Early Disclosure and Patent Value: How Do You Know You Are a Pioneer? *

Makoto Kadowaki † Sadao Nagaoka ‡

March 13, 2024

Abstract

While the patent system plays a dual role in promoting innovation through protection and disclosure, it is widely believed that early disclosure of a patent application weakens patent protection by enhancing knowledge spillovers. However, pre-grant publication enables early establishment of the priority of the invention, which may enhance appropriation. Using the introduction of pre-grant publication in Japan as a natural experiment, we find that early disclosure increased the rejections (and abandonments) of the subsequent duplicative patent applications by others more than the grants of their follow-on patents. As a result, the patent value significantly increased on average. Consistently, the pre-grant publication accelerated and increased the grant of one's own follow-on inventions, more so when competition is significant. Thus, we find that pre-grant publication has a significant effect of promoting appropriation through early determination of who is a pioneer.

Keywords: Disclosure, Priority, Knowledge spillover, Pre-grant publication.
JEL Codes: O33, O31, O38.

*This study is conducted as a part of the Project "Frontiers of Innovation Policy: Evidence from micro data" undertaken at Research Institute of Economy, Trade and Industry (RIETI). This research was also supported by the JSPS Grant-in-Aid for Scientific Research JSPS (B:26285055), and JSPS KAKENHI Grant Number JP90845041. We would like to thank for the comments received for our presentations in the following places: Asia Pacific Innovation Conference (APIC) at Delhi School of Economics, European Association for Research in Industrial Economics (EARIE) at Barcelona School of Economics, and RIETI. We thank for insightfull comment by Yoshimi Okada of the Japan Patent Office.

†Hitotsubashi Institute for Advanced Study (HIAS). kadowaki.makoto@r.hit-u.ac.jp
‡The Research Institute of Economy, Trade and Industry (RIETI). nagaoka-sadao@rieti.go.jp

1 Introduction

It is widely believed that early disclosure of a patent application increases the spillover effects of the invention, thereby reducing the value of the patent and the ex ante incentive for R&D. For this belief, a number of Nobel laureates in economics, physics, chemistry, and medicine strongly opposed the introduction of the pre-grant publication system in the United States in 1999 (Ergenzinger Jr., 2006). Their open letter stated that "*provisions for 18-month publication and prior user rights would reduce patent protection for small firms and individual inventors relative to large multinational corporations, and thus discourage the flow of new inventions.*" The existing theoretical literature on patenting and disclosure provides conclusions consistent with this view (e.g., Horstmann et al. (1985), Anton and Yao (2004), Aoki and Spiegel (2009)), although they rely on the crucial implicit assumption that the priority of the invention is known without publication or grant (or adoption of a pioneer-follower model). That is, they assume that an inventor knows that he or she is the pioneer.

However, it is important to recognize that a pioneer firm does not know whether it is truly a pioneer or not until its priority is established, given the competition in research. Priority is revealed to the firm through the grant process by the fact of being the earliest grant if the pre-grant publication does not exist. If the pre-grant publication exists, priority is revealed to the firm by the fact of being the earliest publication under the first-to-file system. That is, if no other firms have published competing inventions before it, it is the pioneer. Thus, pre-grant publication system significantly accelerates the establishment of priority, since the grant decision usually takes considerable time.

The early establishment of priority through publication can have a significant impact on the value of the patent and the ex ante incentive for R&D. First, the published patent applications deter the competitors from patenting or further investing in duplicative inventions. In addition, in Japan and Europe, examiners can use such publications earlier for rejecting subsequent duplicative patent applications (inventions with only obvious improvements), since only published applications serve as full prior art, so that more subsequent duplicative applications are rejected due to early disclosure.[1] Second, establishing a patent's priority can give the owner of such a patent an incentive advantage in performing the R&D for acquiring an additional follow-on invention. Having a unified ownership over the focal and the complementary invention gives more profit than that from having the ownership only on the complementary invention, due to efficiency effect. Third, early establishment of priority

[1] Publicly undisclosed prior patent applications at a patent office cannot block inventions with only obvious improvements from being granted in Japan and Europe. In the US, they can block such inventions, reflecting the practices under the first to invent system in the past.

allows the pioneer firm to initiate or accelerate downstream investment without worrying about the risk of being held back. It can also help the other firms to initiate complementary R&D projects early, for which the pioneer firm has no capability. All of these effects will increase the value of the disclosed patent and the ex-ante incentive for R&D.

Early disclosure can also accelerate the imitative inventions and their patent applications by other firms, which can substitute the focal patent. It can also allow the other firms to preempt the focal firm from patenting the inventions complementary to the focal invention. Such preemptive patenting by other firms forces the focal firm to share the return from its invention. Thus, these two types of patents reduce the value of the focal patent and the ex-ante incentive for R&D for the focal firm. The net effect of early disclosure on the patent value and the ex-ante incentive for R&D is therefore ambiguous and is an empirical question which this paper addresses.

This paper examines how early disclosure of a patent application affects its private value by influencing the subsequent R&D competition. Early disclosure of a patent application blocks more duplicative patent applications by accelerating the timing when it becomes a full prior art and it also expands its follow-on inventions (substitutes and complements) by accelerating knowledge spillover. We use the introduction of pre-grant publication in Japan in 1970 (implemented in 1971) as a natural experiment to identify these effects of early disclosure as well as on the patent value of the focal patent.

In summary, based on the instrumental variable estimations, using the introduction of pre-grant publication in Japan as a natural experiment, we find that early disclosure increased the rejections (and abandonments) of the subsequent duplicative patent applications by others more than the grants of their follow-on patents. As a result, the patent value increased on average. Consistently, the pre-grant publication accelerated and increased the grants of one's own follow-on inventions granted, more so when competition is significant. Thus, pre-grant publication promoted appropriation through early determination of who was a pioneer.

Recent literature suggest the possibilities of positive effects of early publication for appropriation. There exist two highly relevant literature. Lück et al. (2020) suggest that early disclosure reduced duplicate inventions using USPTO (United States Patent and Trademark Office) patent examination data. Most recently, Hegde et al. (2023) show that, early disclosure after the American Inventors Protection Act (AIPA) in 1999, the technological overlap between highly similar patents decreases, and patent applications are less likely to be abandoned (until granted), suggesting less duplicative R&D. However, neither study analyzes how early disclosure affects the competition with subsequent patent applications and patent value through its effects on early establishment of priority and on knowledge spillover. This study analyzes such mechanism and assess its quantitative impact on patent value.

This paper is organized as follows. In the next Section, we briefly review the existing studies of patent disclosure. Section 3 explains in detail the introduction of Japan's pre-grant publication system. Section 4 presents the hypotheses. Section 5 describes the data set. Section 6 describes the estimation strategy in the econometric model. Section 7 presents the basic results. Section 8 implements a robustness check. Section 9 analyzes the applicant's own follow-on inventions, with or without competition. Section 10 presents additional discussion of Japan's pre-grant publication system, and Section 11 concludes.

2 Prior literature

Existing theoretical analyses of patenting decisions often implicitly assume that priority is automatically established when the invention is made and that its disclosure constrains appropriation. Thus, they effectively adopt the pioneer-follower model without asking how the pioneering firm knows that it is the pioneer. Horstmann et al. (1985) is the first study to analyze patenting behavior when an innovating firm has private information about the profits available to competitors through imitation. In their model, a firm will patent only a fraction of the innovations it produces because patenting is accompanied by disclosure, which limits appropriation. In their model, it is implicitly assumed that if a player succeeds in generating a new innovation, he/she is the pioneer. The same structure is used in Anton and Yao (2004) and Aoki and Spiegel (2009), and more recently in Akcigit and Liu (2016). Aoki and Spiegel (2009) finds that pre-grant publication of patent applications in the context of a cumulative innovation model leads to fewer applications and fewer inventions.

If there is no research competition, such an assumption can make sense. Empirical literature, however, shows that R&D competition often exists and the race is often close, so who is the pioneer is often known only as the outcome of the competition. As an example, the inventor survey (PATVAL survey II) for Japan shows that the majority of the inventors recognize the existence of competitors for their patents: only 7.3% of the inventors say that there were no competitors they recognized, and 9.7% of them say that they do not know whether there were competitors (Nagaoka et al. (2012)). Furthermore, the recent study by Thompson and Kuhn (2020) using USPTO data suggests that patent racing, even according to their ex-post narrow definition (the existence of "patent twins"- sets of patent applications filed at nearly the same time on the same invention), is common, with 10-11% of all patents in races.

If there is research competition, uncertainty about the priority of an invention exists until all inventions preceding that invention are made public. Furthermore, it takes significant time between an invention and its publication, especially when there is no pre-grant publication (it took around 5 years on average until a grant in Japan before the introduction of the pre-grant publication). Thus, one of the essential functions of pre-grant publication may well be early priority determination, i.e., letting the applicant know whether it is a pioneer or not 18 months after filing.

The recent empirical literature suggests potentially positive effects of early disclosure on appropriation. Graham and Hegde (2014, 2015) found that U.S. applicants of purely domestic patent applications often opt for 18-month pre-grant disclosure, even though the U.S. law that introduced 18-month pre-grant disclosure (AIPA in 1999) allows such applicants to keep their inventions secret before a patent grant if they do not apply for foreign patents. That is, only about 7.5% of U.S. patent applications use this U.S. patent law provision to keep their inventions secret before a patent is granted. In addition, they find that small U.S. inventors tend to prefer disclosure over secrecy for their most important inventions.

One potential mechanism for early disclosure to improve appropriation is licensing. Hegde and Luo (2018) investigated the effects of pre-grant publications on patent licenses in biomedical technology to examine how disclosure of a patent application facilitates licensing, separately from the effect of grant. They found that post-AIPA patent applications were licensed significantly earlier than pre-AIPA patent applications, controlling for grant date. This clearly indicates one mechanism of early disclosure causing an increase in the returns to patent rights. Specifically, they found that: i) the probability of licensing in the window between 18 months of publication and patent grant more than doubled for post-AIPA patent applications; ii) post-AIPA patent applications were about 18 percentage points less likely to wait until grant to be licensed; and iii) the overall effects of AIPA were stronger for U.S. patent applications that had no foreign equivalents. Drivas et al. (2018) also found similar evidence for university licensing.

Lück et al. (2020) focus on whether early disclosure of patents would help avoid the duplication of investment by reducing asymmetric information among rival firms. They use USPTO office action data from 2008 to 2017 and found that AIPA significantly reduced the number of rejections in office actions referring the patents applied after the AIPA. Most recently, Hegde et al. (2023) show that technological overlap decreases between highly similar patents, and patent applications are less likely to be abandoned (before the grant) in post-AIPA, suggesting a potential reduction in duplicative R&D. They hypothesize that early disclosure expands the public domain and enables a firm to avoid incurring patenting costs of duplicative inventions. Their study, however, does not investigate the effects of pre-grant publication on early establishment of priority nor the effects of imitative or pre-emptive inventions by others, caused by accelerated knowledge spillover. Their study assumes that all citations (inventor and examiner) are driven by search efforts by inventors, and does not consider the contributions of examiners for rejecting duplicative applications. However, examiner citation begins far earlier and reaches its maximum much earlier than that of applicant citations in the US, as shown by Okada and Nagaoka (2020) (see also Baruffaldi and Simeth (2020)).

These studies do not investigate how early disclosure affects competition with subsequent patent applications and patent values through its impacts on early establishment of priority and on knowledge spillover. We analyze how early disclosure of patent applications affects the private value of a patent by affecting not only knowledge spillover but also the scope of the prior art, using the introduction of pre-grant publication in Japan as a natural experiment. It also analyzes the effect of early disclosure on the first mover advantage in R&D in terms of follow-on inventions. Although there a number of existing studies on patent protection (Galasso and Schankerman (2015), Sampat and Williams (2019)) and early disclosure on knowledge spillover (starting from Johnson and Popp (2003)), there is no study, to our best knowledge, investigating the effects of early disclosure on patent value, considering its effects on early priority setting and on knowledge spillovers jointly.

3 Introduction of pre-grant publication system in Japan

Japan introduced the pre-grant application system in 1970, which became effective for applications filed on or after January 1, 1971. Since then, the patent application has been automatically published within 18 months. Prior to this reform, the JPO (The Japan Patent Office) published the patent application only after the completion of the substantive examination, so that it took an average of about 58 months (1765 days) before publication (see Table 1), so the pre-grant publication greatly accelerated publication.

The pre-grant publication system significantly accelerated the disclosure of an application from 58 months to 18 months after filing. Third parties can use the knowledge disclosed in such patent applications to develop subsequent inventions, and at the same time, such applications can be used by examiners to reject subsequent similar but not identical patent applications on the grounds of inventive step. Table 2 shows that the average number of patents with non-self citations to a focal patent by examiners increased significantly between 1970 and 1971: from 0.26 to 0.46 number of citing patents that resulted in grants, and from 0.23 to 0.44 number of citing patents that resulted in rejections or abandonments (non-grants). These results indicate that early disclosures increase both the technological opportunities for subsequent inventions and the probability for an examiner to issue a rejection to duplicative inventions.

Since there is no new knowledge flow from a pre-grant publication to the applicant firm, the increase in self-citations is likely to indicate a stronger incentive for the applicant's subsequent inventions. The average number of self-citing patents that led to grants increased more than threefold, from 0.006 to 0.022. On the other hand, the average number of self-citing patents that did not result in grants decreased from 0.003 to 0.001. Thus, a pre-grant publication seems to have increased the first mover advantage of the applicant with respect to subsequent inventions.

