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Twenty Years of US Nanopatenting: Maintenance Renewal Scoring as an Indicator of Patent Value

Declarations

Availability of data and material
This article is based on bibliometric and text analyses of sets of nanotechnology-related research publication abstracts retrieved from the *PatStat* database. We provide information on the search routines used to locate, and then download, those records. Those instructions allow an interested party with suitable license to those databases to regenerate comparable datasets.

Code availability
Routines employed in the analyses are available via the analytic software used – *VantagePoint* [www.theVantagePoint.com] and *MS Excel*.

Abstract
This paper introduces a new measure of patent value – Maintenance Renewal Score (MRSc) – reflecting assignee valuing the patent by paying successive renewal fees. We generate MRSc's for nanotechnology patents issued by the US Patent Office from 1999 through 2009, with US assignees and US inventors. Patenting increases over this period, coincident with increased US funding of nanotechnology R&D. We compare maintenance rates over the period, and against a comparison set of all 1999 USPTO grants to US inventors/assignees. We find differences in propensity to maintain the nanopatents by institution type, technological sector, and patent complexity.

Keywords

Nanotechnology, nanopatents, bibliometrics, tech mining, patent renewals, maintenance renewal score

1. Introduction

Nanotechnology (**nano**) is big (excuse the attempt at irony). It entails molecular manipulation from single atoms to matter up to about 100 nanometers (1 nm = 1×10^{-9} meters) scale. US R&D funding through the US National Nanotechnology Initiative (**NNI**) approached \$2 billion per year (Figure 2). Nano has attributes of a general purpose Science and Technology (**S&T**), with applications in materials science and industrial uses of materials, biomedicine, and many other S&T domains [1]. Our searches, elaborated later, identify well over 1 million scientific nano publications in Web of Science and over 50,000 US patents. Nanopatenting has high impacts on technological innovation and the economy.

The NNI -- launched in 2000, with increased funding in 2003 -- expressly aims to advance "discovery, development, and deployment of nanoscale science, engineering, and technology to serve the public good…" Of five NNI goals, Goal 2 is to "Promote commercialization of nanotechnology (**nano**) R&D." That builds on Goal 1 -- for the US to remain a world leader in nano research and development – "through application-driven advanced research and development that leads to new products in the market" (https://www.nano.gov/2021strategicplan - accessed 04/19/2022). And the 2021 NNI Plan amplifies Goal 2: "to accelerate the scale-up, translation, and commercial application of nanotechnology R&D into the marketplace…." The Plan points to "interdisciplinary foundational research that will lay the groundwork for future technologies."

The NNI thus has key goals of nurturing, not just research, but invention leading to commercial innovation. Reflecting on various U.S. government R&D endeavors, this intent to promote commercialization is quite unique. Most Federal R&D support programs fund basic and applied research, even proscribing commercial promotion. The NNI innovation intent should translate into enhanced US patenting. An early assessment by Huang et al. [2], looking at 2001 to 2004, did indeed find that the NNI increased patenting.

Another unusual component of the NNI is the length of sustained funding. The NNI has been operating for over twenty years. Impact of federal funding on private sector patenting has been studied by researchers such as Mansfield [3], but little research exists on the impact of two decades of US government, ongoing innovation-focused funding by a major research program like NNI. Knowing evidence that the NNI increased patenting [2], and that the program has decades of sustained funding, motivates our effort to measure the nature of US patenting in the nano realm and to help assess how well this unusual effort is succeeding over time.

Further, "effective" patenting that fosters innovation is clearly a worthy indicator to track. Higham et al. [4] offer a general caveat, "most patents are simply not worth very much." That concern underlies this paper's thrust to measure both nanopatent quantity and value, thereby to indicate multiple facets of how well US nano invention is growing. To measure patent value, we devise a new measure – Maintenance Renewal Score (MRSc) – more on value and maintenance in Section 2.2.

2. Background

2.1. Patent Analyses – General Considerations

A variety of patent data resources are available, so "which to use?" is a first question. In this study, we concentrate on US patents since our focus is on the NNI. In addition to patent data, we need maintenance data. To capture both, we use IISC PatStat (www.patstat.org), a version of EPO's PatStat database hosted by a partner organization. PatStat contains both patent data and INPADOC legal events data, which allows us to capture both patenting activity and maintenance payments. The PatStat database also contains additional information not typically captured in patent databases, such as assignee sector and NACE classifications.

Porter and Newman [5] favored Derwent World Patent Index (DWPI) data for its inclusion of indexer rewritten abstracts and family structure, which convey topical content better than original patent documents prepared by applicants. However, since this study does not require such topical analysis, the PatStat global database is a better alternative, offering a rich set of fields, especially for calculation of patent maintenance (renewal) activity. Through an Application Programming Interface (API), we also enrich the PatStat data by tapping into Bureau van Dijk (BvD) ORBIS corporate information resources. Additionally, with the IISC version of PatStat, we can analyze the entire PatStat database to enable exploration beyond a given topical search set – e.g., to pursue ramifications of patent activity.

Development of patent analysis capabilities and resources aims mainly toward one or the other of two key aims – sharpened patent searching or interpretive analytics. Our interests lie in the latter – seeking to derive useful Competitive Technical Intelligence (CTI) from patent data resources using advanced tools – i.e., "patent informatics" [6, 7].

2.2. Patent Quality, Value, and Maintenance/Renewal

One dimension of particular interest is patent quality analysis [8, 9]. From a patent office perspective, quality commences with the novelty and inventiveness reflected in a patent's claims, extending to legal defensibility and technical merit [10]. From broader perspectives, Trappey et al. [11] indicate that various factors bear upon patent "quality." These include investment, transactions, litigation, and maintenance. They note that CHI Research used several quality indicators in assessing patent portfolios for investment [12]. These indicators include recency, growth rate, and impact. Drawing on Barney,[1] they identify indicators relating to various quality aspects: number of independent claims, claim length and length of written specification, priority claims, and forward and backward citations. Backward cites can reflect technology absorptive capacity, another potential indicator pertaining to quality [13].

Patent quality is not identical to patent value, but the concepts surely overlap. There are multiple facets of each that one might consider. In our current analyses, we seek to measure value in terms of inventive activity apt to lead to commercial nano innovation. Relying simply on patent counts is less than ideal because this fails to distinguish the value of those patents. Patent value measures could aid in getting a clearer picture of different players' relative contributions, and renewal rates, in particular, have been employed as such a measure [14]. Hu et al. [15] used patent maintenance status and citations as quality measures. Ploskas et al. [16] explore eight criteria for patent evaluation.

Wang and Hsieh [17] review some 40 candidate patent valuation measures, including forward citation, as did Tahmooresnejad and Beaudry [18], including maintenance measures. Wang and Hsieh treat market valuation measures also, including licensing fees, royalties, and estimates of competitive advantage resulting from the patent -- such measures lie beyond our data resources in this study.

Higham et al. [4] ask "how should we define and measure patent quality?" They note overlapping concepts – importance, impact, value, or significance. They distinguish legal quality (likelihood of surviving a legal challenge) as distinct, and hard to pursue due to the rarity of such legal actions. Also, evidence of commercialization is important, but difficult to address because data are highly diffuse. Both ex-ante and ex-post measures may well be of interest.

"Maintenance" (i.e., renewal – paying the required fee to keep a patent in force) is a particularly attractive measure in this study, as it indicates that the assignee places explicit value on securing that patent protection into the future. [While relatively rare, it should be noted that if maintenance fees are not paid on time, a patent can be reinstated by the owner involving a petition process showing that delay was unintentional and fees are paid.[2]] Graham et al. [19] note that, in the U.S., maintenance pertains to utility patents, not to plant or design patents. Hegde and Sampat [20] note that maintenance of a patent is a compelling measure of its value.

Various others have found patent renewal data useful in estimating the value of protected innovations (c.f. [18, 21, 22]). In particular, Tahmooresnejad and Beaudry [18] argue that patent maintenance data give more valid indication of the value of investment in nanotechnology research than just using patent counts.

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[1] J.A. Barney, Statistic measurement of patent quality, Ocean Tomo, LLC. <http://www.oceantomo.com> -- accessed 04/19/2022, 2010.

