta TW}$
	Current system (only EPs)				**New system (UPs option)**				**Difference**
Q. 10 %	12,379	31,086	6,149	43,693	19,567	23,117	4,224	42,845	-1,566
Q. 25 %	30,518	48,498	10,290	79,199	41,148	38,396	7,266	79,825	-208
Median	76,900	83,798	16,051	160,867	92,370	70,739	11,230	163,435	2,443
Q. 75%	185,122	159,989	23,037	345,503	206,871	145,981	12,718	353,191	7,397
Q. 90%	407,600	317,324	30,261	725,672	435,120	305,431	12,718	740,936	16,443
Q. 95%	663,300	502,875	34,941	1,165,461	694,754	492,800	12,718	1,186,715	23,597
Q. 99%	1,838,672	1,386,920	44,207	3,222,940	1,880,094	1,383,328	12,718	3,261,837	43,839
Mean	229,659	193,246	17,358	422,896	246,456	182,104	9,675	428,561	5,665
Min	0	1,503	0	2,552	0	1,504	0	1,514	-10,197
Max	7.2 Bn	6.7 Bn	57,981	13.9 Bn	7.2 Bn	6.7 Bn	12,718	13.9 Bn	4,530,529
N	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200

In Figure 17, we decompose the average effect per patent by country. The upper-left corner shows on the x-axis the discounted sum of renewal fees collected from an average EP in the current regime, decomposed by country where the patent is in force. The y-axis shows the average percentage change in renewal fees collected. To allocate the total renewal fee income received from UPs among national patent offices, we use the assumption of distribution key according to the GDP considered by Danguy and de la Potterie (2014) as the most legitimate and easy to implement. Therefore, the share of UP fees are allocated to the NPOs based on the size of their economy (GDP). It is clear that most patent offices would be worst off as the renewal fee income will decrease. With this key distribution assumption, smaller NPOs (and smaller economies) such as Luxembourg, Denmark or Austria would be strongly affected whereas larger countries such as Italy or France would see an increase or a somewhat smaller decrease in revenues.

The upper-right corner of Figure 17 shows on the x-axis the total private value by nationality of the applicants and the average percentage gain on the y-axis. Applicants from Austria, Luxembourg, France, Italy and the Netherlands will have higher relative gains in terms of private value (around +10%) but also tend to have lower average total private value for their inventions (See also Figure 9). On the other hand, applicants from Ireland, Sweden, Portugal or Belgium who tend to have the highest private value for EP on average will have lower relative gains from the new system (around 6%).

The lower-left corner of Figure 17 shows the effect of UP on the consumer surplus for the countries where the patents are in force. In all countries (except 'other' which is mainly US and Japan, for which there are no effects), consumer surplus decreases. In France, Great Britain and Germany, the effects of the new system on consumer surplus smallest (less than 5%). The reason is that the EPs tend to be validated and renewed for longer periods in these countries and therefore, the UP will affect the renewal and validation decisions in these countries only marginally. On the other side, smaller countries such as Denmark, Greece or Luxembourg will larger consumer surplus decreases (18-24% reduction).

The lower-right corner of Figure 17 shows the total welfare effect (private value and consumer surplus) for all countries; these lie between 1 and 2%.