Table 1: Basic Statistics of Granted Patent in Japan Applied in the first 9 months of 1970 and the last 9 months of 1971

1970 Cohort, first 9 months

Variables	Mean	Sd	Min	Max	N
Lag time between application and publication (days)	1765.1	517.5	582	4990	25810
Lag time between publication and grant (days)	312.8	241.4	148	4294	25806
Grant year	1975.6	1.5	1972	1988	26026
Expiration year	1986.2	3.0	1978	1992	26026
Survival length from application (months)	16.2	3.0	8	22	26026
Full term (%)	18.98	39.22	0	100	26026
Patent value	0.912	1.175	0.002	9.495	26026
Top 10% (%)	0.064	0.245	0	1	26026
Opposition probability	0.081	0.272	0	1	26026

1971 Cohort, last 9 months

Variables	Mean	Sd	Min	Max	N
Lag time between application and publication (days)	548.6	1.2	485	550	28256
Lag time between publication and grant (days)	1833.2	626.1	222	6472	28256
Grant year	1977.7	1.7	1973	1990	28868
Expiration year	1987.4	3.4	1979	1995	28868
Survival length from application (months)	16.4	3.4	8	24	28868
Full term (%)	29.38	45.55	0	100	28868
Patent value	1.215	1.494	0.001	12.069	28867
Top 10% (%)	0.132	0.339	0	1	28867
Opposition probability	0.067	0.249	0	1	28868

Note: This sample of patents is limited to those with priority date equal to the filing date in Japan. We use data for the first and the last 9 months of the respective years to exclude the effect of the accelerations of applications, anticipating the introduction of a pre-grant publication system. The grant and expiration year data is treated as a decimal number for simplification. A “Full term” indicates the proportion of the granted patents maintained for 20 years after application and/or 15 years after the grant. ”Patent value” is the estimated value of a patent at application, based on the survival length and is estimated in Appendix A.3. The unit of Patent value is 1 million in 2022 yen. Top 10% is the proportion of the patents ranked in top 10% in value in all 1970-1971 patents.

Table 2: The Number of Citing Patent to the Granted Patent in Japan Applied in the first 9 months in 1970 and the last 9 months in 1971

1970 Cohort, first 9 months

Variables	Mean	Sd	Min	Max	N
Self-citation from grant patent	0.006	0.082	0	3	26026
Self-citation from non-granted patent	0.003	0.060	0	2	26026
Non-self-citation from grant patent	0.255	0.773	0	36	26026
Non-self-citation from non-granted patent	0.234	0.656	0	15	26026

1971 Cohort, last 9 months

Variables	Mean	Sd	Min	Max	N
Self-citation from grant patent	0.022	0.175	0	5	28868
Self-citation from non-granted patent	0.001	0.036	0	2	28868
Non-self-citation from grant patent	0.457	1.021	0	20	28868
Non-self-citation from non-granted patent	0.444	1.015	0	26	28868

Note: Only examiner citations are counted as a citing patent. We use data for the first and last 9 months of the respective years to exclude the effect of application accelerations due to introducing a pre-grant publication system.

Figure 1 shows the number of patent grants by application month from December 1968 to January 1973. It shows that there exist clear and significant accelerations of applications from early 1971 to late 1970. Such acceleration seems to have occurred due to the concern by many applicants that the introduction of pre-grant applications would weaken patent protections due to early disclosures. To exclude the impact of such strategic acceleration of applications from our estimations, we focus on the first 9 months period from January to September in 1970 (the control) and the last 9 months in 1971 (the treatment) for our primary sample in assessing the effects of early disclosures. In addition, we also use the last 3 months of 1970 and the first 3 months of 1971 as a supplementary sample (we call these months a “shift” period), bearing in mind that a significant sample selection bias exists due to the strategic acceleration of patent applications.

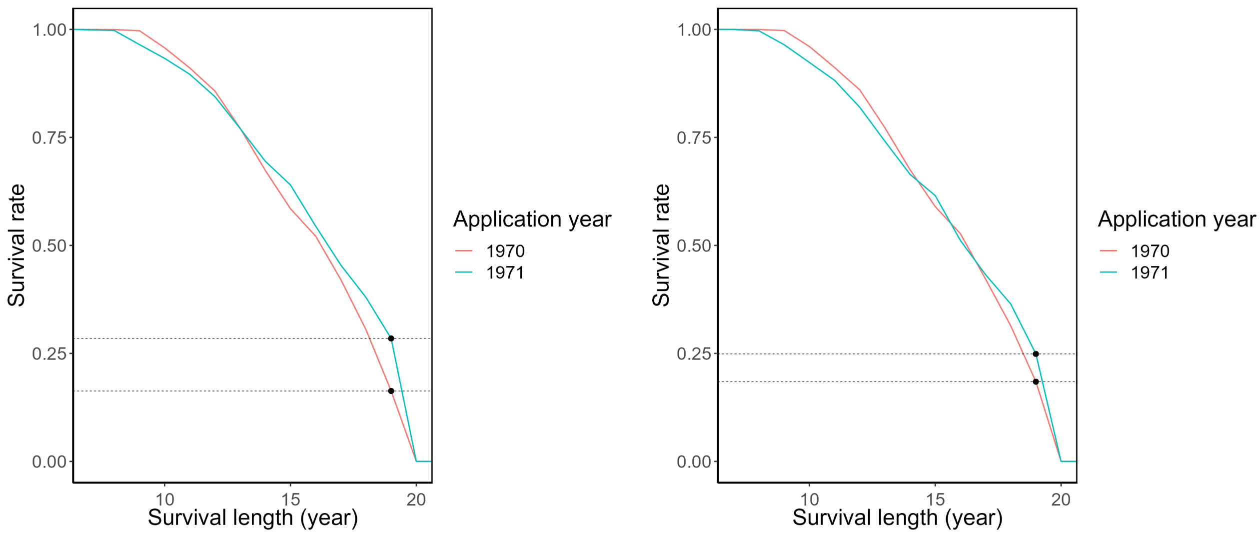
Figure 1: The Number of Patent Grants by Application Month from December 1968 to January 1973

The basic statistics and citation statistics for the shift period data are shown in Table 11 and Table 12 in Appendix A.1, respectively. The number of patents in the last 3 months of 1970 reached 16,685, while that in the first 3 months of 1971 was 5,526, indicating a significant number of accelerations of the applications from 1971 to 1970, amounting to roughly 5500.

Figure 2 (a) shows the cumulative distributions of the survival length of the patents applied during the 1970 (the first 9 months, control) and 1971 (the last 9 months, treatment) periods. The comparison between the two distributions suggests that the upper part of the distribution is heavier for the 1971 cohort than the 1970 cohort. Although the number of patents granted increased slightly from 26,026 to 28,868, the number of patents maintained up to the 20 years or 15 years from the grant (full term) from the application increased substantially from 4,243 to 8,219. This clearly indicates the possibility that the average private value of a patent increased significantly due to early disclosure.

We estimated the patent values at applications, based on the survival length. Appendix A.3 provides details of analysis. As shown in Table 1, the estimated average patent value increased by around by 33% from 0.912 to 1.215 and the proportion of the patents valued at top 10% in the 1970-1971 period (9 month period each) increased from 6.4% to 13.2%. The number of patents ranked in the top 10% as well as their total value increased from 1970 to 1971 because the number of patents granted increased by 10.9% from 1970 to 1971.

Furthermore, very interestingly, even though we focus on those applied in the last 3 months of 1970 and the first 3 months of 1971, the upper part of the distribution of the survival curve is heavier for the 1971 cohort than the 1970 cohort, as shown in Figure 2 (b). In this sample, the patents maintained for 20 years were 3,079 out of 16,685 (18.5%) in 1970 and 1,375 out of 5,526 (24.9%) in 1971. These results also indicate the possibility that the private value of a patent significantly increased on average from 1970 to 1971, due to early disclosure, despite the adverse sample selection for 1971.



(a) First 9 Months of 1970 and Last 9 Months of 1971 (b) Last 3 Months of 1970 and First 3 Months of 1971

Figure 2: The Cumulative Distribution of the Survival Length (from Application) of the Patents

Note: In Figure (a), the number of observations for 1970 and 1971 is N=26,026 and N=28,868, respectively. There were 698 patents in 1970 and 263 in 1971 that expired in the middle of this graph due to the 15-year restriction from the grant. In Figure (b), the number of observations for 1970 and 1971 is N=16,685 and N=5,526, respectively. There were 407 patents in 1970 and 70 in 1971 that expired in the middle of this graph due to the 15-year restriction from the grant.

Note that there were two statutory limitations on the effective life of patent rights: 20 years from application and 15 years from grant. The former restriction was significantly more binding. The number of patents subject to only the latter statutory limit is not as large as the former, with 698 patents in the control and 263 patents in the treatment. The numbers for the last 3 months of 1970 and the first 3 months of 1971 are 407 and 70, respectively.

The introduction of the pre-grant publication in 1971 was accompanied by two other major changes: the introduction of the examination request system and the expansion of the blocking power of pending (undisclosed) patent applications at the JPO. Under the examination request system, the applicant could defer the decision to request the patent examination for up to 7 years. This significant policy change can affect our analysis in two manners: the selection of the inventions for patent applications as well as the forward citation flows. We will discuss the impact on selection in Section 6.2.

The introduction of the examination request system would have affected the citation flows in our analysis only in an insignificant manner. This is because out of the 48,344 patents that cite the 1970 and 1971 patents, only 143 were applied before 1970. That is, almost all of the citation information we exploit was generated under the new process of patent examinations or opposition process in 1971 or later. Since both our control and treatment groups, that is, the patent applications made in the first 9 months of 1970 and in the last 9 months of 1971 served as prior arts almost exclusively for the patent applications made in 1971 or later, we could measure the effects of early disclosure separately from those of the introduction of examination request system.

The power of pending patent applications to bar subsequent patent applications expanded in 1970. In the JPO, a non-disclosed prior patent application used to bar only a subsequent identical patent application in terms of the claim of such prior patent application until 1970. The scope of blocking was expanded from the claim to the invention as a whole on January 1st, 1971. However, the number of examiner citations made before the disclosure is only about one-nineteenth of that after the disclosure.

4 Hypotheses

We develop two hypotheses on prior art effects and knowledge spillover effects of early disclosure on others' subsequent inventions, and on hypothesis on its effect on the own follow-on inventions in this Section.

The power of the focal patent application to bar subsequent patent applications on inventive step ground became effective earlier, due to the acceleration of disclosure through the introduction of pre-grant publication in Japan. Thus, the pre-grant publication accelerates the timing and the cumulative number of rejections by examiner citing the patent applications disclosed early (as well as more abandonments of the applications by the applicants). The effects would be stronger when the acceleration is significant, and research competition for the focal patent is intense, so that we can construct instrumental variables using the publication lag and the level of competition before the policy change. More rejections of the competing subsequent applications induced by these IVs will increase the patent value of the focal patent. If rejections and abandonment of the subsequent patent applications were predominantly driven by the knowledge spillover effect (that is, they are totally duplicative applications), there would be no significant effect on patent value. Thus, we have the following first Hypothesis.

Hypothesis 1.

If prior art effects on reducing duplicative patent grants are significant, we would observe the following two relationships.

1. *Early disclosure of the focal patent application will cause more rejections and abandonment of the subsequent duplicative patent applications, citing such application, but not more grants, and*

2. *Such an increase in non-grant outcomes of the subsequent patent applications increases the private value of the focal patent.*

Early disclosure of the focal patents accelerates knowledge spillover from these patent applications to the other entities and will encourage their imitative, leap-frogging or complementary inventions, which we call their "follow-on" patents. Inventions with significantly new contributions, even based on imitations, will be granted patents and will reduce the value of the focal published patent. Knowledge spillover also enables the complementary inventions by the other entities, preempting such opportunities by the focal firm. Such preemptive complementary inventions by others also reduces the value of the focal patent by forcing its applicant firm to share its profit. On the other hand, if the inventions of such complementary technologies are beyond the capability of the applicant firm, the value of the focal patent would increase. We hypothesize that the negative effects will be dominant for knowledge spillover, given the wide-spread concerns that early disclosures will reduce appropriation. Knowledge spillover would be stronger when the acceleration is more significant and the number of competitors is large. If knowledge spillover effects were absent, the prior art effect will reduce the cumulative number of grants of the subsequent patents citing the follow-on patents and will increase the patent value.

Hypothesis 2.

If knowledge spillover effects are significant, we would observe the following two relationships.

1. *Pre-grant publication of the focal patent application increases the subsequent patents granted to the other firms, citing such patent application, by accelerating knowledge spillover to them.*

2. *Such grants of patents to the other firms reduce the private value of the focal patent when they are imitative or preempts the focal firm from patenting its complementary inventions.*

Pre-grant publication allows an applicant to know early whether its invention is novel because all of the relevant prior art has been published prior to the publication of its invention, although there is no knowledge spillover effect from one' own invention. Early recognition that its invention has priority over competing inventions enables the pioneer to invest early for follow-on complementary inventions. It is important to note that such learning by the applicant occurs over time toward the publication of its invention, because, if no competing inventions appear by the time close to its publication (say, two months before), it is likely that its invention is novel. Such a perspective increases the incentive for the applicant with the focal patent to make follow-on inventions earlier and more intensively.

The anticipation that early disclosure also invites early follow-on inventions by competitors (imitative and preemptive inventions of complements) can further accelerate the follow-on inventions by the pioneer firm by strengthening its preemptive motivations. However, if the pioneer firm anticipates that early disclosure strongly invites imitations and preemptions of complements by competitors, it can reduce its follow-on inventions by reducing the pioneer's ability of appropriation. We hypothesize that the last effect is less important for the patent application which has priority over the other competing applications (the application by a pioneer firm), so that the pioneer firm accelerates and enhances its follow-on inventions, in response to early disclosure. Thus, we have the following Hypothesis 3.

Hypothesis 3.

Early publication of the focal patent application accelerates and enhances the own follow-on inventions by establishing its priority early. It does so even before the disclosure because the applicant can learn its novelty over time toward the publication of its invention. The anticipation by the pioneer that early disclosure invites earlier follow-on inventions by its competitors can enhance such response of the pioneer firm, unless response of its competitors is so strong to significantly reduce the pioneer's ability to appropriate return from its follow-on inventions.