[2] See "Reinstate an expired patent" at https://www.uspto.gov/patents/maintain -- accessed 04/19/2022.

Maintenance behavior can present measurement challenges in that maintenance events present decision points during the years of a patent's life (currently 20 years from first filing in the US). The motivation to pay the first maintenance payment, versus the final payment years later, is subject to exogenous events that often have little to do with the patent. As noted by Hwang et al. [50], patents up for renewal are subject to unpredictable changes in perceived value.

Maintenance payments are also not uniform across patent authorities. For this reason our analysis is limited to the USPTO. Even within a single authority, fees associated with maintenance payments change over time due to changes in patent policy. For a given USPTO patent, renewal fees increase from the initial to last period. Also, one should note that the government mandated fees often represent a fraction of the actual costs of a renewal event. Lawyers are often engaged to complete the requirements, often charging more to fill out the paperwork than the renewal fee itself. Despite these challenges, maintenance activity is a useful measure and one that has been studied. Pakes [23] and Pakes and Simpson [24] provide useful guidance for expected maintenance behavior over time, as well as by technology area. We believe that assessment of this renewal activity, beyond counting patents per se, is critical to interpreting nanopatenting activity.

We should emphasize that we are not conflating patent value with patent "strength" – another common patent dimension of interest. Strength relates to how others view a patent (citation, etc.), whereas value covers both how the assignee and, if transaction data (royalties, license fees, etc.) are available, others view the patent. Kwon [25] notes that the rate of maintenance on "weaker" patents is often higher than on "stronger" patents. Thus, a patent can be weak, yet valuable to the assignee.

In the context of NNI, maintenance is a particularly useful measure. Nanotechnology is a technical sector where universities are particularly active in patenting [18]. For example, based on an exploration of US grants in 1999, using PatStat Standardized Assignee Sectors, 18.1% of nanotechnology patents were from universities. In contrast, across the entire population of 1999 US grants, only 4.6% of patents were from universities. This was before the launch of NNI. We are curious whether this engagement by universities in the patent system led to universities maintaining their patents at a similar rate to companies. In other words, did universities "value" their patents the way firms do, or were they "patenting for the sake of patenting"? For instance, perhaps, filing for patents, to which NNI support contributed, might build goodwill in seeking further NNI funding whereas paying maintenance was outside the scope of grant funding.

Research on maintenance does necessitate patience. Recording maintenance events requires the passage of years post-grant of a patent to generate usable data. Thomas [26] cautions that renewal arrangements vary significantly across patent authorities. USPTO renewal is at 3.5 years to secure patent protection through year 8; next renewal due at 7.5 years, secures through year 12; and last renewal at 11.5 years, to secure for the remainder of US patent life – formerly through year 17 from grant; since 1995, through 20 years from filing. USPTO fees increase for successive renewals.[3]

Given the need for approximately 12 years post-grant to observe whether a US patent is maintained through full term, we are interested in predictors of maintenance that come available earlier. Van Zeebroeck [27] studied European patent renewal patterns, finding high sensitivity to patent policies and changes made to those policies. Wei et al. [28] analyzed predictors of patent maintenance. Earlier, Thomas [26] studied factors affecting US renewal rates. That study of 189,359 patents issued from 12/12/1980 through 12/17/1985 provides base renewal rate information:

- 4 year: patents never renewed [15.6%]

[3] As of March, 2022, USPTO fees are $2,000 for first renewal (at 3.5 years); $3,760 for second renewal (at 7.5 years); and $7,700 for final renewal (at 11.5 years). Small entities pay half those fees; micro-entities pay one-quarter those fees.

- 8 year: patents renewed at 4 years, then allowed to lapse [24.5%]
- 12 year: patents renewed at 4 and 8 years, then allowed to lapse [20.5%]
- 17 year" patents renewed at all three points [39.4%]

So for this early 1980's cohort, some 84% of patents were renewed at least once; almost 40% were renewed through maturity (the maximum available protection period).

US renewal rates vary markedly by field. Thomas [26] illustrates with full term renewals for three IPC subclasses on those early 1980's patents as low as 13-15% in certain patent subclasses. At the other extreme, three subclasses renewed full term at 60-62%. So, one must take great care in cross-field comparison. Other researchers have studied US patent maintenance in particular fields [29].

In personal correspondence, Alan Marco, formerly Chief Economist of USPTO, says about 50% renewal rate for full term is the right ballpark. Highest renewal occurs in electronics (vs. lower in mechanical and biochemical).

Serrano [30 -- published in 2010] reports expiration rates before full maturity (12 years) for patents issued 1983-2001 (so full-term data are not available for grants in the later years of the group). Flipping to look at renewal rates, he finds 40% of small and 50% of large company assignee patents maintaining through full term. He also breaks out by companies' technology field: highest for computers & communications companies – 55% maintained full term -- and lowest for "Other companies," 40% maintained through 12 years (3 renewals).

Bessen [31] examined 1991 USPTO grants. Overall, 42% were maintained full term. Using USPTO entity status, 48% were renewed 3 times by large entities vs. 25% renewed 3 times by small ones. By technology category, computers & communications led at 53% full term, with "Other" as laggard at 33%. In between were mechanical (47%), drugs & medical (44%), chemical (41%), and mechanical (39%). So, Serrano's and Bessen's renewal results are consistent with Marco's overview and our results for 1999 data – *about 50% renewal through term, with larger firms and certain technology domains more apt to maintain through full term*.

2.3. Patent Analyses – Other Aspects

Other measures abound. We consider them in two categories – patent quality measures and other measures of interest. Figure S1 (provided in the Supplemental Materials) offers a screenshot of *VantagePoint* [www.theVantagePoint.com] software showing the summary view of the 2820 abstract records of the 1999-2009 cohort of USPTO grants with a US inventor and assignee located in the US. The Figure shows only some of the data fields available – a number of fields generated by manipulations within *VantagePoint* (e.g., "::Maintenance Renewal Score") and a partial alphabetical listing of other fields (up to the letter "C"). Some fields offer an option to break out "child" fields – see "Citations" shown in Figure S1.

This paper does not address a number of measures treated in the literature [c.f., 8]; we mention some here. Forward citations (to the patent under study) [c.f., 10] indicate strength and likely relevance to further invention. Tallying the number of such cites, by whom (self or others), and the dispersion across fields are some candidate forward citation measures (c.f., [11]). However, *c*itations accrue over time since grant, posing challenges in tabulation and comparison. Citation rates also vary by technology space. The field of nanotechnology covers a wide range of application areas, meaning comparison of citation rates between nanotechnology created in two different fields of application would be problematic.

Alcacer et al. [32] documented that in the US, patent examiners accounted for some 63% of cites for 2001-2003 patents. Hegde and Sampat [20] find that examiner (more so than applicant) citations to a patent are positively related to maintenance fees being paid. Examiner citations to a patent indicate its scope in terms of the number of inventions it potentially blocks. Hence, those should associate with higher tendency to renew, thereby offering a potential ex ante quality measure. However, consistent flagging of examiner cites versus applicant cites within online patent data is problematic because inventor cites are most common in USPTO patent behavior. Within some authorities, such as the European Patent Office (EPO), almost all cites are examiner cites. This difference is due to the variation between the legal frameworks of various patent offices.[4] The US is a maximum disclosure authority. Inventors are penalized if they fail to cite prior art, if they are aware of it. The EPO is a minimum disclosure authority, so most cites are from the examination process.

Given the data challenges for other potential indicators, we selected maintenance as the prime, practical value indicator for this particular study. Even though it is not without issues, US maintenance activity is included in the INPADOC legal status data with full coverage for the time period of interest to us. This coverage enabled us to examine relationships between the two general measures -- patent grant counts and "alive" patent counts by each of the four renewal periods. We then examine other measures in relation to such patent maintenance. Our selection criteria for the variables include availability of the data via PatStat (enhanced with a BVD ORBIS API) and refined via VantagePoint tools (Figure S1, in Supplemental Materials, offers a sense of the fields available), driven by our interest in gauging US nanopatenting over time.

