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Early Disclosure and Patent Value: How do you know that you are a pioneer?[1]

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Abstract

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

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

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1 Introduction

It is widely believed that the 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. To this end, several 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 by adopting a pioneer-follower model. In other words, they assume that an inventor knows that they are the pioneer.

However, given the competition in research, it is important to recognize that a pioneer firm does not know whether it is truly a pioneer until its priority is established. 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. In other words, if no other firms have published competing inventions before it, it is the pioneer. Thus, the pre-grant publication system significantly accelerates the establishment of priority, because the grant decision usually takes considerable time.

Early establishment of priority through publication can enhance the value of patents and ex-ante incentives for R&D through the following channels. First, the published patent applications deter competitors from patenting or investing in duplicative inventions. In particular, in Japan and Europe, examiners can use such publications made earlier to reject subsequent duplicative patent applications (inventions with only obvious improvements), since only published applications serve as full prior art; therefore, more subsequent duplicative applications are rejected due to early disclosure.[1] Second, establishing a patent's priority can give its owner an incentive to perform a complementary R&D and acquire additional follow-on inventions. Having unified ownership over the focal and complementary inventions gives more profit than having ownership only in the complementary invention because of the efficiency effect. Third, the 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. This can also help other firms initiate complementary R&D projects early when the pioneer firm has no capability. These effects increase the value of the disclosed patent and the ex-ante incentive for R&D.

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

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

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

Recent literature suggests that early publication may have positive effects on appropriation. There exist two highly relevant literatures. Using USPTO patent examination data, 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) showed that early disclosure after the American Inventors Protection Act (AIPA) in 1999 decreased the technological overlap between highly similar patents, and patent applications were less likely to be abandoned (until granted), suggesting less duplicative R&D. However, no study has analyzed how early disclosure affects competition with subsequent patent applications and patent value through its effects on the early establishment of priority and knowledge spillovers. This study analyzes this mechanism and assesses its quantitative impact on patent value.

The remainder of this paper is organized as follows. The next section briefly reviews existing studies on 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 dataset. Section 6 describes the econometric model's estimation strategy. The basic results are presented in Section 7. Section 8 presents the robustness check. Section 9 analyzes applicants' follow-on inventions with or without competition. Section 10 presents an additional discussion of Japan's pre-grant publication system and Section 11 concludes the paper.

2 Prior literature

Existing theoretical analyses of patenting decisions often implicitly assume that priority is automatically established when an 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) were the first to analyze patenting behavior when an innovating firm had private information about profits available to competitors through imitation. In their model, firm patents 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 an innovation, it will be the pioneer. The same structure was used by Anton and Yao (2004), Aoki and Spiegel (2009), and more recently, Akcigit and Liu (2016). Aoki and Spiegel (2009) find that the pre-grant publication of patent applications in the context of a cumulative innovation model leads to fewer patent applications and inventions.

If there is no research competition, this assumption is reasonable. However, empirical literature shows that R&D competition often exists and the race is often close, so the pioneer is often known only as the outcome of the competition. Based on a literature survey, Lemley (2012) concludes that the canonical story of the lone genius inventor is largely a myth. Surveys of hundreds of significant new technologies show that almost all of them are invented simultaneously or nearly simultaneously by two or more teams working independently of each other. For example, an inventor survey (PATVAL survey II) for Japan shows that the majority of inventors recognize the existence of competitors for their patents; only 7.3% of inventors say that there were no competitors they recognized, and 9.7% of inventors said that they did 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. Competition is prevalent because inventors have common knowledge on consumer demand, supply constraints, and physical principles for inventions, and invention is often an incremental process (Lemley (2012)).

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

The recent empirical literature suggests a possibility that early disclosure has a positive effect 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, 1999) allows such applicants to keep their inventions secret before a patent grant if they do not apply for foreign patents. That is, only 7.5% of U.S. patent applications use this 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 to secrecy for their most important inventions.

Licensing is one potential mechanism through which early disclosure improves appropriation. Hegde and Luo (2018) investigated the effects of pre-grant publications on patent licenses in biomedical technology to examine how the disclosure of a patent application facilitates licensing separately from the effects of grants. They found that post-AIPA patent applications were licensed significantly earlier than pre-AIPA patent applications, after controlling for grant date. This indicates one specific mechanism by which early disclosure causes an increase in returns on patent rights. Specifically, they found that i) the probability of licensing in the window between 18 months of publication and patent grants more than doubled for post-AIPA patent applications, ii) post-AIPA patent applications were about 18 percentage points less likely to wait until the grant was 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 patent disclosure helps avoid investment duplication by reducing asymmetric information among rival firms. They used USPTO office action data from 2008 to 2017 and found that AIPA significantly reduced the number of blocking office actions in 8 years referring to patents applied for 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) 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 the patenting costs of duplicative inventions. However, their study did not directly investigate the mechanism of how pre-grant publication affects competition with subsequent patent applications and patent values through early establishment of priority as well as through accelerated knowledge spillover (no distinction is made between the two). Their study assumes that all citations (inventors and examiners) are driven by inventors' search efforts and does not consider the contributions of examiners in rejecting duplicative applications. However, examiner citations begin far earlier and reach their maximum much earlier than that of applicant citations in the US, as shown by Okada and Nagaoka (2020) (see also Baruffaldi and Simeth (2020)).