5 Data

5.1 Data construction

We use patent data applied in Japan between January 1970 and December 1971, making our sample period of the analysis one year before and after the introduction of pre-grant publication in Japan. We focus only on the granted applications since non-granted applications were not published before the reform. In constructing the dataset for our empirical analysis, we exclude patent applications whose priority dates are earlier than the application dates due to their international priorities, divisional applications, etc., because such applications have prior patent applications that might have been disclosed earlier. That is, we cover only those applications whose application dates are identical to the priority dates. The data used for the estimation excludes the shift period, which is the first 9 months in 1970 (the control) and the last 9 months in 1971 (the treatment).

We collected patent data, including forward citations made by examiners to the patents applied in the 1970 and the 1971 cohorts ("cited patents" briefly). The cited patent data were collected from the IIP (Institute of Intellectual Property) database. The examiner citation data[2] were collected from examination process data of the JPO maintained by Artificial Life Laboratory, Inc. Since the data period is around 1970, some information in the IIP database has been missing. Such missing publication data and International Patent Classification (IPC) data, were collected from the ORBIS database from Bureau van Dijk, and missing patent family data is collected from the PATSTAT database published by the European Patent Office (EPO).

We matched the first IPC classes of our sample patents with 33 broad classifications based on the World Intellectual Property Organization (WIPO). We also matched the patent data with the Japanese applicants using the National Institute of Science and Technology Policy (NISTEP) dictionary of Japanese firm names and the connection table to the IIP patent database. This matching enables us to differentiate between self-citations and citations by others.

There are 11,625 patents where the applicant firm was not identified in the primary sample.[3] These patents are not used in the regression analysis because we can not identify self-citations and citations by others. The number of observations for the analysis is 43,268. The basic statistics of the estimation data are in Appendix A.2. These are similar to those in Tables 1 and 2.

We estimate the patent value distribution as in Schankerman (1998) and Bessen (2008), under the assumption that it follows a log-normal distribution (see Appendix A.3 for estimation method in details). The analysis of patent value by Schankerman (1998) and other studies assume that a patent value is generated at the time of patent grant. In fact, there is a gap of more than 5 years between the application date and the grant date (see Table 1) and it varies significantly across patents. Especially, it would not be reasonable to assume that the obsolescence of patented technology has not occurred after its application. In this

[2]Some citations were originally proposed by the third parties in the opposition proceedings and approved as relevant prior art by examiners.

[3]The NISTEP dictionary contains mainly Japanese firms. Therefore, information on non-Japanese firms that have applied patents in Japan may be missing.

paper, we use the patent value at application as the primary measure of patent value by assuming that patent value obsolescence begins at the time of application. However, we will also present the estimation results using the patent value at grant as a robustness check (see Appendix A.4).

5.2 Changes of examiner citation dynamics before and after the reform

We classify the citing patents by the timing of their applications *before* or *after* the disclosure (i.e., publication) dates of the cited patents. The patent applications before disclosure is not a full prior art in Japan and in Europe. Table 3 shows the citation flows to two cohorts (the control and the treatment) from citing patents before and after disclosure. Table 3 shows that the citation flows from patents applied after disclosure increased significantly in 1971 compared to 1970. Citations from patents applied before disclosure did not change significantly, although the publication lag was significantly longer for the 1970 patent cohorts than for the 1971 patent cohorts, as shown in Table 1 (1765 days vs. 549 days).

We focus on the citation flows of the subsequent patent applications made *after* the disclosure of the cited patents in order to assess the reactions of other inventors and examiners to the introduction of pre-grant publications in assessing Hypothesis 1 and 2. The citation flows to the pre-disclosure patent applications accounts for less than 5% of the total number of citing patents in our data. Therefore, to simplify our analysis, we do not include them in the analysis of the main paper, but present the analysis including them as controls in Appendix A.5.

Table 3: Patent Citation Data, Divided into Before and After the Disclosed

1970 Cohort, first 9 months

Variables	Mean	Sd	Min	Max	N
Before Disclosure					
Self-citation from grant patent	0.002	0.047	0	2	26026
Non-self-citation from grant patent	0.018	0.145	0	5	26026
Non-self-citation from non-granted patent	0.024	0.176	0	4	26026
After Disclosure					
Self-citation from grant patent	0.004	0.066	0	3	26026
Non-self-citation from grant patent	0.237	0.751	0	36	26026
Non-self-citation from non-granted patent	0.210	0.620	0	15	26026

1971 Cohort, last 9 months

Variables	Mean	Sd	Min	Max	N
Before Disclosure					
Self-citation from grant patent	0.005	0.079	0	4	28868
Non-self-citation from grant patent	0.012	0.120	0	3	28868
Non-self-citation from non-granted patent	0.015	0.135	0	5	28868
After Disclosure					
Self-citation from grant patent	0.017	0.153	0	5	28868
Non-self-citation from grant patent	0.444	1.005	0	20	28868
Non-self-citation from non-granted patent	0.429	0.993	0	26	28868

Note: Only examiner citations are counted as a citing patent. We use data for 9 months each year to exclude the effect of application accelerations due to introducing a pre-grant publication system.

Figure 3 illustrates the citation flows to the focal patents of the two cohorts. Figure 3 shows that citation flows to the 1971 cohort occur much earlier and more intensively than those to the 1970 cohort for all three types of citation flows. Both non-self-citations from non-granted patent applications and from granted patent applications start much earlier, and their peak also arrives much earlier for the 1971 cohort: 2 years earlier for citation flows from non-granted patents (from the 6th to the 4th year after the application), and 3 years earlier for citation flows from granted patents (from the 7th to the 4th year after the application).[4] The level of the citation peak and the total number of citing patents that resulted in non-grants more than doubled. The number of citing patents that resulted in grants increased less than the number of citing patents that of non-grants, but almost

[4]We use "patents" instead of "patent applications" for brevity where confusions are unlikely to occur.

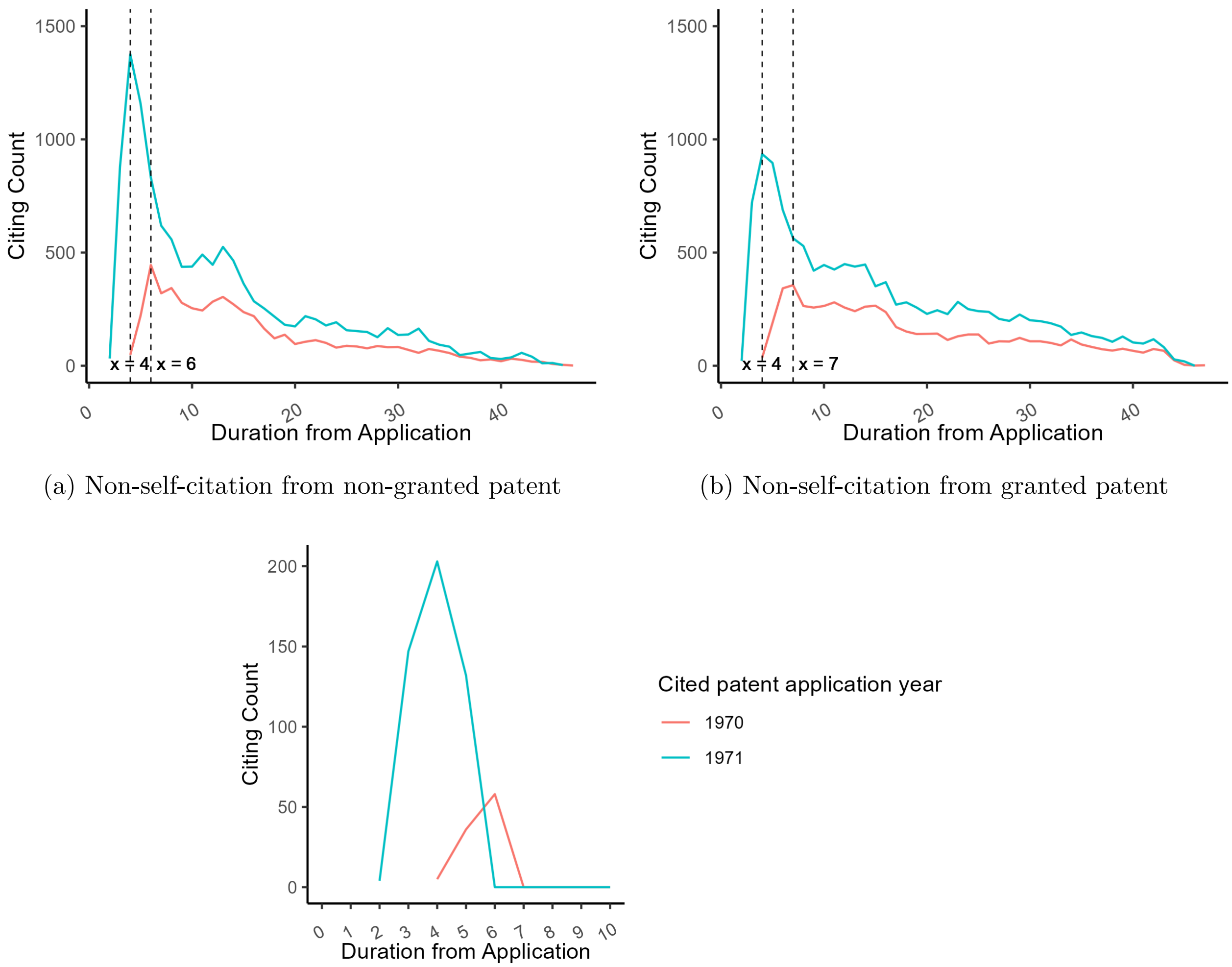
doubled.

The increase in the level of non-self-citation flow from the non-granted patent applications, as shown in Figure 3 (a), implies that there were earlier and more rejections (or abandonments) of the subsequent duplicative patent applications following the pre-grant publication of the focal patent, supporting Hypothesis 1. It indicates that there are dense subsequent patent applications competing with the focal patents, reflecting a high level of research competition. Many of such applications were rejected or abandoned because the patent applications in 1971 became prior are significantly earlier. If we focus on the patent applications in the period up to the fourth year from 1970 and 1971, there were no rejections or abandoned patent applications, citing the 1970 applications but there were a significant amount of such patent applications, citing the 1971 applications (almost 20% of the total citation flows of the entire period).

Pre-grant publication also increased the non-self-citation flow from granted patents, as shown in Figure 3 (b). It came earlier and its level doubled, supporting Hypothesis 2. The fact that both the level and the increase of citation flow from granted patent applications are smaller than those of the citation flows from non-granted patent applications suggests that the reduction in duplication is more important than the increase in competing patents for the effect of early disclosure on the value of the focal patent, which will be formally tested in the following Section. Given that it would take some time for an inventor of the other firms to recognize the focal patent and add new value through its invention, the early part of the citation flows would indicate a rejection or reduction of the patent scope of independent parallel patent applications in light of the focal patent published as prior art. On the other hand, the later part of the citation flow would be more indicative of non-duplicative new inventions.

Figure 3 also shows that the increase in citation flow is long term, suggesting that the effect of accelerating knowledge spillover is cumulative. A new invention based on the combination of knowledge from the focal patent and a new idea becomes the source of another new invention that exploits the knowledge from the focal patent. Indeed, a significant fraction of citation flows in later years cite not only the focal patent, but also the subsequent patents that directly or indirectly cite the focal patent, according to our analysis of citations in citation flows. "Old" knowledge retains its value as a source of knowledge through its combination with new knowledge, and early publication accelerates the arrival of such new combinations.

Pre-grant publication also significantly accelerated and increased the self-citation flow from granted patents, as shown in Figure 3 (c). The level of citations more than quadrupled, although the effect is more short-lived than the flow of citations from other firms. Since the pre-grant publication would not affect the knowledge flow within the applicant, such an increase in self-citations shows a stronger incentive for "pioneer" applicants to undertake follow-on research, as suggested by Hypothesis 3.



(a) Non-self-citation from non-granted patent

(b) Non-self-citation from granted patent

(c) Self-citation from granted patent

Figure 3: Response of Citation Flows from Subsequent Patents that Applied after the Disclosure of the Focal Patents

Note: The horizontal axis indicates the lag between cited and citing patent application years, and the vertical axis indicates the number of citing patents with the respective application lag.

6 Econometric model

6.1 Estimation model for hypothesis testing

Our central dependent variable is a patent value, and our central explanatory variables are the citation flows from granted or non-granted subsequent patent applications, so that controlling for the unobserved patent quality is critically important for our estimation. We use instrumental variable estimation, using the introduction of the pre-grant publication as an exogenous shock. In the first stage of our instrumental variable estimations, we estimate how the introduction of pre-grant publication affected the subsequent examiner citation flows from both non-granted and granted patent applications to the patents in the 1971 cohort year relative to those in the 1970 cohort year, depending on the publication delays as well as on the level of competition in technology sectors by firms before the policy change.

We denote the cohort year by t: before the policy change (control, 1970 cohort) and after the policy change (treatment, 1971 cohort). We also denote the cumulative number of subsequent grants and non-granted patent applications for which examiners cite a focal patent i of cohort t by $Grants_{i,t}$ and $Non\ Grants_{i,t}$ respectively. Similarly, we define $Own\ follow\text{-}on\ grants_{i,t}$ as the cumulative number of granted patent applications in the assessment for which examiners cite the focal patent i of the applicant. To construct $Grants_{i,t}$ and $Non\ Grants_{i,t}$, only citations *after* the disclosure of the focal patent are counted. On the other hand, the $Own\ follow\text{-}on\ grants_{i,t}$ counts citations before and after the disclosure. This is because the applicant learns the priority of its invention over time until its disclosure, and the applicant adjusts its investment in anticipation of the effects of the disclosure of its invention and its investment on competitors.

We use the estimated $Patent\ value_{i,t}$ as our main measure for patent value. $Patent\ value_{i,t}$ denotes the value of patent i in the cohort with application year t. Using renewal data, we estimate the distribution of patent value at application assuming a log-normal distribution, and calculate the estimated value of each patent in the Appendix A.3. We also use the indicator for the top 10% in patent value to analyze the impact of early disclosure on the upper part of the value distribution. It is an estimate of the probability that the patent value is ranked in the top 10% of the value distribution of the combined sample of 1970 and 1971 patents. $Top\ 10\%_{i,t}$ takes 1 if the patent is included in the top 10%, 0 otherwise. The number of top 10% patents in each cohort and their basic statistics are summarized in Table 13 in Appendix A.2.