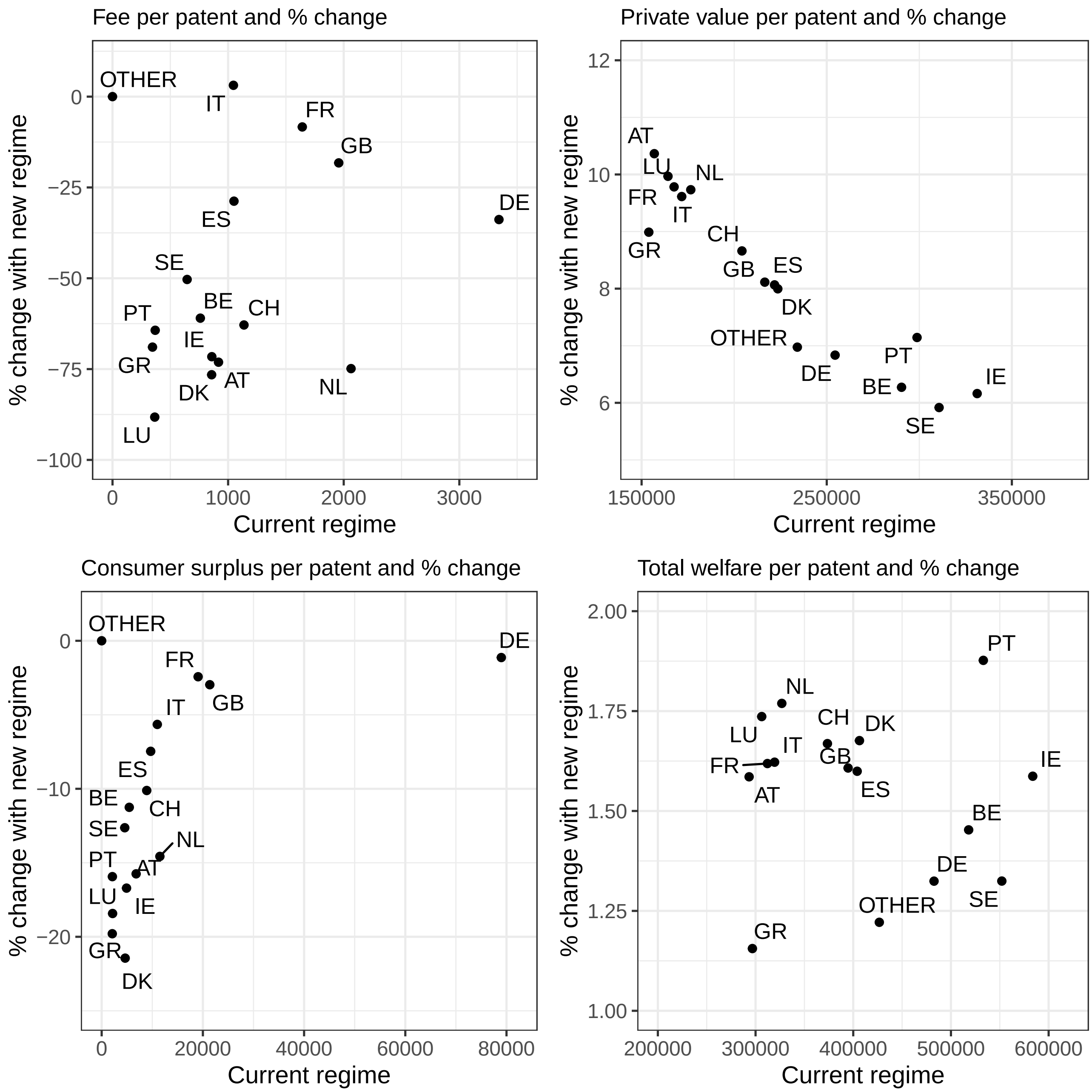


Figure 17: Effects of UP decomposed by country ($\rho = 1$)

Table 9 shows the total welfare in millions and relative to the population in 2000. Change in total welfare varies from €1.2M in Greece to €1,653M in Germany and €3,604M in the group "other countries". The total welfare change is particularly large for other countries because a significant proportion of patents are applied for by applicants from other countries (mainly the US and Japan, see Figure A.1). Relative to population, the welfare effects are highest in Switzerland, Luxembourg and Germany. The introduction of UP has a marginal effect on welfare per capita.

Table 9: Total welfare in both regimes, in €M and by population

	$TW^{current}$	TW^{new}	$TW^{current}$/pop	TW^{new}/pop
DE	1,653	1,675	20.16	20.43
GB	321	326	5.49	5.58
FR	373	379	6.34	6.44
IT	123	125	2.13	2.17
NL	167	170	10.27	10.45
ES	32	32	0.74	0.75
SE	171	173	18.93	19.18
CH	255	259	35.18	35.77
BE	113	115	10.81	10.97
AT	37	37	4.48	4.55
DK	77	78	14.14	14.38
LU	16	16	34.26	34.85
GR	1.2	1.2	0.11	0.11
PT	3.7	3.8	0.36	0.36
IE	26	26	6.19	6.29
OTHER	3,604	3,649		

7 Conclusion

We provide an ex-ante evaluation of the forthcoming introduction of the so-called unitary patent in Europe. Europe moves a big step towards a truly European patent system with this change. UP offers inventors the option of obtaining a patent which, as long as it is renewed, offers European-wide intellectual property protection. However, the system continues to offer the current possibility of obtaining a collection of national patents (the "European Patent"). These can be individually and separately renewed or allowed to lapse, offering thereby more flexibility to the inventor at the cost of higher renewal fees.