Our contribution is to analyze how the early disclosure of patent applications affects the private value of a patent by affecting not only knowledge spillover but also the scope of prior art, using the introduction of pre-grant publications in Japan as a natural experiment. Our analysis covers the effects on competitors as well as on own follow-on inventions. Although there are several 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)), to the best of our knowledge, no study has investigated the effects of early disclosure on patent value, considering its mechanism through early priority setting and knowledge spillovers explicitly and jointly.

3 Introduction of pre-grant publication system in Japan

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

Figure 1 illustrates the number of patent grants by application month from December 1968 to January 1973. This shows that there were clear and significant accelerations in applications from early 1971 to the late 1970. Such acceleration seems to have occurred because of the concern of many applicants that the introduction of pre-grant applications would weaken patent protection because of early disclosures. To exclude the impact of such strategic acceleration of applications from our estimations, we focus on the first nine months from January to September 1970 (control) and the last nine months in 1971 (treatment) for our primary sample to assess 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 for patents and citations during the shift period data are presented in Tables 11 and 12, respectively, in Appendix A. 1. The number of patents in the last three months of 1970 reached 16,685, while that in the first three months of 1971 was 5,526, indicating that a significant number of applications accelerated from 1971 to 1970, amounting to approximately 5500.

The pre-grant publication system significantly accelerated the disclosure of applications from 58 to 18 months after filing (from 1765 days to 549 days, as seen from Table 1). Third parties can use the knowledge disclosed in such patent applications to develop subsequent inventions, and such applications can be used by examiners to reject subsequent similar but not identical patent applications on the grounds of inventive steps. 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 the number of citing patents that resulted in grants and from 0.23 to 0.44 number of citing patents that resulted in rejection or abandonment (non-grants). These results indicate that early disclosures increase both technological opportunities for subsequent inventions and the probability of an examiner issuing a rejection of duplicative inventions.

As there is no new knowledge flow from a pre-grant publication to the applicant firm, an 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. However, 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 applicant's first-mover advantage 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 (the number of patent grants 26,026)

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 (the number of patent grants 28,868)

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: The sample of patents is limited to those with priority dates equal to their filing date in Japan. We used data for the first and last nine months of the respective years to exclude the effect of the acceleration of applications, anticipating the introduction of a pre-grant publication system. For simplicity, the grant and expiration year data were treated as decimal numbers. 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 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 patents ranked in the top 10% of 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

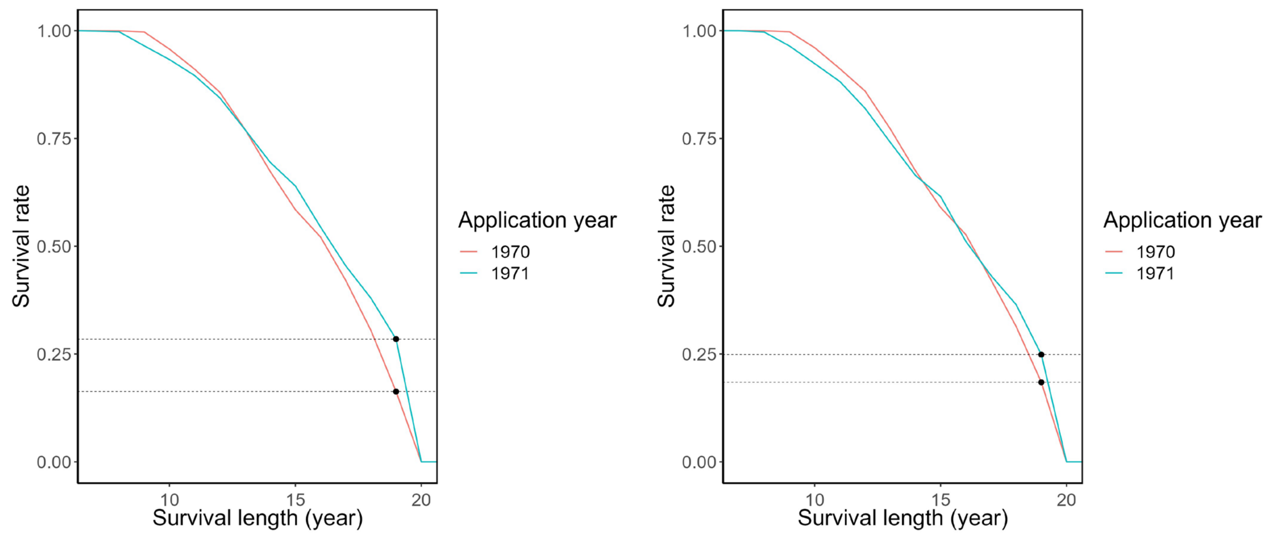
Note: Only examiner citations are counted as citing patents. We used data for the first and last 9 months of the respective years to exclude the effect of application acceleration due to the introduction of a pre-grant publication system.

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

We estimated the patent values for applications based on survival length. Appendix A.3 provides details of the analysis. As demonstrated in Table 1, the estimated average patent value increased by approximately 33% from 0.912 to 1.215, and the proportion of patents valued at the 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%, and their total value increased from 1970 to 1971 because the number of patents granted increased by 10.9% from 1970 to 1971.

Furthermore, although we focus on those applied in the last three months of 1970 and the first three months of 1971, the upper part of the distribution of the survival curve is heavier for the 1971 cohort than for 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 increased significantly, on average, from 1970 to 1971 because of 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 are N=26,026 and N=28,868, respectively. There were 698 patents in 1970 and 263 patents in 1971 that expired in the middle of this graph because of the 15-year grant restriction. In Figure (b), the numbers 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, as shown in the middle of this graph, owing to the 15-year restriction from the grant.