Furthermore, we also use the $Survival\ length_{i,t}$ of a patent right as a supplementary measure for patent value, which informs us of a mechanism of the variations of patent value. The longer the right is maintained, the higher the patent value is. It is important to note that the survival measure is truncated due to statutory limitations on the length of the patent term (this makes the regression coefficients downward biased). The average patent $Survival\ length_{i,t}$ for the 1970 cohort to the 1971 cohort increased slightly from 16.16 months to 16.40 months. However, the percentage of patents maintained to their full term (20 years from application and/or 15 years from grant) increased from 18.98% to 29.38%. The latter made the estimated patent values of the 1971 cohort significantly more valuable (as shown in Table 1).

We specify the following second-stage equation for the patent value, for which the key explanatory variables are the number of granted patents citing the focal patent, which has a negative coefficient, and the number of rejected or abandoned patent applications citing the focal patent, which has a positive coefficient.

$$\begin{aligned} Patent\ value_{i,t}\ (Top\ 10\%_{i,t},\ Survival\ length_{i,t}) = \beta_1 Grants_{i,t} + \beta_2 Non\ Grants_{i,t} \\ + \boldsymbol{\beta}_c Controls_{i,t} + \beta_\mu \mu_{u,t} + \alpha_{i,t} + \epsilon_{i,t} \end{aligned} \tag{1}$$

We also use a parsimonious model for which we assume that $Grants_{i,t}$ and $Non\ Grants_{i,t}$ have the same coefficients ($\beta_1 = -\beta_2$), for avoiding using significantly collinear two explanatory variables. Our empirical justification of such a model is that $Grants_{i,t}$ and $Non\ Grants_{i,t}$ have coefficients of similar magnitude and opposite signs in the patent value equations (see Section 7.1). Thus, we also use following model (2) with uses $Difference_{i,t} = Grants_{i,t} - Non\ Grants_{i,t}$ as the primary explanatory variable, which signifies the relative magnitude of knowledge spillover effect and the prior art effect, and has a negative expected coefficient. If the prior art effect is more important, $Difference_{i,t}$ is negative and the patent value increases.

$$\begin{aligned} Patent\ value_{i,t}\ (Top\ 10\%_{i,t},\ Survival\ length_{i,t}) = \beta_3 Difference_{i,t} \\ + \boldsymbol{\beta}_c Controls_{i,t} + \beta_\mu \mu_{u,t} + \alpha_{i,t} + \epsilon_{i,t} \end{aligned} \tag{2}$$

We have the following first-stage equation for the two endogenous variables in Equation (1) and (2).

$$\begin{aligned} Grants_{i,t}\ (Non\ Grants_{i,t}, Difference_{i,t}) = \gamma_1 Publication\ lag\ IV_{i,t} + \gamma_2 Opposition\ period\ IV_{i,t} \\ + \boldsymbol{\beta}_c Controls_{i,t} + \beta_\mu \mu_{u,t} + \alpha_{i,t} + \epsilon_{i,t} \end{aligned} \tag{3}$$

In the above equation (3), $\mu_{u,t}, \alpha_{i,t}$ and $\epsilon_{i,t}$ represent respectively the fixed effect for technology sector u by cohort year t, unobserved quality of patent i by cohort year t, and the random component, independent of the other explanatory variables. We use 33 technology classifications (denoted by u) based on 33 WIPO classifications (see Table 19 in Appendix A.3). $\mu_{u,t}$ captures the effects of the variations of technological and market opportunities across sectors and over two year, including the variations of patenting propensity and sectoral trends. It can also control for the variations of the effects of introducing the examination request system across sectors (Section 6.2 provides further discussions).

A key identification problem is unobserved heterogeneity in patent quality $\alpha_{i,t}$. A high quality patent is more likely to be cited, so that an OLS estimation of the patent value equation (1) leads to significant upward biases in the coefficients of the citation variables (see the OLS result in Appendix A.6). To address this problem, we introduce two instrumental variables based on the introduction of pre-grant publication within 18 months of filing, which is an exogenous change in patent law in Japan for applicants, in addition to a set of control variables for patent quality. The pre-grant publication expands the prior art, which would decrease $Grants_{i,t}$ and to increase $Non\ Grants_{i,t}$, and it also accelerates the flow of knowledge, which would increase both $Grants_{i,t}$ and $Non\ Grants_{i,t}$.

The introduction of the pre-grant publication led to a large reduction in the lag from the application date to the publication date (publication lag), depending on the pre-existing lags of the sectors and firms. That is, the reductions in lags tend to be larger in those sectors or firms with large lags due to longer publication lags before the patent law change. For our first instrument, we use the pre-reform average publication lags from the application to the publication of a patent for each combination of technology sector and applicant firm in 1970. This instrument reflects the variation in the acceleration of knowledge flow across combinations of technology sector and applicant firm.

The effect of early disclosure is also likely to be larger when there are more competitors in R&D. More and earlier knowledge flows would take place as the number of competitors increases. More rejections and abandonments would also take place. For the second instrument, we use average lags from publication to patent grant (we call this as the opposition period) for each combination of technology sector and applicant firm in 1970. The pre-grant opposition system existed in Japan until the 1994 amendment of the Japanese patent law. Opposition period becomes longer as more oppositions are filed, so the length of the period would serve as a measure of the number of competitors in R&D.[5] One alternative for opposition period is the number of the parties who opposed the patent grant, which, as an instrument, gave us very similar estimation results as to those using based on the opposition

[5]Rival firms have a strong incentive to challenge the patent grants. The study group by the JPO pointed out that there are "quite a few" cases where such parties conduct oppositions anonymously. `https://www.jpo.go.jp/resources/shingikai/sangyo-kouzou/shousai/hunsou-shoi/02-gijiroku.html`. [Accessed October 26, 2023. Written in Japanese.]

period as an instrument.

Thus, we adopt the following two instrumental variables as indicated in the first stage equation (3): *Publication lag IV* and *Opposition period IV*. *Publication lag IV* is the interaction term between the patent law change dummy ($Reform\ IV = 1\ for\ t = 1971,\ and\ 0,\ otherwise$) and the average publication lag in 1970 (year before the reform) for each combination of technology sector and applicant firm, the mean centered on the aggregate average of the publication lag. If the variation in the increase of the full prior art is more important, large *Publication lag IV* will reduce the number of grants and increase the number of non-grants. *Opposition period IV* is the interaction term between the patent law change dummy and the average opposition period for each combination of technology sector and applicant firm in 1970, the mean centered on the aggregate average opposition period. We expect that large *Opposition prob IV* will have larger effects in both the number of grants and non-grants, if it reflects more the knowledge flow effect. Since we used the mean centering for the logs of publication lag and opposition period variables in generating the IV variables and introduce sector by year dummies as controls, these two IV instruments exploit only the variations of these two variables across sectors.

$Controls_{i,t}$ is a vector of variables that control for the invention quality of patent i and for applicant characteristics. The patents with higher invention quality tend to be more cited and have high values, so that invention quality is an important source for the positive correlations between the two. We use the size of the international patent family ($Patent\ family_{i,t}$) to which the focal patent belongs as an indicator of the patent quality. When the invention quality is high, its family size tends to be large.

We also control for the following basic firm characteristics for an applicant firm f: firm size in terms of the flow and stock of patent grants as well as invention quality in terms of the number of non-grants. We introduce *Grants*, *Non Grants*, aggregated for each firm from patents applied in 1969 ($Previous\ Grants_f$, $Previous\ Non\ Grants_f$), and the number of patents owned by a firm in the same year ($Owned\ Patents_f$). Table 15 in Appendix A.2 shows the basic statistics for each instrumental variables and control variables.

Finally, we control for sectoral differences and their variations over two periods in technological opportunities and demand conditions by the interactions of WIPO 33 technology classes and two cohort years. Thus, we do not exploit the overall and sectoral variations over two years in our estimations. Given these controls, we expect that the two instruments based on the patent law change dummy at the technology sector by firm level are unlikely to be significantly correlated with an unobserved heterogeneity of individual patent quality.

Introducing technology by year fixed effects makes us to use only the variations over two years within each technology sector for our estimation, which can result in the significant loss of information from the responses of the firms to the policy change. Thus, we also conduct estimations based on a model introducing the policy discontinuity as a single instrument and WIPO technology sector dummies and pre-trend (monthly trend whose slope is estimated based on 1970 data only), instead of sector by year dummies, as controls, in Section 8 as a robustness check. Such a model allows us to use the entire discontinuities in the patent values and citation variables over two years (see Section 8 for further details) for estimating parameters and avoids using the variations across firms as instruments.

To test hypothesis 3, we use the following reduced form model with the number of subsequent patents, citing the focal patent and granted to the applicant itself ($Own\ follow\text{-}on\ grants_{i,t}$) as a dependent variable. We replace the dependent variable of Equation 3 (the first stage model of IV estimation) by $Own\ follow\text{-}on\ grants_{i,t}$. Due to the weakness of the two IV variables for explaining $Own\ follow\text{-}on\ grants_{i,t}$ with the controls by $\mu_{u,t}$ (sector by year dummies), we use the policy discontinuity dummy from 1970 to 1971 ($Reform\ IV$, $1\ for\ t = 1971,\ and\ 0,\ otherwise$) as the main explanatory variable, with sector dummies μ_u, as a control. As stated in Hypothesis 3, there are two mechanisms by which early disclosure enhances own follow-on inventions, despite no knowledge spillover effect exists for own subsequent invention: first, the effect of establishing its priority early, which exists even when there is no R&D competition, and second, the effect of anticipated early knowledge spillover to the competitors, which would be significant only if there is R&D competition. In order to distinguish the two mechanisms, we introduce a new variable, $Competitive$. $Competitive$ which is a dummy variable for each patent that takes value 0 if the applicant firm faced no opposition[6] in 1970 in the technology sector for which the patent is classified, otherwise 1. We use the cross term $Reform\ IV * Competitive$ to capture the additional effect of policy change through the anticipated early knowledge spillover to the competitors, which would occur in only sectors with R&D competition. Thus, our estimation model is specified as follows:

$$\begin{aligned} Own\ follow\text{-}on\ grants_{i,t} = \delta_1 Reform\ IV_{i,t} + \delta_2 Reform\ IV_{i,t} * Competitive_{i,t} + \\ \boldsymbol{\beta}_c Controls_{i,t} + \beta_\mu \mu_u + \alpha_{i,t} + \epsilon_{i,t} \end{aligned} \tag{4}$$

Early recognition of its priority accelerates the follow-on inventions by the applicant of the focal patent, so that we expect that $Reform\ IV$ has a significantly positive coefficient. We expect that the existence of competition would increase such response. We also expect

[6] The opposition probability at patent level becomes 4% or more, if the opposition period exceeds 286 days. The average probability of opposition for the data set is about 8%, and the shorter the opposition period, the lower the probability of being opposed to.

that this effect exists even for the own follow-on inventions before the disclosure of the focal patent.

6.2 Discussions of the assumptions of the estimation model

There are two issues to be addressed regarding the appropriateness of our estimation strategy using the 1970 cohort as the control and the 1971 cohort as the treatment. The first is the issue of sample selection due to the effect of early disclosure on the propensity to patent. If early disclosure had a significant negative effect on the use of patenting and increased the use of trade secrets, our analysis could be significantly confounded by such an effect. Early literature (Anton and Yao, 2004) argues that large inventions are primarily protected by secrecy when property rights are weak. However, the total number of patents increased if we exclude the shift period (the 3 month period before and after the reform), as seen in Table 1. Moreover, more secrecy protection of high-value inventions work against us to find support for our hypothesis that early disclosure increased the value of patenting.

The second issue is the effect of the introduction of the examination request system on the sample selection for the 1971 cohort. The examination request rate was 83.2% in 1971, which declined over years and to 71.0% in 5 years later. The average private value of a patent might have increased by allowing the applicant to avoid requesting an examination of those applications that have been found to be of low patent value, over the period of 7 years after the application. At the same time, however, the examination request system encourages firms to try more experimental patent applications in order to exploit their option value, as uncertainty is reduced over time. In fact, the number of grants increased significantly by around 10% from 1970 (first 9 months) to 1971 (last 9 months), as seen in Table 1 and 2. Moreover, it is likely that it does not significantly affect the number of inherently high-value patents[7] because examination requests would be always made for high-value patent applications.

Our basic estimation model in Section 7 controls for differential trends by sector (WIPO technology sectors by year dummies, see equation (1)), which can control for average changes in patent values at the technology sector level, including those due to the introduction of the examination request system and due to the changes in the propensity to patent. Our estimation models in Section 8 do not introduce such WIPO technology sectors by year dummies, except that we control for pre-trends observed in 1970. However, in Section 8, we conduct a subsample analysis that divides the data by the levels of examination request rates, showing that the results do not significantly depend on such levels once we control for

[7]"Inherently high-value patents" mean that they are of high-value, disregarding the effects of early disclosure.

the levels of the publication lag before the reform.

7 Basic results based on the primary sample

We present the result for the first stage of the IV estimation in Table 4 based on the model specified in equations (1) and (2) in Section 6.1 (basic estimation model). Our first instrument *Publication lag IV* has a significantly positive coefficient for $Non\ Grants_{i,t}$, and a negative but weakly significant coefficient for $Grants_{i,t}$, as shown in Table 4. Long publication lag in 1970 means large acceleration in publication due to the policy change, because the publication lag in 1971 is uniform across sectors and firms (one year and half). After the acceleration of the disclosure, the number of non-grants (rejections or abandonments) citing the focal patent ($Non\ Grants_{i,t}$) increased significantly more in the sectors and firms with longer publication lags before the legal change. At the same time, the number of grants citing the focal patent ($Grants_{i,t}$) tended to decrease more in those with longer publication lags. Larger publication lag reduce $Difference_{i,t}$ significantly through these two effects.