We extend the existing research on the value of European patents by estimating a patent renewal model that allows for free correlation of value across country-pairs. We use the estimated parameters to study whether inventors of chemical patents, applied for in 2000, would have taken up the possibility of a Unitary Patent instead of the then available European Patent. We find that the vast majority would have done so.

We find that the average private value of European Patents, summed up over all countries, is €229,659. The country-specific values are positively correlated, with correlations ranging from a low of 0.3 to a high of 0.8.

We then extend the literature by a adding a patent production function to the renewal model to study how much the quality of the existing EP patents would have increased, had UP been available in 2000. The average private value of these patents would have increased by €16,807. The vast majority of this comes from reduced renewal fees and increased duration of the patent, with increased geographical scope and improved quality both accounting for a small share.

As our final exercise, we study the welfare implications of the introduction of UP and, as a side product, a welfare evaluation of the current EP-based patent protection. We find that the total welfare increases by 0.4 to 1.9% on average which corresponds to €3,645 to €6,624 depending on the assumptions on the demand (ρ). This modest welfare increase hides a transfer of surplus from consumers to the inventors. In relative terms, Austrian, Luxembourgish, Dutch, French and Italian inventors gain the most while Danish, Greek, Irish and Luxembourgish consumers lose the most. Portugal and The Netherlands gain the most overall in relative terms.

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A.1 Renewal fees European Patent

All fees are expressed in euros 2010. See Table A.1.

A.2 Renewal and validation rates

Validation and renewal data are available in Table A.2.

[16]Note that a 15% reduction in the renewal fees are available for patent holders who file a statement on a licence of right with the EPO

Table A.1: Renewal fees in EUR 2010

Countries/Year	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th
Austria (AT)	78	87	113	121	166	209	297	366	445	559	628	698	1021	1283	1396	1746	2095	2095
Belgium (BE)	37	55	74	92	111	135	160	184	209	233	270	307	350	393	436	485	534	584
Denmark (DK)	82	180	204	229	261	294	335	375	416	457	498	539	588	637	686	735	784	833
France (FR)	38	44	61	121	150	180	209	239	270	303	340	380	424	472	523	578	637	699
Germany (DE)	82	82	106	153	211	282	341	411	552	728	893	1069	1245	1445	1657	1868	2068	2279
Greece (GR)	50	64	75	98	117	137	159	187	215	257	299	338	380	450	500	548	601	660
Ireland (IE)	75	112	142	167	187	220	242	275	302	331	356	388	418	444	477	509	547	584
Italy (IT)	39	45	58	84	116	161	193	226	322	451	516	580	709	709	709	709	709	709
Luxembourg (LU)	38	48	61	77	96	116	135	153	169	188	208	227	247	266	286	305	325	351
Netherlands (NL)	269	311	353	392	434	491	547	603	645	687	729	785	897	953	995	1037	1093	1135
Portugal (PT)	43	53	67	75	85	96	107	117	128	142	160	178	196	214	231	255	285	313
Spain (ES)	26	33	63	92	124	153	184	214	259	305	350	395	440	502	561	622	682	742
Sweden (SE)	45	64	77	96	115	134	153	185	217	249	281	313	345	383	421	460	498	536
Switzerland (CH)	75	89	105	119	149	178	208	252	297	343	402	460	521	595	670	744	892	1041
Great Britain (GB)	-	-	101	141	182	222	262	303	343	383	424	464	504	545	605	666	726	807