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

The introduction of pre-grant publications in 1971 was accompanied by two other major changes: the introduction of an 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 can defer the decision to request a patent examination for up to seven years. This significant policy change can affect our analysis in two ways: the selection of inventions for patent applications and forward citation flows. We discuss the impact of the selection in Section 6.2.

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

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

4 Hypotheses

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

The power of the focal patent application to bar subsequent patent applications on inventive step grounds became effective earlier owing to the acceleration of disclosure through the introduction of pre-grant publication in Japan. Thus, pre-grant publication accelerates the timing and cumulative number of rejections by the examiner citing the patent applications disclosed early (as well as the abandonment of the applications by applicants). The effects would be stronger when the acceleration is significant and research competition for the focal patent is intense; thus, we can construct instrumental variables using the publication lag and the level of competition before the policy change. Further rejection of competing subsequent applications induced by these IVs will increase the patent value of the focal patent. If the rejection and abandonment of subsequent patent applications are predominantly driven by the knowledge spillover effect (i.e., they are totally duplicative applications), there would be no significant effect on patent value. Thus, we propose the following 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 significant new contributions, even those based on imitations, will be granted patents, which will reduce the value of the focal published patent. Knowledge spillover also enables complementary inventions by other entities, thus preempting opportunities for the focal firm. Such preemptive complementary inventions also reduce the value of the focal patent by forcing the applicant firm to share its profits. However, if the inventions of complementary technologies are beyond the capability of the applicant firm, the value of the focal patent increases. We hypothesize that the negative effects will be dominant for knowledge spillover, given the widespread concern that early disclosure will reduce appropriation. Knowledge spillover is stronger when acceleration is significant and the number of competitors is large. If knowledge spillover effects are absent, the prior art effect will reduce the cumulative number of grants for subsequent patents citing follow-on patents and increase 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.*
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 relevant prior art has been published prior to the publication of its invention, although there is no knowledge spillover effect from one's own invention. Early recognition that an invention has priority over competing inventions enables the pioneer to invest early in 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. This perspective increases the incentive for applicants with focal patents to create follow-on inventions earlier and more intensively.

The anticipation that early disclosure invites early follow-on inventions by competitors (imitative and preemptive inventions of complements) can accelerate 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 from 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 patent applications that have priority over other competing applications (applications by a pioneer firm), so that the pioneer firm accelerates and enhances its follow-on inventions in response to early disclosure. Thus, we propose 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 analysis period one year before and one year after the introduction of pre-grant publication in Japan. We focus only on granted applications, because 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, owing to their international priorities, divisional applications, and so on, because such applications have prior patent applications that might have been disclosed earlier. In other words, we cover only applications whose application dates are identical to their priority dates. The data used for the estimation exclude the shift period, which is the first nine months in 1970 (control) and the last nine months in 1971 (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). Cited patent data were collected from the IIP (Institute of Intellectual Property) database. Examiner citation data[2] were collected from the examination process data of the JPO, maintained by Artificial Life Laboratory, Inc. Because the data period is approximately 1970, some information in the IIP database is missing. Missing publications and International Patent Classification (IPC) data were collected from the ORBIS database of Bureau van Dijk, and missing patent family data were 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 a connection table to the IIP patent database. This matching enabled us to differentiate between self-citation and citations by others.

There were 11,625 patents for which the applicant firms were not identified in the primary sample.[3] These patents were not included in the regression analysis because we could not identify self-citations or citations by others. The total number of observations in this analysis is 43,268. The basic statistics of the estimation data are in Appendix A.2. These results are similar to those presented 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 the estimation method in detail). 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 five years between the application and grant dates (see Table 1), which varies significantly across patents. In particular, it is not reasonable to assume that the obsolescence of patented technology did not occur after its application. In this study, we used the patent value at the time of application as the primary measure of patent value by assuming that patent value obsolescence begins at the

[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.

time of application. We also present the estimation results using the patent value at the grant as a robustness check (see Appendix A.4).

5.2 Changes of examiner citation dynamics before and after the reform

We classified the citing patents according to the timing of their applications *before* or *after* the disclosure (i.e., publication) of the cited patents. Patent applications before disclosure are not full in Japan and Europe. Table 3 presents the citation flow to the two cohorts (control and treatment) from the citing patents before and after disclosure. Table 3 shows that the citation flows from patent applications after disclosure increased significantly in 1971 compared with 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 subsequent patent applications made *after* the disclosure of cited patents to assess the reactions of other inventors and examiners to the introduction of pre-grant publications in assessing Hypotheses 1 and 2. Citation flows to pre-disclosure patent applications account 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 citing patents. We used data for nine months of each year to exclude the effect of application acceleration due to the introduction of a pre-grant publication system.

Figure 3 illustrates the flow of citations of the focal patents of the two cohorts. Figure 3 shows that citation flows to the 1971 cohort occurred much earlier and more intensively than those to the 1970 cohort for all three types of citation flow. Both non-self-citations from non-granted and granted patent applications start much earlier, and their peak arrives much earlier for the 1971 cohort: two years earlier for citation flows from non-granted patents (from the 6th to the 4th year after the application) and three 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 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 non-granted patents which almost doubled.