Our second instrument *Opposition period IV* has significantly positive coefficients for both $Grants_{i,t}$, and $Non\ Grants_{i,t}$, as shown in Table 4. Controlling for the level of the acceleration of the publication, both the number of grants and the number of non-grants citing the focal patent increased significantly more in the sectors and firms with longer opposition periods. *Opposition period IV* has a only weakly significant coefficient with small value for $Difference_{i,t}$, because the coefficients for $Grants_{i,t}$, and $Non\ Grants_{i,t}$, are both positive.

The results that both *Publication lag IV* and *Opposition period IV* have significantly positive coefficients for $Non\ Grants_{i,t}$ provide support to the first part of Hypothesis 1 that earlier publication reduced duplications by making the focal patent become full prior art earlier. The results that *Opposition period IV* has a significantly positive coefficient for $Grants_{i,t}$ provide support to the first part of Hypothesis 2 that earlier publication increases the subsequent patents granted to the other firms by accelerating knowledge spillover to them.

The second stage of the IV estimation for $Patent\ value_{i,t}$, $Top\ 10\%_{i,t}$ and $Survival\ length_{i,t}$ as the dependent variables are reported in Table 5.[8] Table 5 shows that $Grants_{i,t}$ and $Non\ Grants_{i,t}$ have highly significant coefficients with similar magnitude but opposite signs for all of these dependent variables in Model 1, 3 and 5. $Difference_{i,t}$ also has highly significant negative coefficients for all of these dependent variables. Thus, the increase of the number of non-grant outcomes of the subsequent patent applications and the decrease in

[8]The estimation details for patent value (the unit is 1 million yen in 2022) are given in Appendix A.3

the number of grant outcomes of the subsequent patent applications, both citing the focal patent, are significantly positively associated with the increase of the patent value and the survival length of the cited patents. The probability of the patent being ranked in the top 10% and the survival time of the patent also increase significantly with such changes. These results strongly support the second part of Hypothesis 1 and 2.

Note that the estimations for Model 1, 3 and 5 do not satisfy the threshold of weak instrument test (See the row of IV Test in Table 5), so that the coefficients estimated for these Models may not be robust. However, the estimations for Model 2, 4 and 6 roughly satisfy the threshold of weak instrument test, so that the coefficients of $Difference_{i,t}$ are robust. Thus, we can confidently say that the decrease of the grants of others' follow-on patents or the increase of the rejections (and abandonments) of others' duplicative patent applications by one unit increased the patent value by 1.6 Million Yen and the probability of top 10% patents by 0.34 percent point. Moreover, the coefficient of $Difference_{i,t}$ is close to those of $Grants_{i,t}$ and $Non\ Grants_{i,t}$ for each dependent variable, indicating that the difference formulation works well.

Appendix A.4 reports the results of estimations based on patent value at grant for second stage estimations. They are very similar to those reported in this Section for the probability of Top 10%. The size of the coefficients for patent value are significantly smaller than those reported in this Section, because there exist depreciations of patent values starting from applications, but they remain significant and share the same signs. Thus, the results are robust even if we patent value at grand instead of patent value at grant.

Table 4: First Stage Regression Result of Instrumental Variable Estimation for Equation (1)

	Grants	Non grants	Difference
	Model 1	Model 2	Model 3
Publication lag IV	-0.086*	0.130***	-0.215***
	(0.050)	(0.047)	(0.054)
Opposition period IV	0.130***	0.073***	0.057*
	(0.030)	(0.028)	(0.033)
(Intercept)	0.316***	0.300***	0.015
	(0.032)	(0.030)	(0.034)
Controls	Yes	Yes	Yes
Tech Sector x Year Dummies	Yes	Yes	Yes
Num.Obs.	43268	43268	43268
R2	0.031	0.031	0.005
R2 Adj.	0.030	0.030	0.004

*** 1% significance, ** 5% significance, * 10% significance

Table 5: Second Stage Regression Result for Equation (1)

	Patent value		Top 10%		Survival length	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Grants	-1.578***		-0.328***		-2.263**	
	(0.515)		(0.110)		(0.956)	
Non grants	1.809***		0.375**		2.979**	
	(0.691)		(0.148)		(1.284)	
Difference		-1.644***		-0.342***		-2.468***
		(0.467)		(0.100)		(0.863)
(Intercept)	0.640***	0.710***	0.002	0.016	15.671***	15.890***
	(0.227)	(0.071)	(0.049)	(0.015)	(0.422)	(0.132)
IV Test	6.89	9.76	6.89	9.76	6.89	9.76
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Tech Sector x Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Num.Obs.	43268	43268	43268	43268	43268	43268

*** 1% significance, ** 5% significance, * 10% significance

Note: The unit of Patent value is 1 million in 2022 yen. IV test is the F-value from the Stock and Yogo (2005) weak IV test.

8 Robustness check

This Section conducts robustness checks of the basic estimation results in Section 7, using the policy discontinuity between 1970 and 1971 ($Reform\ IV$) as the instrumental variable. In the estimations in Section 7, we used only the relative variations of the variables across sectors by firms and introduces technology sector by year dummies as controls, so that we may have lost significant information contained in the inventors' responses to discontinuity in the policy from 1970 in identifying the policy effect. We can fully exploit that by the combination of $Reform\ IV$ and technology sector dummies un-interacted with years. An additional advantage of $Reform\ IV$ is that its discontinuity is clearly uncorrelated with missing patent quality $\alpha_{i,t}$. in equation (2) and (3) in Section 7. That is, we do use only the variations across technology sectors for identifying the effects of the policy change in this Section. We use the parsimonious model using only Difference as an endogenous explanatory variable, since we have only one instrument.

Since we do not introduce year by sector dummies, our estimations in this Section do not directly control for the impact from the introduction of the examination request system in 1971 on the average patent values through sample selection. Thus, the coefficients of $Reform\ IV$ could partially reflect the effect of the introduction of the examination request system. We assess how significant such confounding effect is by conducting a subsample analysis in the latter part of this Section.

Robustness check for patent value estimations

We introduce a new IV ($Reform\ IV$) which directly exploits the policy discontinuity from 1970 to 1971 for the endogenous explanatory variable $Difference_{i,t}$ which is the difference between $Grants_{i,t}$ and $Non\ Grants_{i,t}$. We use equation (2) in Section 6.1 for our second stage estimation for patent value, with the following differences: We use sectoral dummies, and pre-trend as controls if it is significant, instead of sector (and firm) by year firm dummies. We estimate such models for three dependent variables ($Patent\ value_{i,t}$, $Top\ 10\%_{i,t}$ and $Own\ follow\text{-}on\ grants_{i,t}$). We estimated the pre-trend of the dependent and endogenous variables, using the data for the first 9 months in 1970.[9] The estimated monthly pre-trends are reported in Table 16 in Appendix A.2. The estimated monthly pre-trends are subtracted from each variable with a significant pre-trend, in order to prevent these pre-trends to confound our estimations.

The estimation results for the first stage are presented in Table 6, which show that $Reform\ IV$

[9] For an example, $Patent\ value_{i,t}$ has a significant pre-trend of 0.008 per month, equivalent to 0.096 per year, which is a third of the change from 1970 to 1971.

is highly significant for $Difference_{i,t}$, controlling for the pre-trends, and the other control variables. The estimated coefficient is -0.096. We also present the estimation results for the $Grants_{i,t}$ and $Non\ Grants_{i,t}$, 0.18, and 0.28 respectively. All of these three estimates are highly significant, implying that the policy change led to the increase of $Non\ Grants_{i,t}$ by 0.28 and that of $Grants_{i,t}$ by 0.18, casing the reduction of $Difference_{i,t}$ by 0.096 on average.

We conducted the second stage estimation for the models using $Difference_{i,t}$ as the main explanatory variable. Table 7 shows that $Difference_{i,t}$ is highly significant for three dependent variables. The estimated coefficients for $Patent\ value_{i,t}$ and the probability of Top 10% are highly significant and have the same signs as those in Table 5. Their estimated coefficients are larger than those in Table 5 in absolute values: -2.35 vs. -1.80, and -0.54 vs. -0.34, but are of the same sign and of similar magnitudes. Thus, the main empirical findings from Section 7 are robust under an alternative IV approach using the policy discontinuity fully. Early disclosure enhanced patent value by increasing the number of rejections and abandonments citing the focal patent more than the number of grants citing the focal patent. The simulated increase of the average patent value is 0.23 for patent value and 0.052 or 5.2 percent points. These values are close to what we observe in Table 2: the increase of 0.30 for patent value and the increase of 6.2 percent for the probability of top 10% patent.

Table 6: First Stage Regression Result of a Model Using Only Reform IV

	Difference	Grants	Non grants
	Model 1	Model 2	Model 3
Reform IV	-0.096***	0.177***	0.281***
	(0.011)	(0.010)	(0.009)
(Intercept)	-0.080***	0.203***	0.284***
	(0.028)	(0.026)	(0.024)
Controls	Yes	Yes	Yes
Tech Sector Dummies	Yes	Yes	Yes
Subtract Pre-Trend	Yes	Yes	Yes
Num.Obs.	43268	43268	43268
R2	0.006	0.019	0.030
R2 Adj.	0.005	0.018	0.029

*** 1% significance, ** 5% significance, * 10% significance

Table 7: Second Stage Regression Result of a Model Using Only Reform IV

	Patent value	Top 10%	Survival length
	Model 1	Model 2	Model 3
Difference	-2.348***	-0.544***	-1.823***
	(0.291)	(0.067)	(0.374)
(Intercept)	0.758***	0.057***	15.969***
	(0.082)	(0.019)	(0.105)
IV Test	83.58	83.58	83.58
Controls	Yes	Yes	Yes
Tech Sector Dummies	Yes	Yes	Yes
Subtract Pre-Trend	Yes	Yes	Yes
Num.Obs.	43268	43268	43268

*** 1% significance, ** 5% significance, * 10% significance

Note: The unit of Patent value is 1 million in 2022 yen. IV test is the F-value from the Stock and Yogo (2005) weak IV test.

As discussed in Section 6.2, the coefficients of $ReformIV$ could partially reflect the effect of the introduction of the examination request system. We perform the following subsample analysis to assess the effect of the examination request system on our estimations. We implement estimations for the following four subsamples. Model 1 (large lags and small examination requests): All patents applied 1970 and 1971 in the sectors with publication lag longer than 1970 average and the examination request rate lower than 1971 average. Models 2 (large lags and large examination requests): those in the sectors with Publication lag longer than 1970 average and the examination request rate higher than 1971 average, Model 3 (small lags and small examination requests), those in the sectors with publication lag shorter than 1970 average and the examination request rate lower than 1971 average. Model 4 (small lags and large examination requests), those in the sectors with publication lag shorter than 1970 average and the examination request rate larger than 1971 average. The number of patents in 1971 corresponding to each model are 6,390, 6,094, 4,233, and 5,688, respectively.

Table 8 and 9 show the results of the first and second stages of IV estimation for these models with subsample. The first stage results on $Difference_{i,t}$ are significant and similar across the four models, according to Table 8. As shown in Table 9, once we control for publication lag either at large or small, the difference in the level of examination request rates are not associated with large differences of the estimated coefficients of $Difference_{i,t}$. They are similar between Models 1 and 2 (-2.63 and -2.88) and between Models 3 and 4

(-1.90 and -2.10). On the other hand, even if we control for the level of examination request rates either at large or small, the difference in the publication lag is associated with large differences of the estimated coefficients of $Difference_{i,t}$. A Model with larger publication lag has a significantly larger coefficient: -2.63 for Model 1 vs. -1.90 for Model 3 and $-2,88$ for Model 2 vs. -2.10 for Model 4.

The above results suggest that the difference of the publication lag or the extent of the difference of acceleration from the policy change is the more important driver of the increase of the average patent value in 1971. They would also provide a partial explanation of why we observe a larger coefficient for $Difference_{i,t}$. in this Section than in Section 7 (-2.35 in Table 5 vs. -1.64 in Table 7), for which we control extensively for the effects of the introduction of examination request system by technology sector by year dummies.

Table 8: First Stage Regression Result of a Model Using Only Reform IV, Subsample Analysis

	Difference			
	Model 1 (Large lags and small examination requests)	Model 2 (Large lags and large examination requests)	Model 3 (Small lags and small examination requests)	Model 4 (Small lags and small examination requests)
Reform IV	-0.098***	-0.075***	-0.110***	-0.097***
	(0.017)	(0.022)	(0.020)	(0.019)
(Intercept)	-0.100***	-0.088***	-0.117***	-0.118***
	(0.035)	(0.028)	(0.034)	(0.035)
Controls	Yes	Yes	Yes	Yes
Tech Sector Dummies	Yes	Yes	Yes	Yes
Subtract Pre-Trend	Yes	Yes	Yes	Yes
Num.Obs.	27253	26957	25096	26551
R2	0.009	0.006	0.007	0.007
R2 Adj.	0.008	0.005	0.005	0.006

*** 1% significance, ** 5% significance, * 10% significance

Table 9: Second Stage Regression Result of a Model Using Only Reform IV, Subsample Analysis

	Patent value			
	Model 1 (Large lags and small examination requests)	Model 2 (Large lags and large examination requests)	Model 3 (Small lags and small examination requests)	Model 4 (Small lags and small examination requests)
Difference	-2.634***	-2.878***	-1.900***	-2.099***
	(0.507)	(0.930)	(0.405)	(0.479)
(Intercept)	0.646***	0.715***	0.709***	0.687***
	(0.116)	(0.141)	(0.091)	(0.101)
IV Test	11.2	32.75	25.33	30.7
Controls	Yes	Yes	Yes	Yes
Tech Sector Dummies	Yes	Yes	Yes	Yes
Subtract Pre-Trend	Yes	Yes	Yes	Yes
Num.Obs.	27253	26957	25096	26551

*** 1% significance, ** 5% significance, * 10% significance

Note: The unit of Patent value is 1 million in 2022 yen. IV test is the F-value from the Stock and Yogo (2005) weak IV test.

