Patent Disclosures Enhance Price Discovery and Reduce R&D Uncertainty

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Abstract

This paper examines the effect of firms' invention disclosures via patents on financial markets by leveraging the American Inventor's Protection Act of 1999 (AIPA), which generally required the public disclosure of patent applications 18 months from filing rather than 3-4 years after filing at patent grant. We find a significant improvement in the speed of stock price discovery after AIPA, which expedited the disclosure of patent applications. This improvement is stronger for more valuable inventions and more pronounced for firms with limited alternative disclosures on R&D activities, fast-moving product market, and a large institutional ownership or analyst coverage. We further find that AIPA lowered investors' risk perceptions of firms' R&D investments and share mispricing, in particular, the under-pricing of securities of R&D intensive firms. Our findings highlight the importance of timely patent disclosures in alleviating the information frictions faced by investors in innovative firms.

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I. Introduction

Investors find it difficult to price firms' research and development (R&D) and other innovative activities due to the secrecy, complexity and long time horizons associated with such projects (e.g., Arrow 1962; Lev 2001; Kothari, Laguerre, and Leone 2002). The scarcity of information on firms' R&D activities available to investors—most firms disclose just their periodic R&D expenditures—is exacerbated by the absence of a clear, generally accepted definition of R&D, allowing some firms to over- or under-report R&D spending by shifting expenses across income statement line items.[1] Consequently, R&D-intensive firms tend to be under-valued in public markets, and face high cost of capital, impeding their growth (e.g., Eberhart, Maxwell, and Siddique 2004; Hirshleifer, Hsu, and Li 2017).

Can regulations regarding the timing of firms' public disclosures of their innovative activity affect investors' decisions? In this study, we employ the passage of the American Inventor's Protection Act (AIPA), which generally required publication of the entire U.S. patent application document 18 months after filing[2], as an exogenous shock to public information on firms' innovation activities to answer this question. AIPA is regarded as one of the most significant change to U.S. patent laws in the past half-century (Slind-Flor 1999), but whether it informs public investors is not immediately obvious. This is because several legal scholars have

[1] See Koh and Reeb (2015) for evidence on R&D under-reporting, and Skaife, Swenson, and Wangerin (2013) for R&D over-reporting.

[2] AIPA requires all U.S. patent applications which seek foreign protections and encourages applicants which only seek U.S. protections to disclose in the patent document 18 months after the first filing date. In fact, more than 90% of patents are disclosed before grant. We discuss the institutional background in detail in Section I.

questioned whether patent applications disclose anything meaningful (see, for example, Roin 2005), and firms can always voluntarily disclose information that materially benefits them, including information about their innovation activities, through other channels.

Prior to AIPA, the existence and the content of patent applications were disclosed only upon patent grant, which typically takes over three years from application. AIPA thus advanced patent disclosures to the public by roughly 20 months. Important to our empirical strategy is the de facto staggered phase-in of the 18-month disclosure rule for firms. Since firms applied for patents at different points in time after this rule became effective on November 29, 2000, 525 firms in our sample had their first 18-month patent disclosure in 2001, 511 in 2002, and 182 in 2003. This staggered phase-in allows us to sharpen our identification of the impact of the18-month patent disclosures and to isolate AIPA's impact from other economic or regulatory changes. [3]

Prior studies on innovation and securities valuation mainly focused on patent *grants* (e.g., Long 2001; Heeley, Matusik, and Jain 2002; Hottenrott, Hall, and Czarnitzki 2016). However, patent grants *both* disclose the technical details of the underlying inventions and inform investors of the exclusive rights awarded to the patenting firm, making it hard to distinguish the technological information from the grant of exclusive rights. In contrast, the 18-month patent disclosures examined here reveal the patent technical details, regardless of whether the applications will later be granted by the patent office or not. Thus, by comparing how investors respond to publicly listed firms around the staggered phase-in of the 18-month disclosure rule we isolate the impact of information disclosure on investors.

[3] The AIPA impact we identify likely understates the overall impact of R&D-related disclosures for two reasons. First, AIPA mainly changes the timing of patent disclosures for patent applications that are eventually granted. Second, firms which apply for foreign patent applications for the same underlying invention have to disclose the applications in 18 months in the foreign patent offices both before and after AIPA.