2.4. Nanopatent Analyses

Our group's prior paper by Youtie et al. [33] described efforts to compile abstract publication and patent records pertaining to US nano R&D.[5] That paper keyed on "corporate entry" into nano R&D, by US city and state, over time. Shapira et al. [34] compared corporate nano publishing and patenting, finding a shift in the early 2000s. National, compared to international, innovation measures were found to be more influential in predicting corporate patenting. In contrast, this paper pursues the issue of US nanopatent valuation in relation to an array of factors. We are interested in corporate and other (e.g., academic) patenting as well.

We note prior nano patent studies of particular interest. Huang et al. [35, 36] profiled the growth of USPTO patent activity by topical area and nationality. Roco [37] included USPTO patenting growth as an indicator to help understand nano development 10 years after the inception of the NNI. He noted strong (35%) annual growth in patent activity from 2000 to 2008. Updates [38, 39] addressed patents, as well as publications, particularly noting international gains in nanopatenting. Tahmooresnejad and Beaudry [18] focused on Canadian academic nanopatenting in the USPTO. Others have presented nanopatent analyses drawing on international patenting (e.g., European Patent Office activity), noting fast growth of China, South Korea, and other Asian patenting [40, 41].

3. Data

3.1. Overview

The driving motivation for this study was to investigate whether the US nanotechnology funding initiative (NNI) influenced patenting. As introduced in Section 1, it is strikingly rare for a US National Science

[4] "The Patent Guide" from the Informatics Team of the United Kingdom Intellectual Property Office has an excellent illustration of citation variation in the Citations section. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/463319/The_Patents_Guide_2nd_edition.pdf -- accessed 04/19/2022.

[5] This research drew support from a supplement to the NSF project noted (see "Funding").

Foundation (NSF) funding program to allow, no less have as a prominent objective, to support R&D serving commercial innovation. As such, determining if the NNI fostered increased patenting is of particular interest. As laid out earlier, our inquiry sought to measure quantity of nanopatenting over time and, particularly, patent valuation. Further, Section 2 offered the background leading us to focus on the extent of maintaining those patents as an indicator of patent value.

Our keen data challenge was to gather patent maintenance data, as discussed in the following sections.

3.2. Dealing with Renewal Count Data

Our novel measurement effort is generation of what we call MRSc's – Maintenance Renewal Scores. This key methodological element is quite straightforward – we count how many times a given patent is renewed – from 0 to 3. Furthermore, a patent must be renewed for the initial term beyond year 4 to be able to be renewed beyond that. So no patent is renewed for period 3 without being done so for periods 1 and 2.

Consider the nature of these data – they are "count data," representing financial transactions. The initial patent grant provides protection for 4 years; the available USPTO renewals offer:

- the first renewal, adds 4 years (through year 8), for a fee of $2,000
- the second renewal, 4 years (through year 12), for a fee of $3,760
- the third renewal, 8 years (through year 20), for a fee of $7,700.

Small entities (organizations) pay half those fees; micro-entities pay one-quarter.

How to handle renewal activity? We choose to do so on a renewal action basis – counting the number of such actions – 0, 1, 2, or 3. One could, instead, tally the renewal fees paid, thereby weighting later renewals more heavily. That is not intuitively attractive. Also, adjusting for lower fees for smaller organizations is not very appealing; the fees are lower because USPTO recognizes that the cost tends to weigh more heavily on smaller organizations.

Or, one could weight by the term, making the third renewal count more as it is (usually) longer (since 1995, when USPTO policy changed; see Footnote 6). Again, that feels less attractive at getting at patent value than counting each renewal equivalently – as a decision "unit."

In treating renewals this way, we recognize that there are underlying data attributes to take into account. For one, we are not sampling from a larger population of events, which we seek to use statistical inference to represent. Our dataset constitutes all the recognized US nanopatents meeting the requirements noted. Also, our data don't entail a distribution of a sample of observations. If we did, then we would want to address the non-normal distribution of such count data (e.g., use of linear regression modeling would pose concerns, so one might use Poisson regression). We have modest numbers of count data – i.e., the number of renewals for a given patent, ranging from 0 to 3. Our data can take only the non-negative integer values (0,1,2,3), so directly presenting counts for each is quite manageable.

Given that we are not generalizing to a population, we present simple count comparisons for our various categories. For instance, consider Table 3 that examines renewal activity by institutional type. We choose to present the central tendency using the mean as our primary measure (MRSc), augmented by the distribution of renewal counts – 0,1,2,3. This combination allows us to consider the patterns with respect to particular interpretations. Imagine that, perhaps, economic climate and/or technological maturation changes promote different renewal patterns. Interestingly in Table 3, we discern that universities are less likely to never renew their nanopatents, but also less likely to renew through full term. A non-parametric test would compare entire distributions, not just medians, but doesn't provide the nuance of seeing the counts for the separate renewal values. Because we are not trying to generalize to a population, our analyses are straightforward tabulations presenting the means for these relatively flat distribution count data (MRScs), with the percentages of patents renewed 0, 1, 2, or 3 times.

In addition, we gathered data on other patent attributes so as to analyze their relationship to patent maintenance. As per Section 2.1, this was done largely within our PatStat database, augmented with BvD ORBIS organizational information.

3.3. Nanopatent Data Search Background

A key task in R&D profiling is to identify the more pertinent documents reflecting the target domain. Over the years, the Georgia Tech Program in Science, Technology & Innovation Policy (STIP), often collaborating with Search Technology, has worked on how to design data search strategies for various emerging technologies [c.f., 7, 42]. In so doing, it can be advantageous to combine key term Boolean searching and patent code (e.g., IPC) search criteria. For instance, colleagues incorporated over 140 terms and nearly 1,000 IPC or CPC subcodes (e.g., G06F 8/33 level) in searching for Artificial Intelligence patents in the PatentSight database [c.f., 10].

Our research group has devised and refined a Boolean search strategy to retrieve nanotechnology research [43]. This paper's Supplemental Materials present this strategy, adjusted for patent searching, as Table S1. A follow-on exclusion stage removes documents referring to "nano" with respect to size or non-engineered matter, and various unrelated concepts and noise, for our purposes (e.g., "$NaNO_2$" – is sodium nitrite, not nano). Tables S2 & S3 present the exclusion terms (provided in Supplemental Materials).

Additional rounds of nano analyses have updated the original "nano" search to capture changes in the field, such as two-dimensional nanomaterials (e.g., graphene) [44, 45, 46]. Huang et al. [47] reviewed six nano search strategies, finding our 2008 version well-positioned -- "middle of the road."

Preliminarily, we examined 1991-1995 applications to USPTO. We considered what information to use to separate US patent activity. One could consider location of inventor, assignee, or filing authority. In this sample dataset, inventor country coverage was only 55%; same for assignee country.[6] We therefore start with applications -- patents filed with the USPTO. In addition to those practicalities, this has legal support in the requirement that first filing should be in the country of invention, although this is not applied universally. Within the USPTO *grants*, we located a subset for which the assignee was US – and -- at least one inventor had a US address.

3.4. Nanopatent Data

In April, 2020, we searched for nano-related patents using www.PatStat.org. The latest available version of PatStat was the Autumn, 2019, edition. The COVID-19 pandemic contributed to uncertainty and delay in updates of PatStat. This provided data through 2018, with partial 2019 coverage. Our analyses start with patent application level data, consolidating to the family level as suitable. When addressing families, we use the INPADOC Family information provided in PatStat.

As just noted, we constructed the PatStat nano search based on the Georgia Tech (**GT**) nano search strategy – see Wang et al. [45] for details on use in the Web of Science (**WoS**) database. We migrated the search strategy to apply it to the PatStat database, using www.PatStat.org. The syntax works directly. We adapt the strategy by dropping two modules -- the WoS Category search and nano journal search -- and adding a patent classification module to search for B82* in the PatStat IPC field (Table S1).

[6] Data on Assignee country varies by patent authority – e.g., of 3366 Japanese patents, PatStat reports Assignee country for only 19; for Canada, 416 of 536; for China, 159 of 229, but for the US, 2060 of 2063.