9 Ones' Own Follow-on inventions

We use the reduced form model on $Own\ follow\text{-}on\ grants_{i,t}$ (that is, own follow-on inventions granted), using $Reform\ IV$ as exogenous variable, as in Section 8. As shown in Table 3, the frequency of the $Own\ follow\text{-}on\ grants_{i,t}$ is two orders of magnitude smaller than those of $Grants_{i,t}$ and $Non\ Grants_{i,t}$, so that it is difficult for us to estimate the policy impact, using the estimation model in Section 7, using only the variations of the effects of the policy shock across sectors and firms as IVs. The combination of $Reform\ IV$ and sector dummies allow us to estimate the impact of the policy change on own follow-on inventions. There is no pre-trend for $Own\ follow\text{-}on\ grants_{i,t}$ (see Table 16), so that we do not control for this.

We also use *Competition* introduced in Section 6.1 to identify the two mechanisms (the effect of establishing its priority early and the effect of anticipated early knowledge spillover to the competitors) by which early disclosure enhances own subsequent inventions. For 36% of the patents the firm had no oppositions in 1970 in the corresponding sector. Our estimation model is specified based on equation (4) in Section 6.1.

Table 10 reports the results: In Model 1 to 4, the coefficient of $Reform\ IV$ is highly significant and the estimated coefficient implies a significant increase of the $Own\ follow\text{-}on\ grants_{i,t}$ by 0.021 in the case of Model 1 and by 0.004 if we focus on citations made only before disclosure in Model 3. The result indicated that early disclosure enhanced the own follow-on patents by the applicant and that it did so even if we focus on those citations made before the disclosure of a focal patent. Because the disclosure itself got accelerated in 1971, the result indicated that the own follow-on inventions accelerated and increased significantly.

The Model 2 and 4 provide estimations differentiating applicants by sectors facing competition or not. $ReformIV$ is significant in both Model 2 and 4, while $ReformIV * Competitive$ is significant only in Model 2. The significance of $ReformIV$ in both Models suggests that early disclosure significantly increased and accelerated the own follow-on patents even if competition is absent or weak, suggesting that the pure effect of establishing priority early was significant for such investment. The significance of the interaction term ($ReformIV * Competitive$) in Model 2 also implies that the applicant's response to competition was also a significant reason for the positive effect of early disclosure on own follow-on patents, although it is less important than the effect of early establishment of priority. The interaction term is not significant in model 2, suggesting that most responses of the applicant to competition occurred after the disclosure of its own patent application.

Table 10: Regression Result for Own Follow-on Inventions

	Own follow-on grants (all)		(Excluding citations after disclosure)	
	Model 1	Model 2	Model 3	Model 4
Reform IV	0.021***	0.022***	0.004***	0.004***
	(0.002)	(0.002)	(0.001)	(0.001)
Reform IV * Competitive		0.008***		0.000
		(0.002)		(0.001)
(Intercept)	-0.006	-0.012***	0.000	-0.001
	(0.004)	(0.004)	(0.002)	(0.002)
Controls	Yes	Yes	Yes	Yes
Tech Sector Dummies	Yes	Yes	Yes	Yes
Subtract Pre-Trend	Yes	Yes	Yes	Yes
Num.Obs.	43268	43268	43268	43268
R2	0.006	0.007	0.002	0.002
R2 Adj.	0.006	0.006	0.001	0.001

*** 1% significance, ** 5% significance, * 10% significance

Note: We confirm that there is no trend for the number of self citation before disclosure in our regression analysis.

10 Discussion based on the secondary sample

As a further extension, we discuss the effect of the pre-grant publication, using the patents applied in the last 3 months of 1970 and in the first 3 months of 1971. As shown in Figure 1 and Table 3 in Section 3 and Appendix A.1, there were very significant shifts of the applications from the first quarter 1971 to the last quarter of 1970, amounting to a half of the average number of patents granted quarterly during for these two years.

There are two strong evidence suggesting that the applicants accelerated the applications of high quality inventions from 1971 to 1970. First, Tables 2 in Section 2 and 12 in Appendix A.1 show that the average number of non-self citations from granted patents for the sample of the first 9 months and that of the last 3 months in 1970. It is 0.25 for 9 months period, which is smaller than 0.28 for the 3 months period. Second, according to Tables 1 and 11 for 1970, $Patent\ value_{i,t}$ is higher in the last 3 month period than in the first 9 month period (0.912 for the 9 month period, and 0.917 for the 3 month period). These two differences suggest that the applicants shifted their relatively high quality patents to the last 3 months of 1970.

Consistently, the opposite relationship is observed in the 1971 sample from which the patent applications were shifted. The number of citing patents that resulted in grants for the last 9 month period is 0.46 (Table 2), while it is 0.42 that for the first 3 month period (Table 12). The Patent value is 1.215 in the 9 month period (Table 1), while 1.205 for the 3 month period (Table 11). Thus, the average patent quality of the 3 month period in 1971 is lower than that of the 9 month period, supporting the strategic shift by the applicants of their relatively high quality inventions from 1971 to 1970.

Despite this shift of the patents which is adverse to the 1971 sample, the average patent value for the first 3 months in 1971 is larger than that for the last 3 months 1970. Such reversal of the values can then be attributed to the pre-grant publication of the applications made only for the patents applied in 1971.

These findings suggest that from an ex-post point of view this was not a rational acceleration by companies. It is unclear what caused this seemingly irrational shift in Japan in 1970, given that about 92.5% of the U.S. firms chose pre-grant publications for the AIPA in 2001. One hypothesis is a prisoner's dilemma: an applicant prefers to protect secrecy longer by accelerating application as a unilateral action, even if all applicants gain from coordinated earlier disclosures. Unless most applicants commit to early disclosure, early publication by one applicant does not establish priority with certainty. Another hypothesis is the lack of understanding by Japanese firms regarding the effects of information disclosure in 1970. The risk of imitation through disclosure of patent information is easily recognized, while the value of establishing priority of patent is not easily recognized.

11 Conclusions

This paper has examined how early publication of a patent application affects the private value of a patent not only by accelerating knowledge spillover but also by establishing its priority early, using the introduction of pre-grant publication in Japan as a natural experiment. We find that early disclosure increased the rejections (and abandonment) of the subsequent duplicative patent applications by others more than the grants of their follow-on patents. Larger increase of non-granted patent applications than that of the granted patent applications significantly reduced the patent value, so that the patent value increased on average. Furthermore, consistent with the importance of early priority setting, early publication also increased the number of grants of the own follow-on inventions, more so when competition is significant. Thus, pre-grant publication promoted appropriation through early determination of who was a pioneer.

For these identifications, we have introduced two instrumental variables: the introduction of pre-grant publication in Japan interacted with variations in the extent of publication lag and with those in the level of competition before the introduction of pre-grant publication. They capture well the following two distinct mechanisms of how early publication affects subsequent inventions. We find that earlier publication increased non-grants but not grants (a weak but negative effect on grants), citing the focal patent, controlling for the level of competition. The results are consistent with the expected effect of making the focal patent becoming a full prior art earlier. We also find that more competitors (measured by longer opposition period) increased both the number of grants and the number of non-grants citing the focal patent, controlling for the extent of publication acceleration. The latter results are consistent with the expected positive effect of the number of competitors on knowledge spillover.

The results of the difference between the grant and non-grant outcomes citing the focal patent and on its value are robust, irrespective of whether we use only cross-sectional variations of the effects of the introduction of pre-grant publication as instrumental variables or we use the policy discontinuity between 1970 and 1971 (beyond pre-trends) as an instrumental variable. The results are also robust, whether we use the patent values at applications or those at grants.

Our sample for estimations did not cover the three months before and after the introduction of the pre-grant publication in Japan in January 1970, because we observe a significant shift of patent applications from 1971 to 1970 just before the policy reform, apparently to avoid the pre-grant publication. Very interestingly, our evidence suggests that such acceleration led to a reduction in the private values of these patents, contrary to the intentions of the applicants. One explanation for such irrational acceleration is a Prisoner's dilemma, since unilateral disclosure does not establish priority and invites one-way spillover. An alternative explanation is that the applicants did not well recognize the value of early disclosure well, as those scholars opposing the introduction of pre-grant publication in the US.

This paper has established a hitherto not well established role of disclosure as well as its significance: it plays an essential role in establishing the priority of the invention. As a result, pre-grant publication can enhance the patent value and the ex-ante incentive for RD by reducing duplications and accelerating own follow-on inventions. Early disclosure has a major potential advantage as an innovation policy: it can potentially promote both diffusion and appropriation. Although pre-grant publication would have smaller impact on priority in the US where undisclosed prior patent applications at a patent office works fully as prior art, it would still play an important role for making competitors becoming aware of the prior art early and for making the inventing firm know early whether it is a "pioneer" firm or not. Early publication may also help examiners to identify prior art more completely. [10]

[10] The timing of the examiner citations accelerated sharply with the introduction of the pre-grant pub-

Although the effect on appropriation depends on the balance between grant outcomes and non-grant outcomes of the follow-on patent applications, there is a possibility that the current 18 months secrecy period before the publication is too long for the appropriation objective itself. The policy makers could consider several policy options, which would include general coordinated acceleration of disclosure, earlier disclosure in the technology sectors with short technology cycles, and early disclosure for the patent applications using the grace period.

lication in the US (the American Inventor's Protection Act (AIPA) in 1999), suggesting the importance of publications for the examination even before the AIA (see Okada and Nagaoka (2020))

References

Akcigit, Ufuk and Qingmin Liu, "The Role of Information in Innovation and Competition," *Journal of the European Economic Association*, 2016, *14* (4), 828–870.

Anton, James J. and Dennis A. Yao, "Little Patents and Big Secrets: Managing Intellectual Property," *The RAND Journal of Economics*, 2004, *35* (1), 1–22.

Aoki, Reiko and Yossi Spiegel, "Pre-Grant Patent Publication and Cumulative Innovation," *International Journal of Industrial Organization*, May 2009, *27* (3), 333–345.

Baruffaldi, Stefano H. and Markus Simeth, "Patents and Knowledge Diffusion: The Effect of Early Disclosure," *Research Policy*, May 2020, *49* (4), 103927.

Bessen, James, "The Value of U.S. Patents by Owner and Patent Characteristics," *Research Policy*, June 2008, *37* (5), 932–945.

Drivas, Kyriakos, Zhen Lei, and Brian D. Wright, "Application Publication or Confirmation of Grant: Which Matters More for Academic Technology Transfer?," *International Journal of Industrial Organization*, January 2018, *56*, 204–228.

Galasso, Alberto and Mark Schankerman, "Patents and Cumulative Innovation: Causal Evidence from the Courts," *The Quarterly Journal of Economics*, 2015, *130* (1), 317–370.

Graham, Stuart J. H. and Deepak Hegde, "Do Inventors Value Secrecy in Patenting? Evidence from the American Inventor's Protection Act of 1999," https://papers.ssrn.com/abstract=2170555 December 2014.

_ and _ , "Disclosing Patents' Secrets," *Science*, January 2015, *347* (6219), 236–237.

Hegde, Deepak and Hong Luo, "Patent Publication and the Market for Ideas," *Management Science*, February 2018, *64* (2), 652–672.

_ , Kyle Herkenhoff, and Chenqi Zhu, "Patent Publication and Innovation," *Journal of Political Economy*, July 2023, *131* (7), 1845–1903.

Horstmann, Ignatius, Glenn M. MacDonald, and Alan Slivinski, "Patents as Information Transfer Mechanisms: To Patent or (Maybe) Not to Patent," *Journal of Political Economy*, 1985, *93* (5), 837–858.

Johnson, Daniel K. N. and David Popp, "Forced out of the Closet: The Impact of the American Inventors Protection Act on the Timing of Patent Disclosure," *The RAND Journal of Economics*, 2003, *34* (1), 96–112.

Jr., Edward R Ergenzinger, "THE AMERICAN INVENTOR'S PROTECTION ACT: A LEGISLATIVE HISTORY," *Wake Forest Journal of Business and Intellectual Property Law*, 2006, *7* (1), 28.

Lück, Sonja, Benjamin Balsmeier, Florian Seliger, and Lee Fleming, "Early Disclosure of Invention and Reduced Duplication: An Empirical Test," *Management Science*, June 2020, *66* (6), 2677–2685.

Nagaoka, S., N. Tsukada, K. Onishi, and Y. Nishimura, "Innovation Process in Japan in the Early 2000s as Seen from Inventors: Agenda for Strengthening Innovative Capability," *RIETI Discussion Paper Series*, 2012, *12-J-033.*

Okada, Y. and S. Nagaoka, "Effects of Early Patent Publication on Knowledge Dissemination: Evidence from U.S. Patent Law Reform," *Information Economics and Policy*, June 2020, *51*, 100852.

Sampat, Bhaven and Heidi L. Williams, "How Do Patents Affect Follow-On Innovation? Evidence from the Human Genome," *The American Economic Review*, 2019, *109* (1), 203–236.

Schankerman, Mark, "How Valuable Is Patent Protection? Estimates by Technology Field," *The RAND Journal of Economics*, 1998, *29* (1), 77–107.

Stock, James and Motohiro Yogo, *Identification and Inference for Econometric Models*, New York: Cambridge University Press, 2005.

Thompson, Neil C. and Jeffrey M. Kuhn, "Does Winning a Patent Race Lead to More Follow-on Innovation?," *Journal of Legal Analysis*, 2020, *12*, 183–220.