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

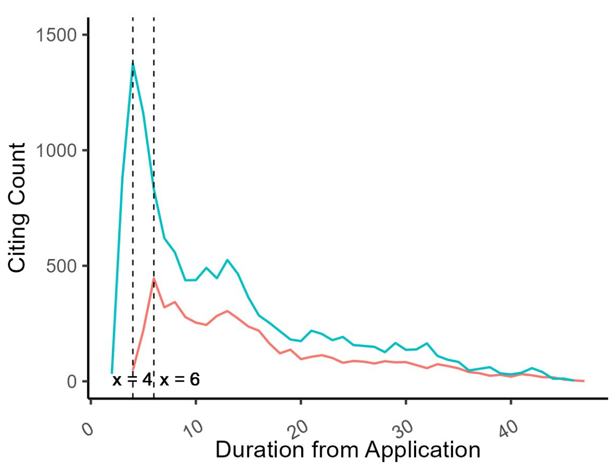
Pre-grant publications also increased the non-self-citation flow of granted patents, as shown in Figure 3 (b). It came earlier and its level doubled, supporting Hypothesis 2. The fact that both the level and increase in citation flows from granted patent applications are smaller than those of the

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

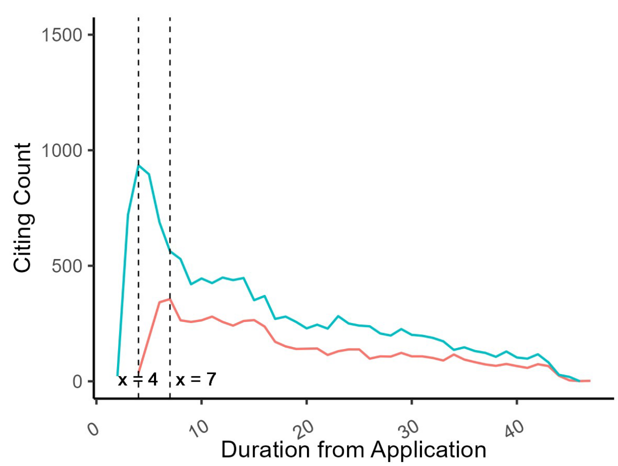
citation flows from non-granted patent applications suggests that the reduction in duplication is more important than the increase in competing patents in terms of the effect of early disclosure on the value of the focal patent, which will be formally tested in the following section. Given that it would take some time for an inventor of another firm 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 in the patent scope of independent parallel patent applications in light of the focal patent published as prior art. However, the latter part of the citation flow is more indicative of new non-duplicative 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 a combination of knowledge from the focal patent and a new idea becomes the source of another new invention that exploits 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.

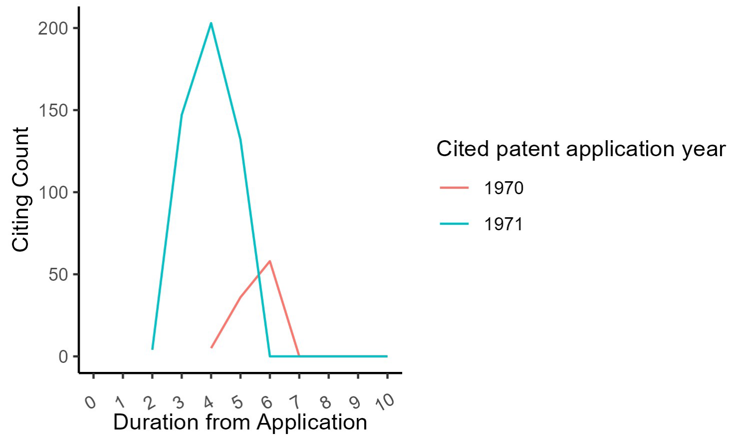
Pre-grant publications also significantly accelerated and increased the self-citation flow from granted patents, as shown in Figure 3 (c). The number of citations more than quadrupled, although the effect is more short-lived than the flow of citations from other firms. Since the pre-grant publication 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 patents



(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 the 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 patent value and our central explanatory variables are the citation flows from granted or non-granted subsequent patent applications; thus, controlling for unobserved patent quality is critically important for our estimation. We use instrumental variable estimation by introducing pre-grant publications as an exogenous shock. In the first stage of our instrumental variable estimations, we estimate how the introduction of pre-grant publications 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 publication delays and the level of competition in technology sectors by firms before the policy change.

We denote the cohort year as 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 focal patent i of cohort t as $Grants_{i,t}$ 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 focal patent i of the applicant. To construct $Grants_{i,t}$ and $Non\ Grants_{i,t}$, only the 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 disclosure. This is because the applicant learns the priority of its invention over time until its disclosure, and adjusts its investment in anticipation of the effects of the disclosure of its invention and its investment in competitors.

We used the estimated $Patent\ value_{i,t}$ as our main measure of 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 Appendix A.3. We also use the indicator for the top 10% of patent values to analyze the impact of early disclosure on the upper part of the value distribution. This 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 the value of 1 if the patent is included in the top 10%, and 0 otherwise. The top 10% of patents in each cohort and their basic statistics are summarized in Table 13 in Appendix A.2.

Furthermore, we use the $Survival\ length_{i,t}$ of a patent right as a supplementary measure for patent value, which informs us of the mechanism of variations in patent value. The longer the right is maintained, the higher the patent value. It is important to note that the survival measure is truncated owing 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 for the full term (20 years after the application and/or 15 years after the grant) increased from 18.98% to 29.38%. This made the estimated patent values for the 1971 cohort significantly more valuable (see Table 1).