Table 1 steps through choices made in searching and treating the PatStat data. Some points of note:

- Search all records (applications and grants); all modules reflect search in the Title and Abstract fields, except for the module that searches for B82* *[where "*" indicates wildcard]*.
- Search for the nano class B82*, in the IPC field, that is used by all patent offices; we determined not to separately search in the CPC or Japanese FI and F-Terms fields.
- Download all available fields; PatStat does not have Claims.
- Most analyses are consolidated to the Family level (consolidating same or highly similar inventions filed in multiple patent authorities); we analyze Family using the extended INPADOC families. In the current analyses, we use this to distinguish US-only patents from "international" patent families that contain US and at least one other patent authority.
- To get at priority patents, we identify the application within a Family with the earliest filing date.
- In the "Application Kind" field, remove "U" (Utility Models – there are relatively few) records.

Table 1. Nanopatent File Progression

Step #	Action	Date Modified	Size
1	Download full nano query from PatStat	4/22/2020	15.1 GB
2	Remove years prior to 1991	4/22/2022	14.8 GB
3	Remove less stringent Patent Kind = U	4/23/2022	14.4 GB
4	Run scripts to get earliest patents in family	5/5/2022	14.6 GB
5	Remove duplicates → 439,021 Families (INPADOC)	5/14/2022	8.6 GB
6	Remove nano noise (Matlab) → 287,684	5/20/2022	6.4 GB
7	Put back records containing query module terms [151,337 removed from the 439,021 by Matlab → 350,924]	5/22/2022	6.0 GB
8	Add back from the outtakes (151,337 reduced to 91,822): B82*'s = 371,530; Remove from the 371,530 -- 939 Mengjun Yang & 128 fire extinguish/retardant patents that don't include "graphene, fullerene, or C60" → 370,463 [nanopatent Families without nano* junk]	5/24/2022	8.4 GB

The file is downloaded in *VantagePoint* format ("vpt") and is quite large. We used VantagePoint software (www.theVantagePoint.com) to refine and analyze the data for the present study.

In February, 2022, we ran a new PatStat search to update the maintenance data via these steps:

1. Start with the 370,463 INPADOC families (from Step 8 in Table 1).
2. Filter by US patent numbers = 55,469 (to remove all non-US patent numbers)
3. Filter by Assignee Country Code for US = 25,639 records (to remove all non-US assignees)
4. Filter those by Application Country Code (earliest priority) for US = 17026 (to restrict to records for patents first filed in the US).[7]
5. Filter those by Publication First Grant = 13,187 (restricts to patents granted).
6. Filter by MatLab removal (see Table 1) = 9671 (to remove non-nanotechnology content – see Tables S3 & S4).
7. Filter to US Inventor address = 9384 (to restrict to at least one inventor located in the US).
8. Pull those 9384 Families (INPADOC) to give those US patents and their family information.
9. Extract the "PatStat Applin_Id's" from the 9384 records.[8]
10. Query PatStat, Autumn, 2021, edition using the Applin_id's.
11. Download the resulting data file. This file contained the updated maintenance information for the records we are interested in, plus all the global family members.
12. Run a list comparison[9] in VantagePoint to find the US Patent Numbers common between the old and updated data. This process removes all the non-US family members from the data.

[7] This removes foreign filers who have a US IP base. For example, Unilever had a US IP holding company, but first filings are from the country where the R&D lab was located – the UK.

[8] "Applin_id's" are the only identification numbers consistent between releases of PatStat.

[9] "List comparison" described in Tip 5: Identifying Your Competitors Differences and Similarities Using VantagePoint List Comparison. https://www.youtube.com/watch?v=V82qkzFCDzU&t=544s – accessed 04/19/2022.

As noted, we updated our nanopatent dataset in February, 2022. The version of PatStat available was dated Autumn, 2021. Given that full-term renewal payment is due 12 years post-grant, this implies that our maintenance data should be complete for 2008 grants. We push this envelope to examine 2009 grants as well here.

4. Methods

4.1. Calculating Maintenance Renewal Scores (MRSc's)

MRSc reflects the number of times that a US patent assignee pays the USPTO fees to renew the patent. Calculation entails a simple count of the number of times the assignee pays the renewal fee. An MRSc of "0" indicates no renewal, so the patent goes in force for 4 years; "1" indicates paying to keep the patent in force through 8 years; "2," extending patent protection through 12 years; and 3, through full term.[10] The MRSc calculation is straightforward. For example, in Table, to get an MRSc score for the 105 patents granted in 1999, we multiply the 15 with 0 renews by 0; the 20 with 1 renew by 1; the 19 with 2 renews by 2; and the 51 with 3 renews by 3. Tallying up, 0 + 20 + 38 + 153 = 211. Dividing that by 105 gives MRSc = 2.01.

So, for a set of patents, if they are all maintained to maturity, the MRSc = 3.0. If on average they maintain through 2 renewals, the MRSc = 2.0. Likewise, renewing on average just once gives an MRSc of 1.0. Note that one can get a particular intermediate score various ways. For example, in a set of 10 patents, were 5 maintained through all 3 renewals and 5 renewed once, MRSc = 2.0. But imagine another set of 10 in which all were renewed just through 2 periods; the MRSc = 2.0 as well.

4.2. US Patent Maintenance Baseline

As a baseline for examination of US nanopatents, we examined all 83,523 USPTO grants (not limited to nano) in 1999. We imposed three criteria --US earliest priority, US assignee, and at least one US inventor. Of those, 52.5% paid all three fees – i.e., they renewed through to maturity. We found 16.1% renewing through 2 payments; 17.0% through just 1 renewal; and 14.5% not renewing at all. This is notably higher maintenance than Thomas reported for the earlier (1981-1985) data just noted. This difference might be due in part to our limitation to grants for US sourced activity. It is not clear from Thomas if the analysis is on US priority grants or all US grants. The inclusion of foreign filings could have significant impact on maintenance rates. The motivation for renewal in the US can be very different for foreign filers.

4.3. Processing the Nanopatent Data

In the early years covered in these analyses, the INPADOC Legal Event Code "FPAY" was used to indicate payment of a US maintenance fee. This code was supplanted by INPADOC Legal Event Code "MAFP" in 2018. In order to account for this switch in data categorization, all instances of MAFP were converted to FPAY. We spot-checked records against legal status data from Google Patents for confirmation. It was determined that this approach did not result in any double-counting of maintenance events.

Maintenance Renewal Scores are presented in a coming section. Those draw upon this consolidated field of maintenance fee payments to tally the instances of such payments for each patent. This value ranges from 0 – no renewal of the patent – to 3 – payments logged for 1, 2 or 3 periods to extend patent protection.

[10] In 1995 patent term calculations changed from 17 years after grant to 20 years from first filing.

5. Results

5.1. US Nanopatenting

Based on the PatStat search described in Section 3, we now analyze US nanopatenting over the period 1999-2009. We restrict to patents granted by the USPTO, with a US earliest filing, from US assignees with at least one inventor having a US address. This process removes foreign filings and should limit the inventive activity to only that which most likely occurred in the US, to match the funding target of NNI. We do gather select information from the patent families associated with those US grants for use as an indicator. The 1999-2009 period is of special interest because of the enactment of the NNI in 2000 and marked increase in its funding from 2003. And, the availability of information on patents and attendant legal activity (i.e., renewals through 12 years post-grant) limits these analyses to 2009 and earlier.

To provide some overall context, Figure 1 presents the trend in US nanopatenting (i.e., US priority, by US assignees, with at least one US addressed inventor) across a longer time frame. We note an over three-fold growth in US nanopatenting over this period. That would be considered very desirable, as per the NNI charter. The upward arrow in the Figure locates the NNI funding initiation, as a point of reference.