Table A.2: Survival rates and validation rate in per cent

	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Validation (%)
DE	99.9	99.2	97.2	93.9	89.5	84.5	78.5	72.1	65.6	60.1	54.9	49.6	44.4	39.3	34.3	29.7	24.6	89.1
GB	99.7	98.2	94.7	90	84.6	79	72.6	66.1	59.5	53.8	48.7	43.6	38.7	33.9	29.6	25.6	21.3	82.8
FR	99.9	98.4	95	90.2	84.9	79.2	72.8	66.3	60.1	54.5	49.3	44.2	39.1	34.4	29.9	25.9	21.5	82.4
IT	99.3	94.6	87.4	80.5	72.9	66.1	59.6	53.2	46.7	40.8	35.8	31.6	27.6	24	20.7	17.6	14.6	59.9
NL	99.2	94.1	84.3	72.9	62	53	45.6	39.3	34	29.5	25.8	22.5	19.4	16.8	14.5	12.3	10.2	45.1
ES	99.5	94.9	86.3	76	66.6	58.4	51.2	44.8	39.1	34.3	29.8	26.3	23	19.9	17.2	14.6	12.2	52.1
SE	99.1	92.2	80.1	66.7	54.7	45.3	37.9	32	26.9	22.8	19.5	16.6	14.3	12.1	10.4	8.8	7.2	33.5
CH	99.2	93.2	82.2	70	58.9	50.3	43.2	37.4	32.5	28.1	24.5	21.4	18.5	16	13.8	11.8	9.8	42.3
BE	99.3	93.5	83.1	71	59.8	50.8	43.5	37.2	31.7	27.4	23.5	20.3	17.4	15	12.8	10.9	9.1	41.6
AT	99.2	92.5	80.4	67	54.8	45.3	37.8	31.8	26.6	22.6	19.1	16.2	13.8	11.8	10.1	8.5	7	33.5
DK	99	91.1	77.7	63.1	50.6	41	33.8	28.2	23.4	19.7	16.7	14.3	12.2	10.5	9	7.6	6.3	27.9
LU	98.8	89.9	75.2	59.5	46	36	28.8	23.3	18.6	15.2	12.5	10.3	8.7	7.3	6.1	5.1	4.2	20.8
GR	98.8	90.1	75.6	60.1	46.8	37	29.6	24.2	19.5	15.9	13.2	11	9.3	7.9	6.6	5.5	4.5	21.5
PT	98.9	90.5	76.5	61.4	48.4	38.6	31.3	25.7	21	17.4	14.5	12.1	10.3	8.7	7.3	6.1	5.1	23.7
IE	98.9	90.9	77.6	63.3	51.1	41.9	34.8	29.2	24.6	20.7	17.6	15	12.8	11	9.3	7.9	6.6	29.8