We specify the following second-stage equation for patent value, in 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.

$$Patent\ value_{i,t}\ (Top\ 10\%_{i,t},\ Survival\ length_{i,t}) = \beta_1 Grants_{i,t} + \beta_2 Non\ Grants_{i,t} + \beta_c Controls_{i,t} + \beta_\mu \mu_{u,t} + \alpha_{i,t} + \epsilon_{i,t} \quad (1)$$

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 for such a model is that $Grants_{i,t}$ and $Non\ Grants_{i,t}$ have coefficients of similar magnitudes 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.

$$Patent\ value_{i,t}\ (Top\ 10\%_{i,t},\ Survival\ length_{i,t}) = \beta_3 Difference_{i,t} + \beta_c Controls_{i,t} + \beta_\mu \mu_{u,t} + \alpha_{i,t} + \epsilon_{i,t} \quad (2)$$

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

$$Grants_{i,t}\ (Non\ Grants_{i,t}, Difference_{i,t}) = \gamma_1 Publication\ lag\ IV_{i,t} + \gamma_2 Opposition\ period\ IV_{i,t} + \beta_c Controls_{i,t} + \beta_\mu \mu_{u,t} + \alpha_{i,t} + \epsilon_{i,t} \quad (3)$$

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 the 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 variations in the effects of introducing an 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; therefore, an OLS estimation of the patent value in 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 publications 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 prior art, which would decrease $Grants_{i,t}$ and increase $Non\ Grants_{i,t}$ and accelerate the flow of knowledge, which would increase both $Grants_{i,t}$ and $Non\ Grants_{i,t}$.

The introduction of pre-grant publications led to a significant 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 sectors or firms with large lags because of longer publication lags before patent law changes. For our first instrument, we used 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 variations in the acceleration of knowledge flow across combinations of technology sectors and applicant firms.

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

Thus, we adopt the following two instrumental variables, as indicated in the first stage of 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 (the year before the reform) for each combination of the technology sector and applicant firm, the mean centered on the aggregate average of the publication lag. If the variation in the increase in full prior art is more important, a 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, with the mean centered on the aggregate average opposition period. We expect that a large *Opposition prob IV* will have a greater effect on both the number of grants and non-grants if it reflects the knowledge flow effect. Since we use mean centering for the logs of publication lag and opposition period variables to generate 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 controls for the invention quality of patent i and applicant characteristics. Patents with higher invention quality tend to be cited more frequently and have high values; therefore, invention quality is an important source of positive correlations between the two. We use the size of the international patent family ($Patent\ family_{i,t}$) to which the focal

[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.]

patent belongs as an indicator of patent quality. When invention quality is high, the family size tends to be large.

We also control for the following basic firm characteristics for applicant firm f: firm size in terms of the flow and stock of patent grants, and invention quality in terms of the number of non-grants. We introduce *Grants Non Grants*, aggregated for each firm from patents applied for 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 and control variable.

Finally, we control for sectoral differences and their variations over two periods of technological opportunities and demand conditions through the interactions of the WIPO 33 technology classes and two cohort years. Thus, in our estimations, we do not exploit the overall or sectoral variations over the two years. Given these controls, we expect the two instruments based on the patent law change dummy in the technology sector at the firm level to be unlikely to be significantly correlated with the 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 a significant loss of information from firms' responses to the policy change. Thus, we also conduct estimations based on a model introducing 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 all discontinuities in the patent values and citation variables over two years (see Section 8 for further details) to estimate the parameters and avoid using 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 one's own follow-on inventions, although no knowledge spillover effect exists for one's own subsequent invention: first, the effect of establishing priority early, which exists even when there is no R&D competition; second, the effect of anticipated early knowledge spillover to competitors, which would be significant only if there is R&D competition. To distinguish between the two mechanisms, we introduce a new variable, *Competitive*. *Competitive* is a dummy variable for each patent that takes the value of 0 if the applicant firm faced no opposition[6] in 1970 in the technology sector for which the patent was classified; otherwise, it is 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 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 follow-on inventions by the applicant of the focal patent. Thus, we expect *Reform IV* to have a significantly positive coefficient, and competition to increase this response. We also expect this effect to exist even for the own follow-on inventions before the disclosure of the focal patent.

6.2 Discussions of the assumptions of the estimation model

Two issues need 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, owing to the effect of early disclosure on the propensity for patents. If early disclosure has a significantly negative effect on the use of patents and increases the use of trade secrets, our analysis could be significantly confounded by such an effect. The 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 when we excluded the shift period (the 3 month period before and after the reform), as shown in Table 1. Moreover, more secrecy protection of high-value inventions works 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 to 71.0% after five years. The average private value of a patent may have increased by allowing the applicant to avoid requesting an examination of applications that were found to have low patent value over a period of seven years after the application. However, the examination request system encourages firms to try more experimental patent applications to exploit their option value, as uncertainty is reduced over time (Yamauchi and Nagaoka (2015)). In fact, the number of

[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.

grants increased significantly by approximately 10% from 1970 (first nine months) to 1971 (last nine months), as shown in Tables 1 and 2. Moreover, it is likely that this does not significantly affect the number of inherently high-value patents[7] because examination requests are always made for high-value patent applications. Together, it is likely that the introduction of the examination request system reduced the average value of a patent, while it increased the aggregate value of patents.