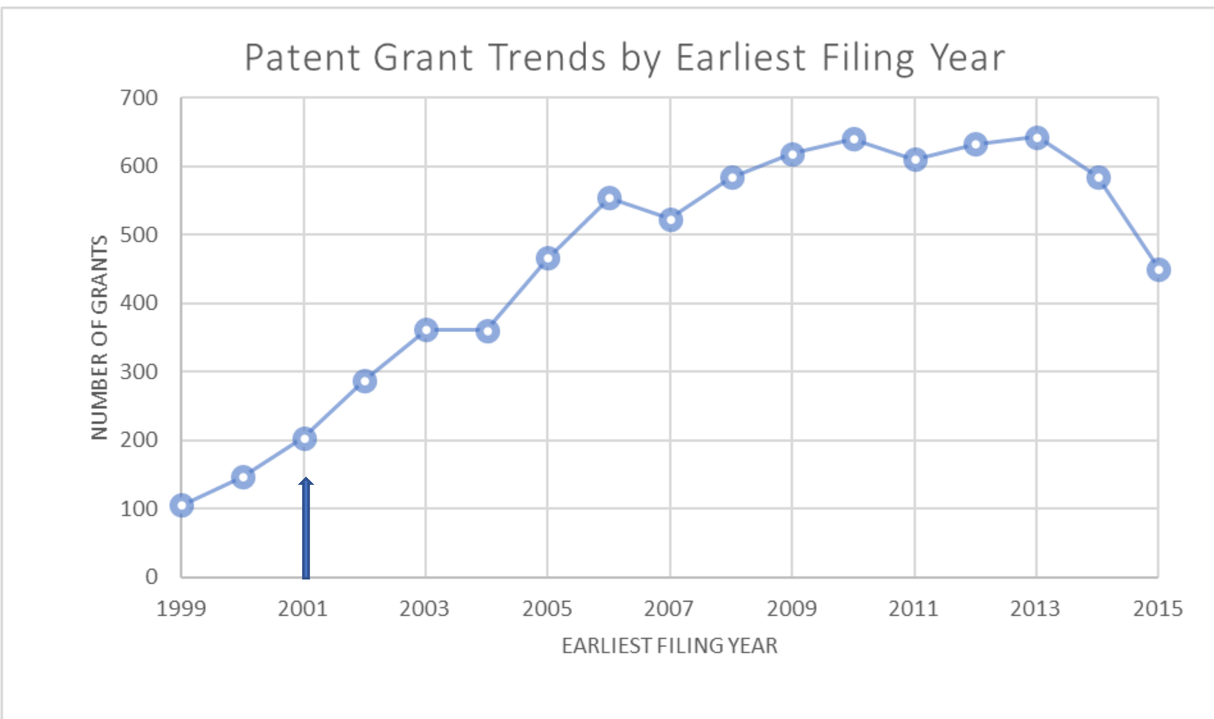

Figure 1. Growth in US Nanopatenting based on Earliest Filing Year, from 1999 to 2015

Figure 2 shows the trend (current $millions, circa FY2015) in US Federal R&D support (multi-agency) pursuant to the NNI. Growth is strong. The correlation of the NNI funding from 2001 through 2015 with patents granted for 2001 through 2015 (based on earliest filing year) is high = 0.71. This is not direct evidence of causation, but it is nicely consistent with NNI objectives to spur innovation, with patenting being an indicator of intent to commercialize. Do note the sharp increase in patenting after the start of NNI funding and shortly after 2003, when funding increased. It is also interesting to note that a decline in NNI funding in 2013 corresponds with a decline in patenting as well. But, again, we need to be clear that this is not direct evidence of causation. "Earliest filing year" is used to mitigate some of the time lags associated with patent prosecution.

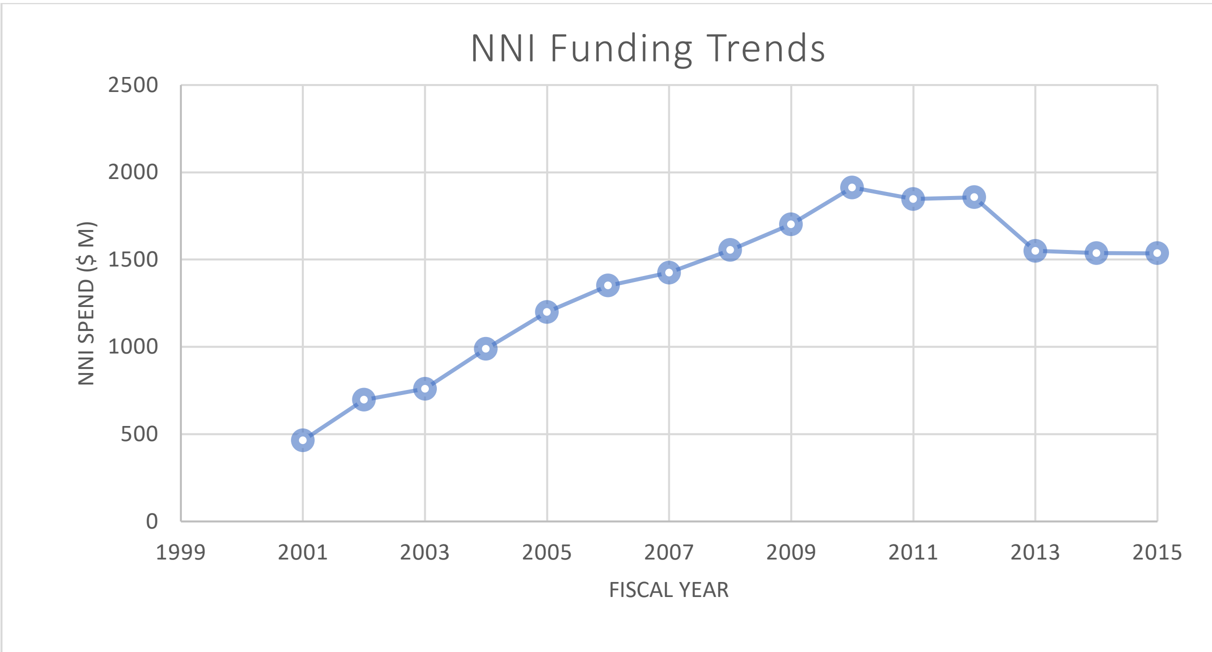

Figure 2. NNI Funding by Year
Note: Data drawn from "NNI Funding, By Agency: FY2001-FY2014 and FY2015 Request" -- https://sgp.fas.org/crs/misc/RL34401.pdf - accessed 04/19/2022 [48].

5.2. Maintenance Renewal Scores (MRSc's)

A prime motivator in our introduction of "Maintenance Renewal Scores" is to enhance measurement beyond simple patent counts. We seek to distinguish higher from lower value patents. MRSc provides one such patent value indicator (recall the introduction to various possible such indicators in Section 2.2).

Table 2 presents renewal data for the US nanopatents for 1999-2009. The percentages indicate the number renewing that many times divided by the # of patents in that row. So, for instance, in the breakout for 1999 (Table 2), 15 (14.3%) of 105 patents were never renewed. Looking to the right, 51 (48.6%) of the 105 patents were renewed as long as possible (3 renewals). The resulting MRSc shows the average being just over 2 renewals (2.01).

Table 2. Overall Maintenance Renewal Patterns for US Nanopatents, 1999-2009

Grant Year \ # Renews	Total	0	1	2	3	MRSc
1999	105	14.3%	19.0%	18.1%	48.6%	2.01
2000	147	8.8%	19.0%	23.8%	48.3%	2.12
2001	181	13.3%	14.4%	21.5%	50.8%	2.1
2002	153	12.4%	22.2%	24.8%	40.5%	1.93
2003	191	12.6%	25.1%	19.9%	42.4%	1.92

2004	252	7.1%	16.7%	31.3%	44.8%	2.14
2005	197	11.2%	24.4%	27.4%	37.1%	1.9
2006	387	14.0%	24.8%	23.5%	37.7%	1.85
2007	393	12.2%	25.2%	24.2%	38.4%	1.89
2008	353	8.8%	25.5%	28.3%	37.4%	1.94
2009	461	11.1%	27.8%	24.3%	36.9%	1.87
1999-2009	**2820**	**11.3%**	**23.4%**	**24.8%**	**40.5%**	**1.95**

As mentioned, renewals are based on the Autumn, 2021, PatStat file, so 2009 data for 3 renewals are likely not complete. However, scanning Table 2, the percentage renewing 3 times for 2009 patents is a bit higher than that for 2005-2008, as is the MRSc score, so we include the 2009 data.