A.3 Nationality of applicants

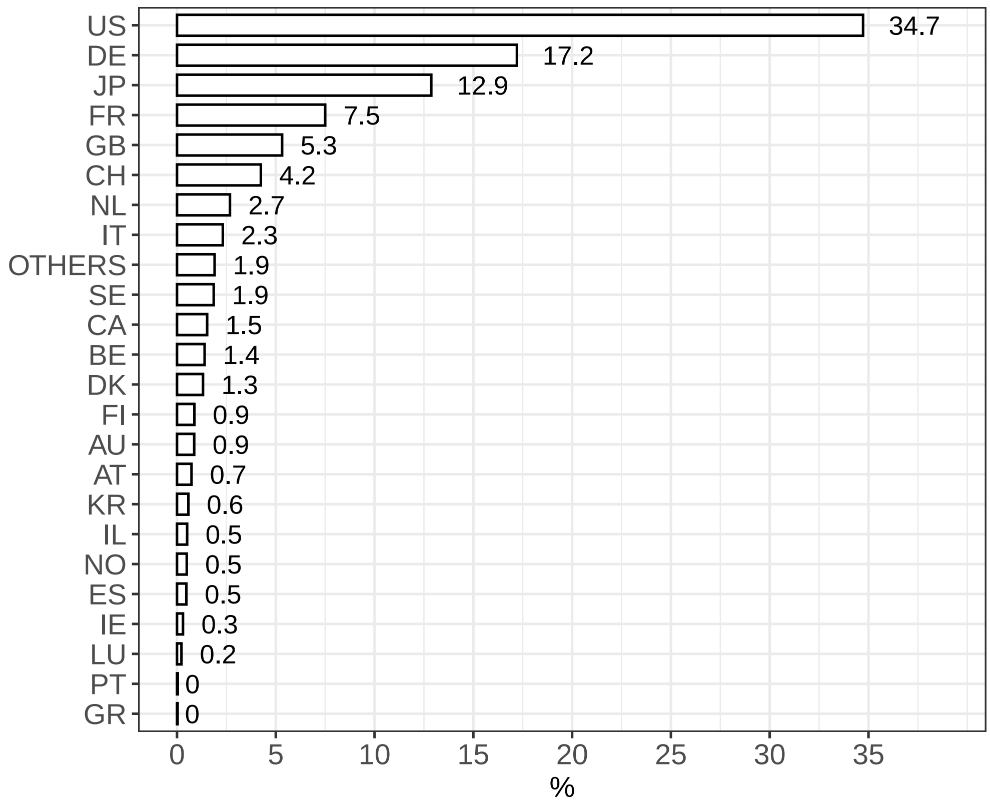

Figure A.1: Nationality of applicants - per cent

A.4 Estimates renewal model

Table A.3: Parameter estimates and standard errors

Param.	**Estimates**	**Param.**	**Estimates**	**Param.**	**Estimates**	**Param.**	**Estimates**
μ_{DE}	6.5321 (0.0641)	δ_{PT}	0.7644 (0.0009)	$r_{GB/DK}$	0.4900 (0.0855)	$r_{ES/LU}$	0.5840 (0.1235)
μ_{GB}	6.4861 (0.0568)	δ_{IE}	0.7963 (0.0043)	$r_{GB/LU}$	0.4451 (0.0592)	$r_{ES/GR}$	0.6264 (0.1561)
μ_{FR}	6.4411 (0.0280)	$\gamma_{FamSize}$	0.0432 (0.0006)	$r_{GB/GR}$	0.4511 (0.0703)	$r_{ES/PT}$	0.6496 (0.1412)
μ_{IT}	5.9909 (0.0248)	$\gamma_{Citations}$	0.0076 (0.0007)	$r_{GB/PT}$	0.4597 (0.0747)	$r_{ES/IE}$	0.6160 (0.1009)
μ_{NL}	6.4439 (0.0199)	γ_{IPC}	0.0056 (0.0005)	$r_{GB/IE}$	0.5033 (0.0738)	$r_{SE/CH}$	0.6958 (0.1706)
μ_{ES}	5.8848 (0.0298)	γ_{Claims}	-0.0061 (0.0005)	$r_{FR/IT}$	0.6880 (0.1223)	$r_{SE/BE}$	0.6995 (0.1948)
μ_{SE}	5.4954 (0.0417)	γ_{DE}	1.1095 (0.1024)	$r_{FR/NL}$	0.5528 (0.0026)	$r_{SE/AT}$	0.7540 (0.1842)
μ_{CH}	5.8602 (0.0471)	γ_{GB}	0.2573 (0.0638)	$r_{FR/ES}$	0.6153 (0.0532)	$r_{SE/DK}$	0.7889 (0.2011)
μ_{BE}	5.5881 (0.0420)	γ_{FR}	0.465 (0.0485)	$r_{FR/SE}$	0.5037 (0.1413)	$r_{SE/LU}$	0.7236 (0.1339)
μ_{AT}	5.7621 (0.0389)	γ_{IT}	0.2929 (0.0589)	$r_{FR/CH}$	0.5357 (0.0918)	$r_{SE/GR}$	0.7486 (0.2134)
μ_{DK}	5.5757 (0.0209)	γ_{NL}	0.6067 (0.0461)	$r_{FR/BE}$	0.5397 (0.0952)	$r_{SE/PT}$	0.7629 (0.1229)
μ_{LU}	5.0812 (0.0027)	γ_{ES}	0.4285 (0.0790)	$r_{FR/AT}$	0.4904 (0.1003)	$r_{SE/IE}$	0.7304 (0.1483)
μ_{GR}	4.9154 (0.0260)	γ_{SE}	0.6785 (0.0381)	$r_{FR/DK}$	0.4785 (0.0702)	$r_{CH/BE}$	0.6875 (0.1770)
μ_{PT}	5.1781 (0.0009)	γ_{CH}	0.6324 (0.0476)	$r_{FR/LU}$	0.4378 (0.0608)	$r_{CH/AT}$	0.7559 (0.1728)
μ_{IE}	5.8099 (0.0178)	γ_{BE}	0.5697 (0.0702)	$r_{FR/GR}$	0.4477 (0.0656)	$r_{CH/DK}$	0.7113 (0.1923)
σ_{DE}	1.7879 (0.0228)	γ_{AT}	0.8061 (0.0464)	$r_{FR/PT}$	0.4589 (0.0745)	$r_{CH/LU}$	0.6834 (0.1359)
σ_{GB}	1.6026 (0.0272)	γ_{DK}	0.4766 (0.0351)	$r_{FR/IE}$	0.4792 (0.0699)	$r_{CH/GR}$	0.6837 (0.1759)
σ_{FR}	1.6120 (0.0127)	γ_{LU}	-0.0831 (0.0500)	$r_{IT/NL}$	0.6113 (0.0991)	$r_{CH/PT}$	0.6951 (0.1409)
σ_{IT}	1.6444 (0.0493)	γ_{GR}	-0.1243 (0.2448)	$r_{IT/ES}$	0.7432 (0.1497)	$r_{CH/IE}$	0.7281 (0.0941)
σ_{NL}	1.3452 (0.0066)	γ_{PT}	0.2219 (0.2536)	$r_{IT/SE}$	0.5826 (0.1682)	$r_{BE/AT}$	0.7375 (0.1946)