A Appendix

A.1 The statistics tables for shift period

Table 11: Basic Statistics of Granted Patent in Japan Applied in the last 3 months of 1970 and the first 3 months of 1971

1970 Cohort, last 3 months

Variables	Mean	Sd	Min	Max	N
Lag time between application and publication (days)	1618.8	519.8	505	4579	16551
Lag time between publication and grant (days)	311.8	234.8	157	4482	16549
Grant year	1975.7	1.5	1972	1987	16685
Expiration year	1986.2	3.1	1978	1990	16685
Survival length from application (months)	16.2	3.1	8	20	16685
Full term (%)	20.89	40.66	0	100	16685
Patent value	0.917	1.174	0	10.244	16685
Top 10% (%)	0.078	0.268	0	1	16685
Opposition probability	0.084	0.278	0	1	16685

1971 Cohort, first 3 months

Variables	Mean	Sd	Min	Max	N
Lag time between application and publication (days)	548.5	1.5	547	550	5303
Lag time between publication and grant (days)	1920.0	606.7	503	5526	5303
Grant year	1977.4	1.7	1973	1987	5526
Expiration year	1987.2	3.4	1978	1991	5526
Survival length from application (months)	16.2	3.4	7	20	5526
Full term (%)	26.15	43.95	0	100	5526
Patent value	1.205	1.511	0	10.463	5526
Top 10% (%)	0.167	0.373	0	1	5526
Opposition probability	0.058	0.233	0	1	5526

Note: We use data for the last and first 3 months of the respective years to capture the feature of the shift period for patent applications. See Note of Table 1 for explanations of the variables constructed.

Table 12: The Number of Citing Patent to the Granted Patent in Japan Applied in the last 3 months in 1970 and the first 3 months in 1971

1970 Cohort, last 3 months

Variables	Mean	Sd	Min	Max	N
Self-citation from grant patent	0.007	0.089	0	3	16685
Self-citation from non-granted patent	0.003	0.058	0	2	16685
Non-self-citation from grant patent	0.280	0.766	0	14	16685
Non-self-citation from non-granted patent	0.248	0.666	0	12	16685

1971 Cohort, first 3 months

Variables	Mean	Sd	Min	Max	N
Self-citation from grant patent	0.015	0.145	0	3	5526
Self-citation from non-granted patent	0.002	0.047	0	1	5526
Non-self-citation from grant patent	0.418	1.004	0	14	5526
Non-self-citation from non-granted patent	0.416	0.965	0	13	5526

Note: Only examiner citations are counted as a citing patent. We use data for the last and first 3 months of the respective years to capture the feature of the shift period for patent applications.

A.2 The statistics tables for estimation

Table 13: Basic Statistics of Granted Patent in Japan Applied in the first 9 months of 1970 and the last 9 months of 1971 (Filtered Data for Estimation)

1970 Cohort, first 9 months

Variables	Mean	Sd	Min	Max	N
Lag time between application and publication (days)	1760.8	505.0	582	4990	20696
Lag time between publication and grant (days)	313.4	242.3	160	3833	20693
Grant year	1975.6	1.5	1972	1986	20863
Expiration year	1986.3	3.0	1978	1992	20863
Survival length from application (months)	16.3	3.0	8	22	20863
Full term (%)	19.36	39.52	0	100	20863
Patent value	0.949	1.212	0.002	9.495	20863
Top 10% (%)	0.075	0.263	0	1	20863
Opposition probability	0.086	0.280	0	1	20863

1971 Cohort, last 9 months

Variables	Mean	Sd	Min	Max	N
Lag time between application and publication (days)	548.5	1.2	485	550	21905
Lag time between publication and grant (days)	1850.3	618.3	222	4960	21905
Grant year	1977.7	1.7	1973	1987	22405
Expiration year	1987.6	3.2	1979	1995	22405
Survival length from application (months)	16.6	3.2	8	24	22405
Full term (%)	30.56	46.07	0	100	22405
Patent value	1.268	1.520	0.001	12.069	22405
Top 10% (%)	0.149	0.357	0	1	22405
Opposition probability	0.072	0.259	0	1	22405

Note: Only data for which the applicant firm could be identified. We use data for the first and last 9 months of the respective years to exclude the effect of the accelerations of applications, anticipating the introduction of a pre-grant publication system. See Note of Table 1 for explanations of the variables constructed.

Table 14: The Number of Citing Patent to the Granted Patent in Japan Applied in the first 9 months in 1970 and the last 9 months in 1971 (Filtered Data for Estimation)

1970 Cohort, first 9 months

Variables	Mean	Sd	Min	Max	N
Self-citation from grant patent	0.007	0.091	0	3	20863
Self-citation from non-granted patent	0.004	0.067	0	2	20863
Non-self-citation from grant patent	0.317	0.852	0	36	20863
Non-self-citation from non-granted patent	0.292	0.722	0	15	20863

1971 Cohort, last 9 months

Variables	Mean	Sd	Min	Max	N
Self-citation from grant patent	0.028	0.198	0	5	22405
Self-citation from non-granted patent	0.001	0.041	0	2	22405
Non-self-citation from grant patent	0.588	1.125	0	20	22405
Non-self-citation from non-granted patent	0.572	1.120	0	26	22405

Note: Only data for which the applicant firm could be identified. Only examiner citations are counted as a citing patent. We use data for the first and last 9 months of the respective years to exclude the effect of application accelerations due to introducing a pre-grant publication system.

Table 15: Basic Statistics of Variables Used in The Estimation

1970 Cohort, first 9 months

Variables	Mean	Sd	Min	Max	N
Instrumental Variables					
Publication lag IV	0	0	0	0	20863
Opposition period IV	0	0	0	0	20863
Control Variables					
Patent Family	1.2	1.1	1	36	20863
Previous Grants	14.4	31.0	0	130	20863
Previous Non grants	13.2	29.2	0	123	20863
Owned Patents	43.8	91.5	0	385	20863
IPC level request rate	1	0	1	1	20863
Patent value at Grant					
Patent value (at Grant)	0.292	0.349	0	2.068	20863
Top 10% (at Grant)	0.101	0.302	0	1	20863

1971 Cohort, last 9 months

Variables	Mean	Sd	Min	Max	N
Instrumental Variables					
Publication lag IV	0.015	0.14	-0.68	0.88	22405
Opposition period IV	-0.042	0.22	-0.66	2.17	22405
Control Variables					
Patent Family	1.3	1.2	1	21	22405
Previous Grants	10.8	25.6	0	130	22405
Previous Non grants	9.9	24.1	0	123	22405
Owned Patents	32.8	75.5	0	385	22405
IPC level request rate	0.83	0.02	0.75	0.87	22405
Patent value at Grant					
Patent value (at Grant)	0.293	0.365	0	2.147	22405
Top 10% (at Grant)	0.118	0.323	0	1	22405

Note: This data contains 1,391 applicant firms and 8,709 combinations of applicant firms and WIPO technology sectors. “Patent value” is the estimated value of a patent based on the survival length and is derived in Appendix A.3. The unit of Patent value is 1 million in 2022 yen.

Table 16: Pre-trend Check

	Patent value	Top 10%	Survival length	Own follow-on grants	Non grants	Grants	Difference
Trend (Monthly)	0.008***	0.002***	0.014*	0.000	0.001	0.006***	0.006**
	(0.003)	(0.001)	(0.008)	(0.000)	(0.002)	(0.002)	(0.002)
(Intercept)	0.648***	0.003	15.745***	0.005*	0.313***	0.295***	-0.018
	(0.041)	(0.009)	(0.106)	(0.003)	(0.025)	(0.030)	(0.032)
Num.Obs.	20863	20863	20863	20863	20863	20863	20863
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tech Sector Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.118	0.164	0.033	0.004	0.009	0.014	0.008
R2 Adj.	0.116	0.162	0.032	0.002	0.007	0.013	0.006

*** 1% significance, ** 5% significance, * 10% significance

A.3 Patent value estimation

Assuming that each patent of the technology sectors u follows a log-normal distribution, the value $r_i(t)$ of patent i in technology sectors u, which depreciates with time t, is

$$log\ r_i(0) = \gamma_u + \epsilon_i \tag{5}$$

where γ_u is the log of mean initial patent value for each technology sectors u, and ϵ is an error term following a normal distribution with mean 0 and standard deviation σ_u.

We assume a constant depreciation rate for the patent value for each of the following three periods: d_1 for the pre-publication period, d_2 for the period between post-publication and pre-grant, and d_3 for the post-grant period, although we assume that the profit is realized only after the patent grant as Schankerman and Bessen. Under this assumption, the value of a patent i in year t, a number of years from the application, can be expressed as follows by: denoting the application year of patent i by $t_0(= 0)$, the publication year by t_1, and the grant year by t_2,

$$\begin{gathered} log\ r_i(t) = log\ r_i(0)e^{-dt}, \\ where\ d = \begin{cases} d_1 & (t_0 < t < t_1) \\ d_2 & (t_1 \leq t < t_2) \\ d_3 & (t_2 \leq t) \end{cases} \end{gathered} \tag{6}$$

We can estimate the above three depreciation rates because the length of pre-publication period varied across 1970 cohort of patents. Publication was made when the substantive examination is over and the opposition period begins. On the other hand, the publication was made in 18 months for the 1971 cohort of the patent applications.

The discounted present value from time $t(> t_2)$ to $t + T$ is,

$$\int_t^{t+T} r_i(\phi)e^{-\{A+(d_3+s)\phi\}}d\phi = r_i(0)z_t,$$
$$where \begin{cases} A \equiv (t_1-t_0)d_1 + (t_2-t_1)d_2 + (t_2-t_0)s \\ z \equiv e^{-\{A+(d_3+s)t\}}\frac{1-e^{-\{A+(d_3+s)T\}}}{d_3+s} \end{cases} \tag{7}$$

where s represents the discount rate. We assume s to be 10% as in Bessen (2008) and other previous studies.

We denote the renewal fee of patent i in year τ by $c_{i,\tau}$. τ indicates the number of years which elapsed since the grant year. Patent renewals in Japan are generally implemented with bulk payments for an initial period of 3 years, followed by annual payments for each year thereafter.[11] To simplify the estimation, we assume that the renewal decision is made once every three years. Since patent renewal fees monotonically increase and patent value is depreciates, the optimal year at which to stop renewal is always uniquely determined by the condition (8). The applicant decides to renew a patent right when

$$log\ r_i(0) \geq log\ (\frac{c_{i\tau}}{z_t}) \tag{8}$$

assuming a single crossing condition and the statutory limit on the patent term is not binding at year τ.

In the case that applicants are not subject to the constraint on the statutory expiration date of 20 years from the application, the probability that each patent gives up the right for a specific year τ is expressed as the cumulative distribution function ϕ_u of the standard normal distribution,

$$\begin{aligned}
Prob[patent\ i\ expires\ before\ 4] &= \phi_u\left(\frac{log(\frac{c_{i,3}}{z_3}) - \gamma_u}{\sigma_u}\right) \\
Prob[patent\ i\ expires\ between\ 4\ and\ 6] &= \phi_u\left(\frac{log(\frac{c_{i,6}}{z_6}) - \gamma_u}{\sigma_u}\right) - \phi_u\left(\frac{log(\frac{c_{i,3}}{z_3}) - \gamma_u}{\sigma_u}\right) \\
Prob[patent\ i\ expires\ between\ 7\ and\ 9] &= \phi_u\left(\frac{log(\frac{c_{i,9}}{z_9}) - \gamma_u}{\sigma_u}\right) - \phi_u\left(\frac{log(\frac{c_{i,6}}{z_6}) - \gamma_u}{\sigma_u}\right) \\
Prob[patent\ i\ expires\ between\ 10\ and\ 12] &= \phi_u\left(\frac{log(\frac{c_{i,12}}{z_{12}}) - \gamma_u}{\sigma_u}\right) - \phi_u\left(\frac{log(\frac{c_{i,9}}{z_9}) - \gamma_u}{\sigma_u}\right) \\
Prob[patent\ i\ expires\ after\ 13] &= \left[1 - \phi_u\left(\frac{log(\frac{c_{i,13}}{z_13}) - \gamma_u}{\sigma_u}\right)\right]
\end{aligned} \tag{9}$$

In the other cases where applicants are subject to the statutory constraint on renewal, they can not make the decisions expressed in Equation 9 until the end of the patent term.

[11]This renewal fee data is obtained through an inquiry form on the JPO website. Also, inflation rate data for this period is obtained from the World Bank website.

Instead, the probability formula in equation (9) is replaced after the constrained period by the following.

$$Prob[patent\ i\ expires\ after\ \tau^*] = \left[1 - \phi_u \left(\frac{log(\frac{c_{i,\tau^*}}{z_v}) - \gamma_u}{\sigma_u}\right)\right] \tag{10}$$

τ^* is the last year to make decisions without facing the statutory limit; As shown in Figure 2, many patents expired after the 20-year restriction from the application, so equation (10) holds for a significant number of patents handling. This model employs the same likelihood function of the ordered probit model, except that it estimates 3 types of depreciation rates common to 33 different technological sectors u.

The log-likelihood function is defined as the sum of the logarithm of this probability for each patent. Then the maximum likelihood estimate for the mean γ_u and the standard deviation σ_u of the distribution for each technical sector, and 3 common constant depreciation rates d_1, d_2, and d_3 are estimated. On the basis of the estimated parameters, $\epsilon_i(\hat{\sigma_u})$ satisfying

$$log\left(\frac{c_{i,t}}{z_t(\hat{d})}\right) - \hat{\gamma_u} \leq \epsilon_i \leq log\left(\frac{c_{i,t+3}}{z_{t+3}(\hat{d})}\right) - \hat{\gamma_u} \tag{11}$$

is generated 100 times using a Monte Carlo simulation same as Bessen (2008) and derive each patent mean value $E[\gamma_i]$.

We conducted this estimation using all 1970-1971 data. Table 17 and Table 18 show the estimation results of the distribution parameters. Table 17 shows the estimated mean value $\hat{\gamma_u}$ and standard deviation $\hat{\sigma_u}$ of patents of each technology sectors u (33 WIPO categories). We could not estimate the 3 technology sectors due to a lack of samples. The number of patents belonging to each technology sector u is summarized in Table 19. The $\hat{\gamma_u}$ for each u is about 12, but varies from 11.23 (IPC12) to 12.69 (IPC5). These are 75,357 and 324,486 Japanese yen in 1970, respectively, and approximately \$1,005 and \$4,329 in U.S. dollars in 2022. The standard deviations also vary by u, from a minimum of 1.95 (WIPO33) to a maximum of 3.49 (WIPO5). In the regression in Section 6.1, we use the 2022 standard yen converted from the 1970 standard for $Patent\ value_{i,t}$.[12]

For the primary sample, the average patent value at application increased approximately from 750 thousand yen in 1970 to 885 thousand yen in 1971, an increase of about 18%. Considering that $Survival\ length_{i,t}$ increased by about 1.5%, from 16.16 to 16.40, reflecting the impact of the increase of high-value patents being maintained up to the statutory limit.