In Table 2, we see 3-term renewals for the nanopatents somewhat less frequently (40.5%) than the 52.5% that we discerned for all US assignee/inventor patents granted in 1999. Consistent with that, the MRSc value of 1.95 for this set of nanopatents is lower than the MRSc score of 2.06 for all 1999 US assignee/inventor patents

Figure 3 plots the full-term renewal percentages. We observe a notable downward drift from about 50% (around the overall USPTO renewal rate ballpark) to under 40%. MRSc's show a similar downward trend.

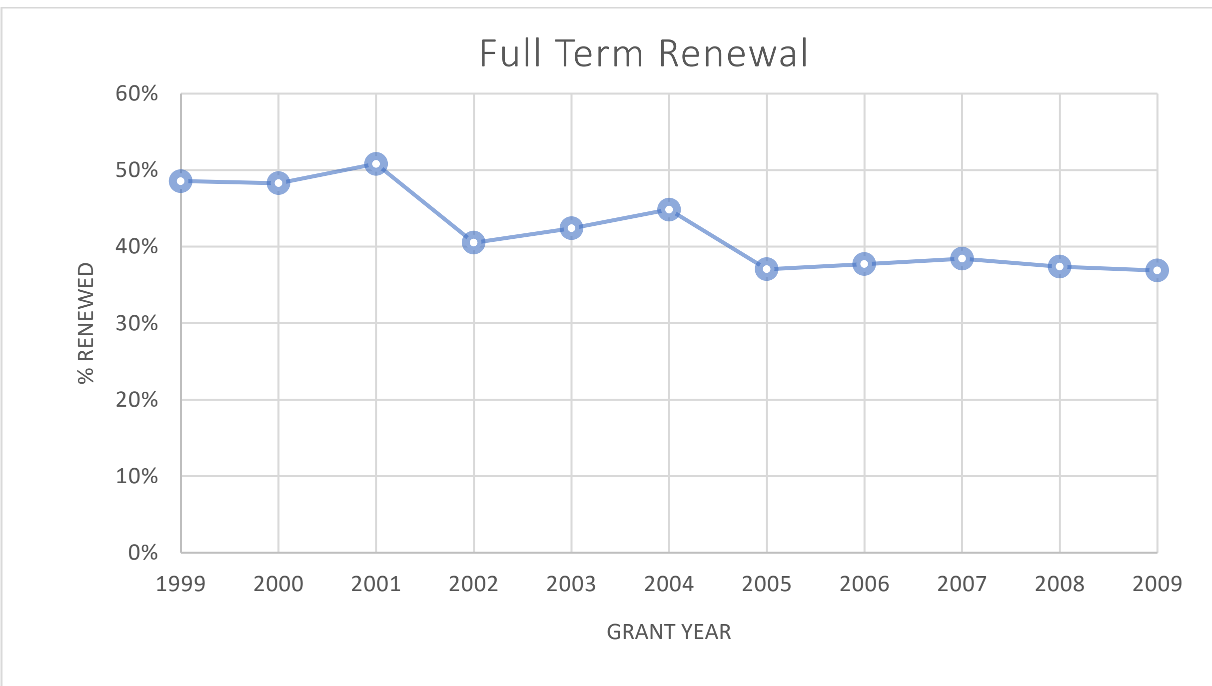

Figure 3. Full-term Renewal Percentage by Nanopatent Grant Year

On the other hand, the nanopatents also show somewhat fewer non-renewals – 11.3% (Table 2) -- than the 14.5% we found in that overall US patent set in 1999. We also don't see a general increase in zero-renews over the course of our 1999-2009 period. Values jump around somewhat, which is not too surprising given that the numbers are in the low hundreds. To gain additional perspective, we split the group into the first five and the last five years (leaving out the mid-year, 2004). We then tally the numbers of patents having made no maintenance payments. We get 12.2% for 1999-2003 vs. 11.5% for 2005-2009 non-renewing.

Put another way, these 2005-2009 patents make at least one renewal payment a bit more often than was the case for the 1999-2003 set.

The intermediate renewal values also tell an interesting tale. For the early grants (1999-2003), 1-term renewal rate averages 20.1% -- vs. 25.7% for the later grants (2005-2009). Likewise, 2-period renewals are less frequent for the early period (21.8%) vs. the later period (25.2%). Somewhat oddly, then, the later period (2005-2009) grantees are more apt to renew through 8 or 12 years, but less likely to renew at 12 years for full-term (recall that since 1995, full term means through 20 years, from filing).

To speculate, with an eye on these data, perhaps nanotechnology has advanced over this period so that the pace of innovation is faster, making nanopatents provide real utility, but for a shorter duration than in the 1999-2003 set? Also, the data do not fit a pattern of US assignees patenting to please NNI program managers, but not really seeing sufficient value in those patents to pay for renewals. That is, after the inception of NNI – with potential influence on patenting behavior starting about 2003 (i.e., reflecting in the 2005-2009 set, but not notably in the earlier 1999-2003 set), more, not less, renewal activity shows forth. That is renewal for 1 or 2 periods, but not for 3 periods. Were patenting perfunctory, to please NNI funders in some way, one might expect that the 2005-2009 patents would tend to not renew at all.

Another perspective on the value placed on a patent might be the ratio of the number of patents renewed full-term to those renewed only through 2 terms. That is, as assignees nearing the 12-year renewal time weigh the value of maintaining the patent through about 5 more years, they have the most information in hand regarding the sequence of maintenance choices. Do they let the patent wane at year-12 or renew through full term (since 1995, 20 years from filing)? Results are surprising – the early cohort (1999-2003) chooses to renew more than twice as many of their still-alive patents (357) as they let wane (169) – a ratio of 2.11. In contrast, the later cohort (2005-2009) lapses a considerably higher share, choosing to renew 672, only 1.49 times as many as they lapse (452).

Interpretation is not certain. We speculate that a speeding nano marketplace development may reduce the value of nanopatents for long duration (full term – i.e., 3 renewals), yet bolster patent value for 8- or 12-year periods. Those early years would also evidence less NNI influence.

5.3. Maintenance Renewal Broken Out by Other Variables

5.3.1. Institutional Type

Table 3 offers the first of a series of breakouts of variables by MRSc. Here we examine the assignee institution type. Our driving research question here is to see whether academics maintain patents less extensively than corporations? We employ PatStat Standardized Sector, noting that a few patent records are associated with more than one category (2867 assignments for these 2820 patents). We leave out four categories, each with 7 or fewer records.

Table 3. Institutional Type vs. Maintenance Renewal Pattern for 1999-2009 US Nanopatents

Count	Std Sector \ # Renews & MRSc	0	1	2	3	MRSc
1979	Company	11.6%	21.4%	22.8%	44.2%	2.00
596	University	7.7%	25.0%	31.4%	35.9%	1.95
171	Government or Non-profit	11.7%	44.4%	22.2%	21.6%	1.54
106	Individual	23.6%	13.2%	33.0%	30.2%	1.70

Results show the majority of the US nanopatenting over the period having a corporate assignee (1979 of 2820 patents). Not surprisingly, companies are most apt to maintain their patents longer. On average, their MRSc is 2, but that is only slightly higher than academic patent longevity (MRSc = 1.95). Were one to combine numbers of 2- or 3-term renewals, companies and universities both show 2/3 of their patents being renewed to that extent (67.0% for companies; 67.3% for universities). However, universities are considerably less inclined to renew full term (3 payments) – 35.9% vs. 44.2% for companies.

Interestingly, universities are most apt to renew at least once, whereas individuals are most apt to never renew (23.6%). Nevertheless, individuals, as assignees, do renew to a considerable extent –indeed, 63% of their patents renewed for either 2 or 3 times. The category of government agencies or non-profit organizations [leading assignees therein are the US Navy (57) and US Army (25)] shows a quite different pattern of letting their patents lapse after 1 renewal (44.4%). They are also least likely to renew through full term.

Consider possible NNI influence to stimulate patenting, but, perhaps, being indifferent to renewing those patents. As noted in the overall renewal examination (Section 4.3), the observations do not align with such an influence. For these data, were that influence at play, we might anticipate universities having a higher non-renewal rate; instead, they show the highest renew-at-least-once rate (100% – 7.7% = 92.3%). If we compare that to the 394 university patents in the later period (2005-2009), the non-renew rate is up a little – 9.4% -- but still relatively low compared to the overall 11.3% for the full set of nanopatents, 1999-2009.