We use a sample of 22,809 firm-years from 1996 to 2005, centered around the enactment of AIPA. Our findings show that share price discovery, measured as the intra-period return timeliness (IPT), following Butler, Kraft, and Weiss (2007) and Blankespoor, deHaan, and Zhu (2017), was significantly expedited after AIPA. This finding cannot be explained by time-invariant firm heterogeneity or macro trends, since we control for firm and year fixed effects. To mitigate concerns of time-variant industry shocks, we add industry-year fixed effects and find the results unchanged. Furthermore, the accelerated price discovery post-AIPA is not driven by pre-AIPA economic trends since we do not find significant changes in IPT in the year before firms had their first 18-month disclosures. Our results are also not a manifestation of the well-documented phenomenon that successful R&D activities are associated with lower uncertainty (Pandit, Wasley, and Zach 2009; Czarnitzki and Toole 2011), as we control for the stock of patent grants as a proxy for R&D success. To sharpen the identification of 18-month disclosures as a valuable information source on R&D, while controlling for firms' fundamental innovativeness, we construct "placebo patent disclosures" by applying the 18-month rule to patent applications that were filed *before* the effective date of AIPA. We do not find a significant impact of placebo patent disclosures on IPT, which provides further evidence that the 18-month disclosures enable investors to better understand firms' R&D activities, thereby accelerating the process of price discovery.

To better understand the informational impact of the 18-month patent disclosures, we examine whether this impact is stronger when investors' demand for R&D information is higher. Specifically, we expect that such information is in greater demand for firms operating in industries characterized by advanced technology or by short product cycles, or when firms are followed by more financial analysts or owned by more institutional investors, who generally have the required expertise to process the patent information. Consistent with our expectations, we find that the improvement in price discovery after AIPA is more pronounced for firms in high-tech or fast-moving industries, and those with a larger analyst coverage or higher ownership of dedicated institutional investors. Collectively, these results indicate that the increased availability of timely, detailed, and credible information on firms' R&D activities, via the 18-month disclosures, had a stronger impact on the efficiency of price discovery, particularly when such information is in greater demand by investors.

We conduct two sets of robustness checks. First, in addition to the dummy variable indicating the phased-in 18-month disclosure rule under AIPA, we also use the *number* of 18-month disclosures per firm in each year to reflect the heterogeneous treatment effects of AIPA across firms with different patenting intensities. We find the improvement in price discovery to increase with the number of 18-month disclosures of successful patent applications (eventually granted). Interestingly, we also find that the 18-month disclosures of eventually failed patent applications (rejected by patent examiners or withdrawn by applicants) also contributed to price discovery, although their impact becomes insignificant after controlling for the disclosures of successful patent applications. Among the subsequently granted applications, their 18-month disclosures have a larger impact on price discovery when the underlying inventions have not been disclosed in prior patent filings (novel inventions), or when they are more technologically valuable (measured by citation counts).

In the second set of robustness checks, we use *price informativeness*, measured as the ability of the stock price to predict next year's earnings, to proxy for the efficiency of price discovery (Bai, Philiphon, and Savov 2016). Complementary to IPT, which quantifies the process by which the stock price incorporates all information available in the current period, the price informativeness measure quantifies the efficiency of the price in incorporating next period's earnings. Our results show that share price informativeness indeed improved after AIPA and that this improvement was more pronounced for firms in fast-moving industries and those followed by more financial analysts or owned by more dedicated institutional investors.

Our second set of tests focuses on investors' R&D uncertainty. We show that the bid-ask spread of patenting firms narrowed after AIPA, as reflected by an 11%-18% decrease in the effective bid-ask spread. We also examine the impact of the 18-month disclosure on price volatility related to R&D and stock mispricing, and document that volatility and under-pricing significantly decreased post AIPA. Taken together, our results indicate that the timely, detailed, and credible information on R&D activities contained in patent documents plays an important role in enhancing capital market efficiency regarding R&D.