σ_{ES}	1.6284 (0.0084)	γ_{IE}	1.0764 (0.0557)	$r_{IT/CH}$	0.5744 (0.1575)	$r_{BE/DK}$	0.7162 (0.2011)
σ_{SE}	1.5085 (0.0165)	$r_{DE/GB}$	0.7723 (0.0485)	$r_{IT/BE}$	0.6012 (0.1718)	$r_{BE/LU}$	0.6872 (0.1415)
σ_{CH}	1.5820 (0.0149)	$r_{DE/FR}$	0.8041 (0.0712)	$r_{IT/AT}$	0.5815 (0.1664)	$r_{BE/GR}$	0.6894 (0.1840)
σ_{BE}	1.5161 (0.0076)	$r_{DE/IT}$	0.6315 (0.1556)	$r_{IT/DK}$	0.5509 (0.1217)	$r_{BE/PT}$	0.7071 (0.1310)
σ_{AT}	1.5480 (0.0426)	$r_{DE/NL}$	0.5164 (0.2026)	$r_{IT/LU}$	0.5102 (0.1084)	$r_{BE/IE}$	0.7057 (0.1148)
σ_{DK}	1.3047 (0.0093)	$r_{DE/ES}$	0.5486 (0.3125)	$r_{IT/GR}$	0.5375 (0.1070)	$r_{AT/DK}$	0.7652 (0.2174)
σ_{LU}	1.4092 (0.0004)	$r_{DE/SE}$	0.4552 (0.0878)	$r_{IT/PT}$	0.5548 (0.1161)	$r_{AT/LU}$	0.7456 (0.1512)
σ_{GR}	1.3767 (0.0085)	$r_{DE/CH}$	0.4977 (0.1038)	$r_{IT/IE}$	0.5438 (0.0935)	$r_{AT/GR}$	0.7624 (0.2318)
σ_{PT}	1.3396 (0.0007)	$r_{DE/BE}$	0.4935 (0.0804)	$r_{NL/ES}$	0.6533 (0.0691)	$r_{AT/PT}$	0.7808 (0.1456)
σ_{IE}	1.3911 (0.0130)	$r_{DE/AT}$	0.4594 (0.1638)	$r_{NL/SE}$	0.6965 (0.1351)	$r_{AT/IE}$	0.7551 (0.1314)
δ_{DE}	0.9438 (0.0022)	$r_{DE/DK}$	0.4278 (0.0440)	$r_{NL/CH}$	0.6565 (0.1153)	$r_{DK/LU}$	0.7778 (0.1054)
δ_{GB}	0.8926 (0.0020)	$r_{DE/LU}$	0.3858 (0.0628)	$r_{NL/BE}$	0.7618 (0.0415)	$r_{DK/GR}$	0.8184 (0.1693)
δ_{FR}	0.8837 (0.0021)	$r_{DE/GR}$	0.3896 (0.0451)	$r_{NL/AT}$	0.6924 (0.1149)	$r_{DK/PT}$	0.8145 (0.1061)
δ_{IT}	0.8579 (0.0059)	$r_{DE/PT}$	0.4009 (0.0665)	$r_{NL/DK}$	0.7182 (0.1135)	$r_{DK/IE}$	0.7979 (0.1750)
δ_{NL}	0.8514 (0.0015)	$r_{DE/IE}$	0.4225 (0.0537)	$r_{NL/LU}$	0.6371 (0.1298)	$r_{LU/GR}$	0.8449 (0.0936)
δ_{ES}	0.8580 (0.0024)	$r_{GB/FR}$	0.7963 (0.0412)	$r_{NL/GR}$	0.6585 (0.0934)	$r_{LU/PT}$	0.8252 (0.0018)
δ_{SE}	0.8139 (0.0029)	$r_{GB/IT}$	0.6416 (0.0462)	$r_{NL/PT}$	0.6780 (0.1300)	$r_{LU/IE}$	0.7953 (0.0384)
δ_{CH}	0.8570 (0.0022)	$r_{GB/NL}$	0.5499 (0.0190)	$r_{NL/IE}$	0.6677 (0.0505)	$r_{GR/PT}$	0.8973 (0.0736)
δ_{BE}	0.8394 (0.0039)	$r_{GB/ES}$	0.5796 (0.0328)	$r_{ES/SE}$	0.6384 (0.1739)	$r_{GR/IE}$	0.8123 (0.0396)
δ_{AT}	0.8362 (0.0022)	$r_{GB/SE}$	0.5048 (0.1530)	$r_{ES/CH}$	0.6089 (0.1694)	$r_{PT/IE}$	0.8032 (0.0849)
δ_{DK}	0.8415 (0.0027)	$r_{GB/CH}$	0.5363 (0.0823)	$r_{ES/BE}$	0.6639 (0.1615)		
δ_{LU}	0.7659 (0.0006)	$r_{GB/BE}$	0.5209 (0.0907)	$r_{ES/AT}$	0.6475 (0.1903)		
δ_{GR}	0.8001 (0.0034)	$r_{GB/AT}$	0.4859 (0.1007)	$r_{ES/DK}$	0.6285 (0.1517)		