We tried another probe – distinguishing those university patents for which the PatStat record indicates a transfer to a new, non-university party. The presumption is that such patents would likely have stronger commercial prospects and, thus, be more assertively renewed. Table 4 supports this hypothesis – note the elevated MRSc for such transferred patents and the higher propensity for full-term renewal.

Table 4. University sub-divided vs. Maintenance Renewal Pattern for 1999-2009 US Nanopatents

Count	University as original assignee	0	1	2	3	MRSc
95	New party - corporation or other	5.3%	13.7%	31.6%	49.5%	2.25
501	University retained	8.2%	27.1%	31.3%	33.3%	1.9

The BvD ORBIS data augmentation provides a measure of company size that we examine for inclination to maintain nanopatents. Consider the two extreme sizes, that constitute most of our assignees – very large and small companies. One might surmise that very large companies would be more apt to maintain their patents. Here we see similar renewal patterns:

- Small companies -- MRSc of 1.93, renewing 40% of their 1047 nanopatents full term
- Very large companies – MRSc of 1.96, renewing 41% of 1144 patents full term.

Medium sized companies are fewer here (204), so results are less firmly grounded, but they show higher MRSc's of 2.18, with 54% full-term renewals.

5.3.2. International vs. Domestic Patents

Next we compare the MRSc for those patents granted only by USPTO vs. those with family members including other patent granting authorities – Table 5. That is, an assignee may wish to obtain patent protection in other countries. The patent family consists of such equivalent patents granted by various authorities. Obtaining those patents means additional expenses for filing fees, translations, and legal counsel. The hypothesis would be that patents warranting international filing would tend to be valued more highly, thus warranting greater maintenance.

Table 5. Maintenance Renewal Pattern for Families including non-US Grants vs. US-only Grants for 1999-2002 US Nanopatents

Count	US-only or International	0	1	2	3	MRSc
2011	US-only Family	11.0%	23.9%	25.7%	39.4%	1.94

1279	Non-US & US Family	9.6%	19.9%	23.3%	47.2%	2.08

Table 5 reports that patents granted only in the US are not maintained as extensively (in the US) – MRSc of 1.94 vs. 2.08 for those in families with additional international patent coverage.[11] Comparison of the rate of full-term renewals reinforces this conclusion – 39% for domestic US vs. 47% for those with foreign family members. This supports the hypothesis of presumed higher value associating with more extensive maintenance.

5.3.3. Technological Sectors

Which technological sectors renew their nanopatents most? Table 6 breaks out NACE2 technological fields.[12] It shows the MRSc for those NACE2 fields with more than 10 patents in the nanopatent set.

Table 6. Maintenance Renewal Pattern by NACE2 Technological Categories for 1999-2009 US Nanopatents

Count	NACE Technological Fields \ # Renewals	0	1	2	3	MRSc
1624	Computer, electronic and optical products	10.7%	23.5%	25.7%	40.0%	1.95
922	Chemicals and chemical products	11.8%	26.1%	23.2%	38.8%	1.89
611	Machinery and equipment n.e.c.	11.3%	25.2%	26.2%	37.3%	1.9
295	Other non-metallic mineral products	12.5%	22.0%	24.1%	41.4%	1.94
244	Other manufacturing	11.9%	21.3%	20.9%	45.9%	2.01
215	Electrical equipment	12.1%	23.3%	20.0%	44.7%	1.97
192	Basic pharmaceutical products and pharmaceutical preparations	8.9%	18.2%	25.0%	47.9%	2.12
127	Fabricated metal products, except machinery and equipment	9.4%	26.0%	29.9%	34.6%	1.9
64	Basic metals	9.4%	20.3%	31.3%	39.1%	2
53	Rubber and plastic products	17.0%	22.6%	17.0%	43.4%	1.87
23	Textiles	17.4%	17.4%	26.1%	39.1%	1.87
22	Printing and reproduction of recorded media	0.0%	22.7%	27.3%	50.0%	2.27
17	Coke and refined petroleum products	11.8%	41.2%	5.9%	41.2%	1.76
15	Food products	6.7%	40.0%	0.0%	53.3%	2
13	Motor vehicles, trailers and semi-trailers	15.4%	0.0%	23.1%	61.5%	2.31
12	Tobacco products	8.3%	8.3%	8.3%	75.0%	2.5
11	Other transport equipment	18.2%	27.3%	27.3%	27.3%	1.64

Most striking is the similarity in maintenance behavior across technological sectors. Noting the variance in roles that patents play in different sectors, we anticipated sizable differences in propensity to renew. Scanning the MRSc values, particularly for the eight fields with over 100 records, values are relatively

[11] The categories are not completely mutually exclusive. That is due to the complexity of the family membership that can contain a mix of applications and grants with varying status.

[12] NACE is the acronym for "Nomenclature statistique des activités économiques dans la Communauté européenne" – i.e., the statistical classification of economic activities in the European Community [https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF – accessed 04/19/2022]. NACE2 is NACE Rev. 2 that took place between 2000 and 2007.

similar – ranging from around 1.90 (chemicals at 1.89; machinery and, also, fabricated metal products at 1.90) -- to 2.12 (pharma). Among those fields with over 100 nanopatents, percentage of patents renewed full term ranges from 34.6% (fabricated metal products) to 47.9% (pharma). More extreme values appear for some of the fields with few nanopatents, but we hesitate to draw conclusions from those data.

5.3.4. Patent Complexity

This section presents three variables pertaining to patent complexity –numbers of claims, numbers of patent classes, and numbers of inventors.

A possible indicator of complexity, and value, is the number of claims by the patent (Table 7). Organizations have different policies on how many claims to make (e.g., Dupont was known for pressing very large numbers). This set ranges from 1 to 296 claims. We group them as shown in Table 7. The grouping is somewhat arbitrary, but we select the number "20" as a breakpoint because each claim more than that is charged $100 currently by USPTO (plus whatever one's attorney charges for filing!). The research question is whether patents with more claims are more technically complex and commercially ambitious, such that the assignee would be more inclined to maintain such patents longer.

Table 7. Number of Publication Claims vs. Maintenance Renewal Score for 1999-2009 US Nanopatents

Count	# of Claims \ # Renews & MRSc	0	1	2	3	MRSc
498	1 to 10	12.9%	27.9%	23.3%	35.9%	1.82
1092	11 to 20	11.2%	24.4%	26.4%	38.1%	1.91
1230	21 or more	10.8%	20.7%	24.1%	44.5%	2.02

Results are consistent with the hypothesized relation of more claims leading to more renewing. In analyzing Canadian academic nanopatents filed in the US (i.e., to USPTO), Thamooresnejad and Beaudry [18] examined whether a higher number of claims associates with higher renewal rates, but could not support that, despite an association of more claims with other indicators of patent quality.

Another measure of patent complexity is the number of patent class codes assigned to it. The hypothesized relationship is that an increasing number of codes assigned to a patent indicates a likelihood of greater technical complexity. Greater complexity could well reflect heightened effort invested and, hence, higher value placed on the patent. And higher valuation should reflect in more investment in maintenance – i.e., higher MRSc.

Table 8 shows the count of International Patent Classification (IPC) Codes bundled in groups. Results are consistent. More IPC codes appear to associate with extended maintenance to a degree. In particular, the highest two categories (i.e., 7 or more IPCs) shows an increase in MRSc – 1.92 for 1 to 6 IPCs vs. 2.07 for 7 or more IPCs. Full-term renewals show a corresponding pattern – 39% for patents with 1 to 6 IPCs; 47% for those with 7 or more.[13]

Table 8. Number of IPC Codes vs. Maintenance Renewal Score for 1999-2009 US Nanopatents

Count	# IPC Codes \ # Renew & MRSc	0	1	2	3	MRSc
450	1	12.0%	24.2%	22.4%	41.3%	1.93
573	2	13.6%	23.4%	27.2%	35.8%	1.85
759	3 or 4	10.8%	24.2%	25.4%	39.5%	1.94

[13] But, such a relationship does not show for the US Class Codes count – maintenance investment appears comparable for all categories. We believe IPCs are more reliable for this time frame.