Table 18 shows the estimation result for three depreciation rates. It shows that the estimated depreciation rate $\hat{d_1}$ is 0.12, $\hat{d_2}$ is 0.16, and $\hat{d_3}$ is 0.09. The depreciation rate increased after the patent publication but decreased after the grant. The depreciation rate would be higher ($\hat{d_2}$ is higher than $\hat{d_1}$) after the patent disclosure since the patent information becomes available to others. On the other hand, patented technologies become obsolete faster when they are new ($\hat{d_3}$ is small relative to $\hat{d_1}$ and $\hat{d_2}$).

[12]The conversion rate is 1970 yen:2022 yen = 1:0.2904.

Table 17: Estimation Result of the Patent Values by 33 WIPO Classification

	Gamma		Sigma	
	Coefficient	z value	Coefficient	z value
IPC1	12.02***	125.22	3.07***	48.31
IPC2	11.99***	130.98	2.83***	50.63
IPC3	12.19***	138.66	2.74***	59.40
IPC4	12.33***	137.86	2.97***	59.69
IPC5	12.69***	138.29	3.46***	63.83
IPC6	11.87***	127.11	2.84***	45.24
IPC7	11.98***	134.77	2.77***	54.07
IPC8	11.79***	110.95	3.02***	34.97
IPC9	11.81***	132.87	2.79***	52.83
IPC10	12.02***	138.21	2.84***	60.17
IPC11	11.74***	117.57	3***	40.61
IPC12	11.81***	132.06	2.8***	51.58
IPC13	11.77***	105.92	3.11***	32.25
IPC14	11.23***	129.67	2.61***	45.11
IPC15	11.71***	129.99	2.76***	45.41
IPC16	11.68***	100.76	3.08***	27.75
IPC17	11.83***	116.98	2.93***	35.98
IPC18	11.82***	115.98	3.05***	40.99
IPC20	11.85***	71.83	2.22***	19.77
IPC22	11.57***	124.43	2.85***	44.68
IPC23	11.91***	96.03	3.12***	27.53
IPC24	12***	137.61	2.84***	58.96
IPC25	11.88***	121.01	2.97***	42.19
IPC27	11.71***	132.90	2.7***	50.68
IPC28	11.79***	65.89	2.32***	19.36
IPC29	11.93***	137.45	2.79***	58.17
IPC30	11.83***	63.37	2.14***	18.96
IPC31	12.09***	136.36	2.91***	57.85
IPC32	11.89***	60.74	2.06***	19.10
IPC33	11.97***	63.47	1.95***	19.39

*** 1% significance, ** 5% significance, * 10% significance

Note: The number of observations is 77,104. This estimation is performed assuming that the discount rate s is 10%.

Table 18: Estimation Result of 3 Types of Depreciation Rates for Patent Value

Variable	Coefficient	z value
d_1	0.12***	17.35
d_2	0.16***	26.88
d_3	0.09***	21.95

*** 1% significance

Note: The number of observations is 77,104. This estimation is performed assuming that the discount rate s is 10%.

Table 19: Number of Patents in Each WIPO 33 Category in the Estimation Data

IPC	Title	N
1	Agriculture	2581
2	Food stuffs	2805
3	Personal and domestic articles	3852
4	Health and amusement	4510
5	Drugs	10253
6	Separating, mixing	2427
7	Machine tools, metal working	3269
8	Casting, grinding, layered product	1563
9	Printing	3042
10	Transporting	4252
11	Packing, lifting	1945
12	Non-organic chemistry, fertilizer	2921
13	Organic chemistry, pesticides	1415
14	Organic molecule compounds	2401
15	Dyes, petroleum	2650
16	Biotechnology, beer, fermentation	1196
17	Genetic engineering	1781
18	Metallurgy, coating metals	1903
20	Textile	259
22	Paper	2291
23	Construction	1049
24	Mining, drilling	4068
25	Engine, pump	2111
27	Engineering elements	2885
28	Lighting, steam generation, heating	230
29	Weapons, blasting	3856
30	Measurement, optics, photography	181
31	Clock, controlling, computer	3930
32	Display, information storage, instruments	148
33	Nuclear physics	143

A.4 Estimations based on patent value at grant

In this appendix, we present the results based on our estimates of patent value at grant, which most existing literature uses. Table 20 presents the results of the second stage estimation, based on the basic model in Section 7 but using patent value at grant instead of at application. The first stage result remains the same as in Table 4, although the significance of $Non\ Grants_{i,t}$ is weaker. The results from Table 20 are consistent with our basic results reported in Section 7, that early disclosure increases the average patent value and the probability of top 10% value by increasing $Non\ Grants_{i,t}$ but decreasing $Grants_{i,t}$. Furthermore, $Grants_{i,t}$ and $Non\ Grants_{i,t}$ have the coefficients of similar magnitude to each other but opposite signs, as in Table 5.

The coefficients for the average patent value become much smaller, significantly because the patent value at grant is lower than that at application, due to depreciations (we assume 10% per year). The coefficients for the probability that the patent being ranked at top 10% patent value also decrease but by around 45%. Similarly, the coefficient of the $Difference_{i,t}$ decreases significantly (by 80%) for the average patent value but only moderately (by 40%) for top 10%. Thus, our results are robust to the choice of patent values especially for the top 10% probability.

Table 20: Second Stage Regression Result for Equation (1) (Dependent Variables Constructed from The Patent Value at Grant)

	Patent value		Top 10%	
	Model 1	Model 2	Model 3	Model 4
Grants	-0.308***		-0.209**	
	(0.108)		(0.083)	
Non grants	0.271*		0.206*	
	(0.145)		(0.112)	
Difference		-0.298***		-0.208***
		(0.099)		(0.077)
(Intercept)	0.233***	0.222***	0.011	0.009
	(0.048)	(0.015)	(0.037)	(0.012)
IV Test	6.89	9.76	6.89	9.76
Controls	Yes	Yes	Yes	Yes
Tech Sector x Year Dummies	Yes	Yes	Yes	Yes
Num.Obs.	43268	43268	43268	43268

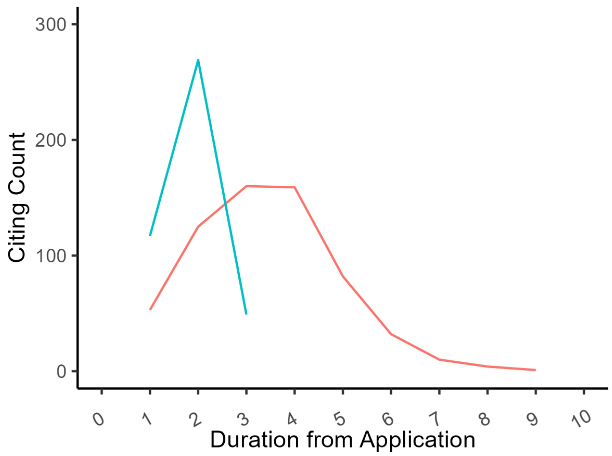
*** 1% significance, ** 5% significance, * 10% significance

Note: The unit of Patent value is 1 million in 2022 yen. IV test is the F-value from the Stock and Yogo (2005) weak IV test.

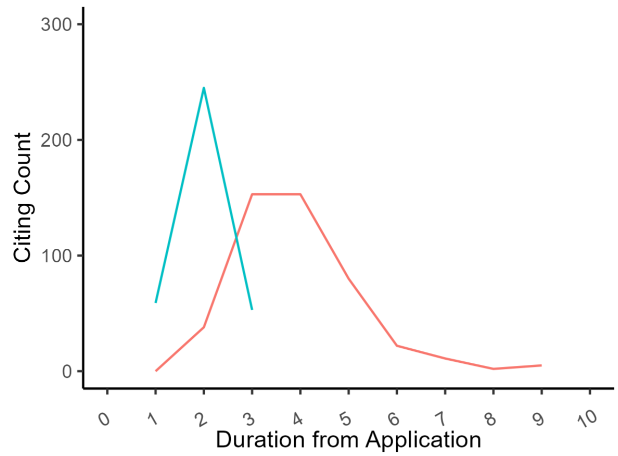
A.5 Estimation result for Equation (1) including citation flow variables made before disclosure

Figure 4 shows the same graph as Figure 3 for the citation flow variables made before disclosure. Focusing on the first year after the application, the citation flow for the cohorts of 1971 increased significantly relative to that of the cohorts of 1970, consistent with the stronger blocking power of a pending application before its disclosure. Table 3 suggests that the citation flow made *before* the disclosure of the focal patents of the cohorts of 1971 declined relative to that of the cohorts of 1970, despite the policy change that the power of the unpublished patent publication barring the subsequent application was strengthened. This is simply because the time to the disclosure for the 1971 cohort declined to a third of that for the 1970 cohort as in Figure 4.

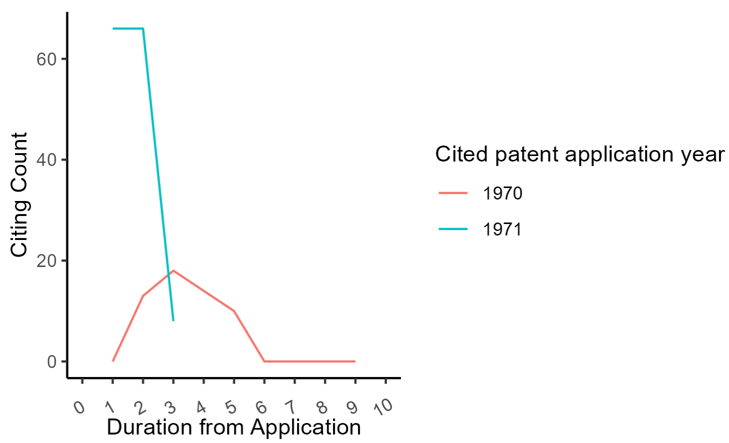
The results of IV estimation corresponding to Tables 4 and 5 in Section 7 are shown in Tables 21 and 22. Clearly, citation flow variables made *before* disclosure do not have significant impact on IV estimation results.



(a) Non-self-citation from non-granted patent



(b) Non-self-citation from granted patent



(c) Self-citation from granted patent

Figure 4: Response of Citation Flows from Subsequent Patents that Applied before the Disclosure of the Focal Patents

Note: The horizontal axis indicates the lag between cited and citing patent application years, and the vertical axis indicates the number of citing patents with the respective application lag.

Table 21: First Stage Regression Result of Instrumental Variable Estimation for Equation (1), Including Citation Flow Variables Before Disclosure

	Grants	Non grants	Difference
	Model 1	Model 2	Model 3
Publication lag IV	-0.088*	0.127***	-0.215***
	(0.049)	(0.046)	(0.054)
Opposition period IV	0.128***	0.071**	0.057*
	(0.030)	(0.028)	(0.033)
(Intercept)	0.306***	0.289***	0.017
	(0.032)	(0.030)	(0.034)
Variables Before Disclosure	Yes	Yes	Yes
Controls	Yes	Yes	Yes
Tech Sector x Year Dummies	Yes	Yes	Yes
Num.Obs.	43268	43268	43268
R2	0.036	0.039	0.005
R2 Adj.	0.035	0.038	0.004

*** 1% significance, ** 5% significance, * 10% significance

Table 22: Second Stage Regression Result for Equation (1), Including Citation Flow Variables Before Disclosure

	Patent value		Top 10%		Survival length	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Grants	-1.580***		-0.329***		-2.266**	
	(0.516)		(0.110)		(0.957)	
Non grants	1.802**		0.375**		2.966**	
	(0.702)		(0.150)		(1.304)	
Difference		-1.643***		-0.342***		-2.465***
		(0.467)		(0.100)		(0.863)
(Intercept)	0.640***	0.705***	0.002	0.015	15.670***	15.876***
	(0.225)	(0.071)	(0.048)	(0.015)	(0.418)	(0.132)
IV Test	6.71	9.73	6.71	9.73	6.71	9.73
Variables Before Disclosure	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Tech Sector x Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Num.Obs.	43268	43268	43268	43268	43268	43268

*** 1% significance, ** 5% significance, * 10% significance

Note: The unit of Patent value is 1 million in 2022 yen. IV test is the F-value from the Stock and Yogo (2005) weak IV test.

A.6 Estimation result for Equation (1) by ordinary OLS

Table 23 shows the OLS results for the Equation (1). $Grants_{i,t}$ and $Non\ Grants_{i,t}$ have significantly positive coefficients, quite contrary to the IV estimation results (Table 5). The contrast indicates the importance of controlling for the unobserved patent quality variable to have a causal interpretation of the coefficients of the citation flows.

Table 23: OLS Estimation Result for Equation (1)

	Patent value		Top 10%		Survival length	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Grants	0.074***		0.008***		0.212***	
	(0.007)		(0.002)		(0.016)	
Non grants	0.086***		0.011***		0.219***	
	(0.007)		(0.002)		(0.017)	
Difference		0.002		0.000		0.019
		(0.006)		(0.001)		(0.014)
(Intercept)	0.635***	0.684***	0.004	0.010	15.717***	15.850***
	(0.043)	(0.043)	(0.010)	(0.010)	(0.099)	(0.099)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Tech Sector x Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Num.Obs.	43268	43268	43268	43268	43268	43268
R2	0.110	0.101	0.138	0.136	0.037	0.025
R2 Adj.	0.108	0.100	0.136	0.134	0.036	0.024

*** 1% significance, ** 5% significance, * 10% significance

Note: The unit of Patent value is 1 million in 2022 yen.