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 changes in the propensity to patent. The estimation models in Section 8 do not introduce such WIPO technology sectors by year dummies, except that we control for the pre-trends observed in 1970.

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. The long publication lag in 1970 means a large acceleration in publication due to policy change, because the publication lag in 1971 was uniform across sectors and firms (one and a half years). After disclosure acceleration, the number of non-grants (rejections or abandonments) citing the focal patent ($Non\ Grants_{i,t}$) increased significantly more in sectors and firms with longer publication lags before the legal change. Simultaneously, the number of grants citing the focal patent ($Grants_{i,t}$) decreased more for those with longer publication lags. A 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 Table 4 shows. Controlling for the level of publication acceleration, both the number of grants and the number of non-grants citing the focal patent increased significantly more in sectors and firms with longer opposition periods. *Opposition period IV* only has a weakly significant coefficient with a small value for $Difference_{i,t}$ because the coefficients for $Grants_{i,t}$ and $Non\ Grants_{i,t}$ are both positive.

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

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

The second stage of the IV estimation with $Patent\ value_{i,t}$, $Top\ 10\%_{i,t}$ and $Survival\ length_{i,t}$ as the dependent variables is reported in Table 5.[8] Table 5 shows that $Grants_{i,t}$ and $Non\ Grants_{i,t}$ have highly significant coefficients with similar magnitudes but opposite signs for all the dependent variables in Models 1, 3, and 5. $Difference_{i,t}$ also has highly significant negative coefficients for all the dependent variables. Thus, the increase in the number of non-grant outcomes of subsequent patent applications and the decrease in the number of grant outcomes of subsequent patent applications, both citing the focal patent, are significantly positively associated with the increase in patent value and survival length of the cited patents. The probability of a patent being ranked in the top 10% and its survival time also increased significantly with such changes. These results strongly support the second part of Hypotheses 1 and 2.

Note that the estimations for Models 1, 3, and 5 do not satisfy the threshold of the weak instrument test (see the row of the IV Test in Table 5); thus, the coefficients estimated for these models may not be robust. However, the estimations for Models 2, 4, and 6 roughly satisfy the threshold of the weak instrument test, indicating that the coefficients of $Difference_{i,t}$ are robust. Thus, we can confidently say that the decrease in the grants of others' follow-on patents or the increase in the rejections (and abandonments) of others' duplicative patent applications by one unit increased patent value by 1.6 million Yen and the probability of the top 10% patents by 0.34 percent point. Moreover, the coefficient of $Difference_{i,t}$ is close to that 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 second-stage estimations based on patent value at the time of grant. These values are very similar to those reported in this section for the probability of Top 10%. The size of the coefficients for patent value is significantly smaller than those reported in this section because there are depreciations in patent values starting from applications, but they remain significant and share the same signs. Thus, the results are robust, even if we use patent value at grant instead of that at application.

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

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's (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 firm and introduced the 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 this by combining *Reform IV* and technology sector dummies that do not interact 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. In other words, we use only the variations across technology sectors to identify the effects of policy changes in this section. We use the parsimonious model with only Difference as an endogenous explanatory variable, because we have only one instrument.

Because we do not introduce year-by-sector dummies, our estimations in this section do not directly control for the impact of the introduction of the examination request system in 1971 on average patent values through sample selection. Thus, the coefficients of *Reform IV* partially reflect the effects of introducing an examination request system.

Estimations using Reform IV without sector by year dummies

We introduce a new IV (*Reform IV*) that 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 of 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 these 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 data from the first nine months of 1970.[9] The estimated monthly pre-trends are reported in Table

[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.

16 of Appendix A.2. The estimated monthly pre-trends were subtracted from each variable with a significant pre-trend 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* is highly significant for $Difference_{i,t}$, controlling for pre-trends and other control variables. The estimated coefficient is -0.096. We also present the estimation results for $Grants_{i,t}$ and $Non\ Grants_{i,t}$ at 0.18, and 0.28, respectively. All three estimates are highly significant, implying that the policy change led to an increase in $Non\ Grants_{i,t}$ by 0.28, and $Grants_{i,t}$ by 0.18, causing a reduction in $Difference_{i,t}$ by 0.096 on average.

We conducted a second-stage estimation of the models using $Difference_{i,t}$ as the main explanatory variable. Table 7 shows that $Difference_{i,t}$ is highly significant for the 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 in Section 7 are robust under an alternative IV approach by fully using the policy discontinuity. Early disclosure enhances patent value by increasing the number of rejections and abandonments citing the focal patent more than it does by increasing 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: an increase of 0.30 for patent value and an increase of 6.2 percent for the probability of the top 10% patents.

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. The IV test is the F-value obtained from Stock and Yogo's (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 an 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 $Non\ Grants_{i,t}$; thus, 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 allows 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); therefore, we did 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 competitors) by which early disclosure enhances own subsequent inventions. For 36% of patents, the firm had no opposition in 1970 in the corresponding sector. Our estimation model is 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. The result indicated that the own follow-on inventions accelerated and increased significantly because the disclosure itself got accelerated in 1971.