Note: Std. Err in parentheses

A.5 Welfare calculation $\rho = -1/2$

Table A.4: Welfare calculation ($\rho = -0.5$)

Statistics	$\mathbf{V^{current}}$	$\mathbf{CS^{current}}$	$\mathbf{Fees^{current}}$	$\mathbf{TW^{current}}$	$\mathbf{V^{new}_{cf2}}$	$\mathbf{CS^{new}_{cf2}}$	$\mathbf{Fee^{new}_{cf2}}$	$\mathbf{TW^{new}_{cf2}}$	$\mathbf{\Delta TW}$
	Current system (only EPs)				**New system (UPs option)**				**Difference**
Q. 10 %	12,379	81,160	6,149	93,706	19,567	70,630	4,224	90,342	-4,350
Q. 25 %	30,518	138,393	10,290	169,032	41,148	125,376	7,266	166,673	-3,097
Median	76,900	261,728	16,051	338,718	92,370	245,128	11,230	337,681	-964
Q. 75%	185,122	529,291	23,037	714,514	206,871	512,187	12,718	1,494,591	4,116
Q. 90%	407,600	1,071,963	30,261	1,479,960	435,120	1,059,570	12,718	2,386,142	15,357
Q. 95%	663,300	1,699,777	34,941	2,362,558	694,754	1,691,821	12,718	2,386,142	25,385
Q. 99%	1,838,672	4,638,663	44,207	6,481,369	1,880,094	4,653,082	12,718	6,536,392	60,051
Mean	229,659	633,499	17,358	863,149	246,456	620,338	9,675	866,795	3,645
Min	0	3,007	0	3,007	0	3,028	0	3,028	-14,033
Max	7.2 Bn	20.6 Bn	57,981	20.6 Bn	7.2 Bn	20.6 Bn	12,718	27.9 Bn	9,028,926
N	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200