484	5 or 6	11.0%	23.3%	25.8%	39.9%	1.95
304	7 to 9	10.9%	19.4%	22.4%	47.4%	2.06
248	10 or more	7.7%	23.8%	22.6%	46.0%	2.07

A third measure of patent complexity is the number of inventors. Table 9 groups the number of inventors on the patent. Single-inventor nanopatents evidence considerably less full-term maintenance – MRSc of 1.82 and 36% full-term renewal rate. Interestingly, patents with 2 or 3 inventors show more maintenance investment than those with 4 or more (MRSc of 2.02 vs. 1.94).

Table 9. Number of Inventors vs. Maintenance Renewal Score for 1999-2009 US Nanopatents

Count	# Inventors \ # Renew & MRSc	0	1	2	3	MRSc
553	1	15.4%	23.7%	24.8%	36.2%	1.82
1279	2 or 3	10.2%	21.4%	24.5%	43.9%	2.02
770	4 or more	10.4%	24.9%	25.2%	39.5%	1.94

In sum, each of the three measures of patent complexity -- # of claims, # of IPC classes assigned, and # of inventors – shows a positive (but not overwhelming) relationship with degree of patent maintenance.

6. Conclusions and Discussion

We demonstrate how to obtain USPTO patent maintenance (renewal) data using PatStat data. We tabulate the number of times (0, 1, 2, or 3) that a given patent assignee chooses to pay the renewal fee to keep the patent in force. This provides the basis for a new measure to investigate patent value and the factors relating to it.

Patent quality and value are vital aspects with multiple dimensions, as per our literature review. Getting at the perceived value of a patent in terms of its assignee's willingness to pay to keep it active is an expressly vital indicator. To facilitate investigation of relationships of other variables with patent maintenance, we devise a measure called Maintenance Renewal Score (MRSc) that counts renewals by their highest number for a given patent – 1, 2, or 3 – and weights them accordingly to obtain a singular value. This MRSc value provides an easily understood score to use to analyze factors that relate to patent maintenance. Having an easily comprehended measure makes it easier to compare maintenance commitments of sets of patents than previous mixes of different renewal statistics. We augment MRSc by showing the percentages of various patent sets choosing to renew 0, 1, 2, or 3 times. The combination facilitates examination of influences on variations in maintenance behavior.

We also demonstrate the incorporation of additional information in the patent analysis. By use of an API, we combine BvD ORBIS information on corporation size in these patent analyses.

The need for an extended time period post-grant to provide renewal data is an obvious limitation. The current analyses conducted in early 2022, using PatStat data as of late 2021, enable analyses of grants through 2009 (and that year is likely not quite complete, as discussed). We have to wait 12 years to ascertain whether the final (third) renewal is paid. However, much like citation analysis, the "life experience" of the patent is what is of interest in terms of value, not just that the patent exists. To get at that aspect of patent valuation necessitates accruing those years post-award.

This study is directed to US nanopatenting over a 20-year period – 1999 to 2019. That overlaps with the inception of the US National Nanotechnology Initiative (NNI). The increase in NNI funding correlates with increased nanopatenting. Although we can't show direct causation, that coincides with a key NNI aim to promote nanotechnology innovation, not just research. We did not evaluate to what level, if any, the NNI impacted private sector patenting in Nanotechnology over the decades of funding or are we assessing the quality of the patent produced during this period. Both are potential issues raised by Gans and Murray [51] concerning the public funding of patenting.

Recalling Table 2, we report that US-invented nanopatents, with a US assignee, for which we have renewal data through 3 possible renewals, show a modestly different renewal pattern compared to general US patenting in 1999. The nanopatent assignees were somewhat more apt to renew at least once (14.5% vs. 11.7%), but somewhat less inclined to pay for full maintenance of 20 years from filing (40.5% vs. 52.5%). We surmise that the lower full-term renewal rate for nanotechnology patents reflects the nature of the technology (rapidly growing, quite pervasive) and the economic climate in the period studied (1999-2019), but further investigation could better determine the case.

The results provide staunch evidence against the possibility that the NNI might have distorted R&D behavior to apply for more patents, but then quickly abandon them as low value. Such a hypothesis has been raised, based on China's experience in its R&D funding policy that incentivized patenting; that led to extensive patenting with very low subsequent maintenance. China accordingly adjusted that policy. Conversely, Tahmooresnejad and Beaudry [18] suggest that government support could be crucial in academic renewal for Canadian nanopatents filed in the US. Another explanation can be found in Baudry and Dumont [49] who suggest that market maturity can reduce later maintenance renewals. Given that the NNI is over twenty years old, market maturity would be a potential factor.

Overall, our results support the hypothesis that NNI support, with stated goal "Promote commercialization of nanotechnology (**nano**) R&D," appears to be associated with increased patenting. Further, the NNI appears not to have stimulated "patenting for the sake of patenting," as maintenance, particularly by universities, was actively pursued. Our data track patenting through 2009, together with renewal activity through 2021. Table 3 shows universities more apt than large companies to maintain nanopatents for 1 or 2 renewals, but somewhat less for the 3rd renewal. That strong maintenance belies a "watch out for repeat of the China experience" hypothesis.

We present tabulations of a series of variables in association with MRSc and percentages of renewal at the three opportunities. To highlight, we show evidence that inclination to maintain one's patent is higher for:

- Companies and universities > government agencies & non-profits, or individuals, as assignee
- Within universities, higher for those patents reassigned > those retained by the university
- By technological sector, high for pharmaceuticals; low for chemicals, machinery, and fabricated metal products
- More complex patents, as indicated by more claims, more IPCs assigned, or more inventors.

These differences in tendencies to renew one's patent through full term warrant reflection. Given national aims to promote innovation, might changes in maintenance policies be warranted? Those considerations reach beyond our analyses, but one could consider the desirability of charging for renewals. Such fees help support the patent office and do not seem excessive, given reduced fees for small organizations (one-half the fee) and micro entities (one-quarter fee). Costs of monitoring renewals coming due and paying them do add to the fees themselves. What might be the merits of doing away with maintenance requirements? But also, what might be the disadvantages (e.g., retaining patents of dubious value in the system longer)?

In future analyses, it would be informative to analyze additional relationships with maintenance as measured by MRSc. To what extent does MRSc correlate with extent of citation to a patent set (forward citation)? Maintenance and citation offer two different facets of patent value and quality (c.f., Ploskas et al. [16]); studying them in conjunction would be of great interest. Additionally, both of these patent indicators tap behavior over time since patent award. Addressing a patent cohort of a certain time period is most suitable for 12 years – last renewal payment in the USPTO system. So, gathering patent citation information for a corresponding period would fit well. For citation, 12 years is not a landmark for time period, but it is certainly reasonable.

Section 2 considers an extensive range of ways to measure patent value/quality, etc. Patent (forward) citations and MRSc both require several years post-award to accrue the data. In terms of their nature, they are generally complementary. Citation reflects valuing a patent by others; MRSc, by its owners (assignees). We recommend pursuing both, but treating them as separate measures – not trying to combine into one.

As our reviewers pointed out, future research to devise an indicator that predicts patent maintenance behavior would be highly attractive. Toward that end, analyses that combine various measures that come available immediately, or early, after patenting with later maintenance warrant study. Present results suggest several candidate variables apt to anticipate future maintenance. These include institutional type (Table 3), whether a patent is transferred (Table 4), whether filed outside the US too (Table 5), its technological sector (NACE – Table 6), and its complexity (Tables 7-8-9). Present results are limited to the dataset here – US nanotechnology patents, 1999-2019; testing whether they generalize to other patent data would be quite worthwhile. Predicting patent maintenance would offer a very attractive "early" patent value indicator, with additional value to assignees and competitors.

Obviously, the current empirical findings are limited to US nanotechnology patents over one period, 1999-2009. It would be valuable to examine other technological domains. Present results should also be extended to address other time periods, as USPTO policies change over time, affecting maintenance decisions by assignees. And, clearly, these results are limited to USPTO patenting, further restricted to US assignees and inventors. Comparative analyses of maintenance behaviors for other patent authorities would illuminate differences associated with other renewal policies. That should be valuable in reconsidering renewal fee schedules that balance patent system aims (i.e., protecting invention to promote innovation) and costs.

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