Models 2 and 4 provide estimations that differentiate applicants by the sector facing competition or not. $Reform\ IV$ is significant in both Model 2 and 4, while $Reform\ IV * Competitive$ is significant only in Model 2. The significance of $Reform\ IV$ in both Models suggests that early disclosure significantly increased and accelerated own-follow-on patents, even if competition was absent or weak, suggesting that the pure effect of establishing priority early was significant for such investment. The significance of the interaction term ($Reform\ IV * Competitive$) 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 was not significant in Model 2, suggesting that most applicant responses to competition occurred after the disclosure of their 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-citations before disclosure in the regression analysis.

10 Discussion based on the secondary sample: irrational strategic accelerations?

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

Two strong evidences suggest that the applicants accelerated the applications of high-quality inventions from 1971 to 1970. First, Table 2 in Sections 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 nine months and last three 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, $\textit{Patent value}_{i,t}$ 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 three months of 1970.

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

Despite this shift in patents, which is adverse to the 1971 sample, the average patent value for the first three months of 1971 is larger than that for the last 3 months 1970 (1.205 > 0.917). Such a reversal of values can be attributed to the pre-grant publication of the applications made only for the patents applied for 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 U.S. firms chose pre-grant publications for AIPA in 2001. One hypothesis is a prisoner's dilemma: an applicant prefers to protect secrecy longer by accelerating the 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 among Japanese firms regarding the effects of information disclosure in 1970. The risk of imitation through the disclosure of patent information is easily recognized, whereas the value of establishing a patent's priority is not.

11 Conclusions

This study examined how the 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 rejection (and abandonment) of subsequent duplicative patent applications by others more than grants of their follow-on patents. Consequently, patent value increased on average. Furthermore, consistent with the importance of early priority setting, early publication also increased the number of grants for own-follow-on inventions, more so when competition was significant. Thus, pre-grant publications promoted appropriation through the early determination of the pioneer.

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

The above results on patent value are robust, irrespective of whether we use only cross-sectional variations in the effects of the introduction of pre-grant publications as instrumental variables, or whether we use the policy discontinuity between 1970 and 1971 (beyond pre-trends) directly as an instrumental variable, without the controls of sector by year dummies. Simultaneously, we find that the potential sample selection bias due to the introduction of examination request system is unlikely to have significantly affected our estimation results. Furthermore, the results are also robust regardless of whether we use patent values at applications or at grants.

Our primary sample for estimations did not cover the three months before and after the introduction of pre-grant publication in Japan in January 1970, because we observed a significant shift in patent applications from 1971 to 1970 just before the policy reform, apparently to avoid pre-grant publication. Our evidence suggests that such strategic acceleration targeted high-value patents. Interestingly, our evidence also suggests that such strategic acceleration of applications led to a reduction in the private value of these patents, contrary to the applicants' intentions. One explanation for this seemingly 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 recognize the value of early disclosure well, as they opposed the introduction of pre-grant publications in the US.

This study has established the hitherto not well recognized role of disclosure as well as its significance: it plays an essential role in establishing the priority of the invention, which has significant economic consequences. Consequently, pre-grant publications can enhance patent value and the ex-ante incentive for R&D by reducing duplications and accelerating follow-on inventions. Early disclosure can have a major advantage as an innovation policy; it can 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 a pivotal role in making competitors aware of the prior art early and for letting 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]Although the effect on appropriation depends on the balance between grant and non-grant outcomes of follow-on patent applications, there is a possibility that the current 18 months of secrecy period before publication is too long for the appropriation objective itself. Policymakers can consider several policy options, including the general coordinated acceleration of disclosure, earlier disclosure in technology sectors with short technology cycles, and earlier disclosure (for an example, 6 months from application) of patent applications using the grace period.

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

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A Appendix

A.1 The statistics tables for shift period

Table 11: Basic Statistics of Granted Patent in Japan Applied for 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 used data from the last and first three months of the respective years to capture the features of the shift period for patent applications. See the Note of Table 1 for explanations of the variables constructed.

Table 12: The Number of Citing Patent to the Granted Patent in Japan Applied for 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 were counted as citing patents. We used data from the last and first three months of the respective years to capture the features of the shift period for patent applications.

A.2 The statistics tables for estimation

Table 13: Basic Statistics of Granted Patent in Japan Applied for 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 applicant firm data can be identified. We used data for the first and last 9 months of the respective years to exclude the effect of the acceleration of applications, anticipating the introduction of a pre-grant publication system. See the Note of Table 1 for explanations of the variables constructed.

Table 14: The Number of Citing Patent to the Granted Patent in Japan Applied for 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 applicant firm data can be identified. Only examiner citations were counted as citing patents. We used data for the first and last 9 months of the respective years to exclude the effect of application acceleration due to the introduction of 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: These data include 1,391 applicant firms and 8,709 combinations of applicant firms in the WIPO technology sector. “Patent value” is the estimated value of a patent based on survival length and is derived in Appendix A.3. The unit of Patent value is 1 million yen in 2022.

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

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

where γ_u is the log of the mean initial patent value for each technology sector 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. However, we assume that profit is realized only after the patent grant, as in Schankerman and Bessen. Under this assumption, the value of patent i in year t, which is the number of years since 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:

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

We can estimate the three depreciation rates above because the length of the pre-publication period varied across the 1970 cohort of patents. Publications were made when the substantive examination was over, and the opposition period began. However, publications were published within 18 months for the 1971 cohort of 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 three years, followed by annual payments for each year thereafter.[11] To simplify the estimation, we assume that the renewal decision is made once every

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

three years. Because patent renewal fees monotonically increase and the patent value depreciates, the optimal year to stop renewal is always uniquely determined by condition (8). The applicant decides to renew the 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 other cases, where applicants are subject to statutory constraints on renewal, they cannot make the decisions expressed in Equation 9 until the end of the patent term. Instead, the probability formula in Equation (9) is replaced after the constrained period, as follows:

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

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. Therefore, Equation (10) holds for a significant number of patents handling. This model employs the same likelihood function as the ordered probit model, except that it estimates three types of depreciation rates common to 33 different technological sectors u.