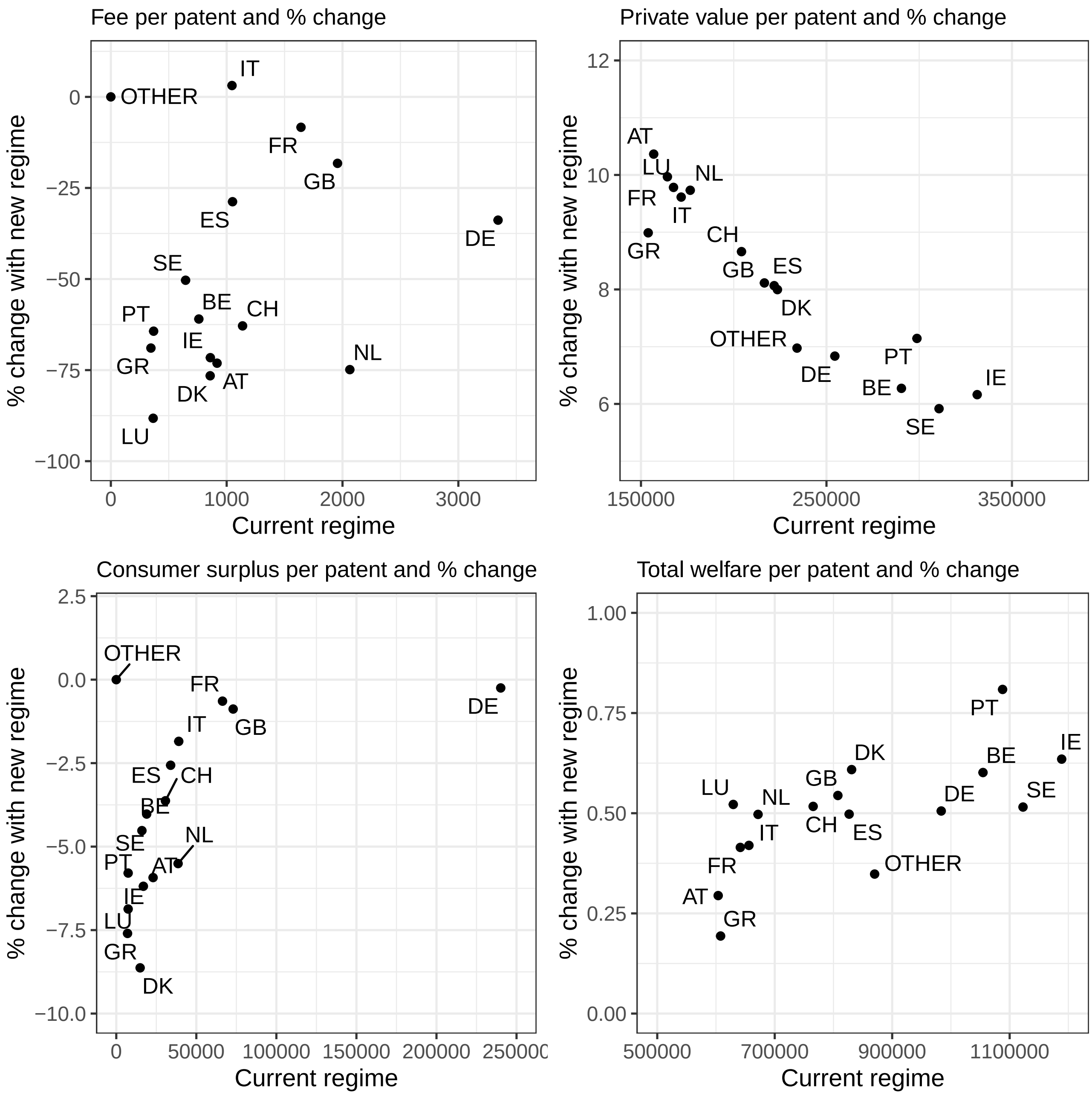

Figure A.2: Effects of the UPs decomposed by country ($\rho = -1/2$)

Table A.5: Total Welfare (in M € and by population) in both regimes ($\rho = -1/2$)

	$TW^{current}$	TW^{new}	$TW^{current}$/pop	TW^{new}/pop
DE	3,369	3,386	41.08	41.29
GB	657	660	11.23	11.29
FR	767	770	13.02	13.07
IT	253	254	4.38	4.40
NL	344	346	21.10	21.20
ES	65	66	1.52	1.52
SE	348	350	38.50	38.70
CH	523	525	72.09	72.46
BE	231	232	22.01	22.14
AT	75	76	9.22	9.24
DK	157	158	28.92	29.09
LU	33	33	70.39	70.76
GR	2.4	2.4	0.22	0.22
PT	7.6	7.7	0.73	0.74
IE	52	53	12.61	12.69
OTHER	7,352	7,377		