The log-likelihood function is defined as the sum of the logarithms of the 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. Tables 17 and 18 present the estimation results for 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 three technology sectors because of 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 were 75,357 and 324,486 Japanese yen in 1970, respectively, and approximately \$1,005 and \$4,329 in 2022. The standard deviations also vary with 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 approximately 18%. $Survival\ length_{i,t}$ increased by approximately 1.5%, from 16.16 to 16.40, reflecting the impact of the increase in high-value patents being maintained up to the statutory limit.

Table 18 presents the estimated results 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 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 Patent Values by the 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: Number of observations is 77,104. This estimation was performed by assuming a discount rate of 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: Number of observations is 77,104. This estimation was performed by assuming a discount rate of 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 the patent value at grant instead of 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 the top 10% value by increasing $Non\ Grants_{i,t}$ but decreasing $Grants_{i,t}$. Furthermore, $Grants_{i,t}$ and $Non\ Grants_{i,t}$ have coefficients of similar magnitude but opposite signs, as shown in Table 5.

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

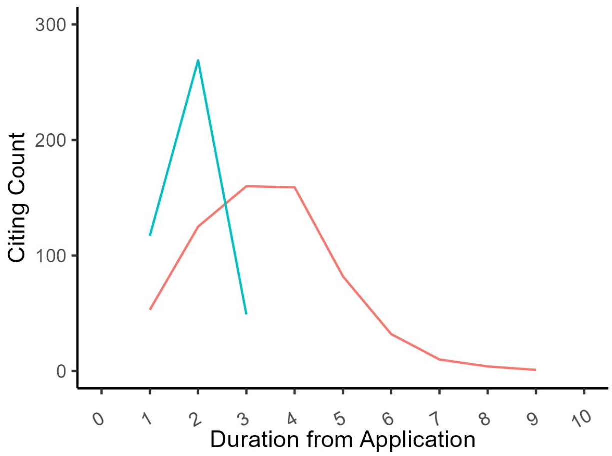
*** 1% significance, ** 5% significance, * 10% significance

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

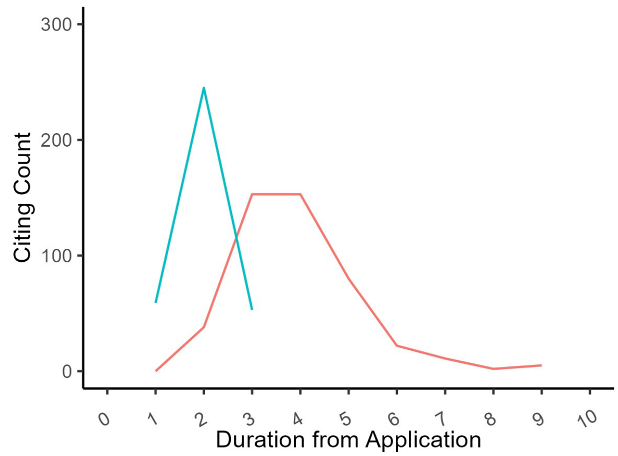
A.5 Estimation result for Equation (1) including citation flow variables made before disclosure

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

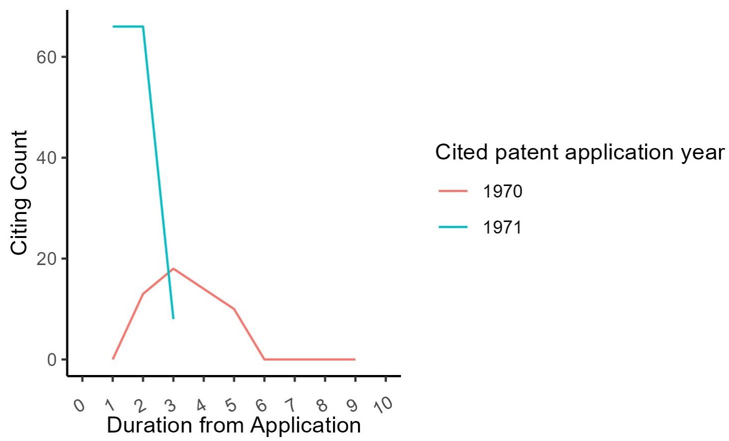
The results of the IV estimation corresponding to Tables 4 and 5 in section 7 are presented in Tables 21 and 22, respectively. Clearly, the citation flow variables *before* disclosure do not have a significant impact on the IV estimation results.



(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 the 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. The IV test is the F-value obtained from Stock and Yogo's (2005) weak IV test.

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

Table 23 presents the OLS (Ordinary Least Squares) results for Equation (1). $Grants_{i,t}$ and $Non\ Grants_{i,t}$ have significantly positive coefficients, quite contrary to the IV estimation results (Table 5). This contrast indicates the importance of controlling for the unobserved patent quality variable to obtain a causal interpretation of the coefficients of 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 yen in 2022.