Our study contributes to the literature in three ways. First, our evidence highlights an important non-GAAP information source for investors—early patent applications disclosed via the USPTO—providing insights regarding firms' technological activities and their future prospects. The importance of this information channel derives from investors' high uncertainty concerning firms' R&D activities, due to the inherent riskiness of technological development, and the paucity of information disclosed by firms concerning R&D and other innovative activities. Reducing R&D information uncertainty is expected to decrease firms' cost of capital and enhance their R&D spending. The question for managers is what is the most effective disclosure that will mitigate investors' R&D uncertainty? Evidence gathered here on the impact of 18-month patent disclosures on price discovery and R&D uncertainty will inform managers about the type of disclosures expected to alleviate investors' R&D uncertainty.

Second, we contribute to the understanding of the financial consequences of patent disclosures. Most economic research on patents focuses on the trade-off between granting exclusive rights to inventors and innovation incentives, while the information role of patents in capital markets is relatively under-studied (see Williams (2017) for a review). For example, papers studying the signaling effect of patents usually focus on relatively opaque start-ups or sophisticated investors, such as venture capitalists. Using a sample of relatively large, established firms we show that patent disclosures convey useful information to investors in general. We argue that the 18-month disclosures are a valuable information source for investors to better understand the firm's R&D activities for three reasons: First, these disclosures are detailed and credible, as the entire patent application is published by the U.S. Patent Office (USPTO) on its website. Investors are thus able to examine the technical details of the invention and verify other R&D-related information voluntarily disclosed by managers, say, via conference calls. Second, the USPTO systematically categorizes all patent applications in a standardized and consistent format, enabling investors to efficiently analyze and compare patent applications of a particular firm with technologically related enterprises. Lastly, the early revelation of patent applications allows investors to identify potential technology leaders early on (see Hegde and Luo 2018).

Lastly, our paper fits into the broader literature examining the impact of institutional and technological changes on share price informativeness in the new economy. The emergence of new economy firms is generally associated with opaque information environment, deteriorating earnings quality, and declining price informativeness, despite the great availability of information technologies and data analytics tools (Srivastava 2014; Bai et al. 2016). For these new economy firms, our evidence suggests that timely, detailed, and credible information of R&D activities alleviates substantially the information frictions, results in faster price discovery, and lowers R&D uncertainty, despite their inherent complexity.

The order of discussion is as follows: Section II provides background information on AIPA, and Section III develops our hypotheses. Sections VI describes the sample and data. We present the empirical analyses for price discovery and R&D uncertainty in Section V and VI, respectively. Section VII concludes the paper.

II. Background

AIPA was described as "the biggest change to patent law since 1952" (Slind-Flor 1999), and was passed by Congress on November 29, 1999, becoming effective for all U.S. patents (patents filed with the USPTO, regardless of applicants' country of origin) on or after November 29, 2000. The most important part of AIPA is the 18-month disclosure rule (Graham and Hegde 2015), and the next paragraph will discuss the rule in detail. Though the early disclosure provision was strongly challenged by many individual inventors and 25 Nobel laureates in science and economics as decreasing innovation incentives[4], AIPA was passed by Congress primarily to facilitate quick technology diffusion, reduce duplicative research, promote innovation activities, and harmonize patent disclosures in the U.S. with virtually all other major countries which already required early patent disclosures.

According to AIPA, all U.S. patent applications with foreign parallel applications (filed with the European or Japanese patent office, for example) are required to be fully published 18 months after the first application, whereas inventors filing patents only in the U.S. can opt out of the 18-month disclosure requirement by submitting a non-publication request to the USPTO.[5] In fact, only 14.2% of our sample patents *without* foreign parallel applications (7.3% of all sample

[4] Please refer to https://www.uspto.gov/ip/rules/comments/18month/index.jsp for comment letters by small inventors and to https://www.congress.gov/congressional-record/1997/11/13/senate-section/article/S12637-1 for the letter from 25 Nobel laureates to the U.S. Senate.
[5] The key condition to request non-disclosure before grant in the post-AIPA period is to commit to not filing patents for the underlying invention internationally (Manual of Patent Examining Procedure §1122).

patents) opted out of the 18-month disclosure requirement.[6] Given the current 38-month average time lag from patent application to grant, the 18-month disclosure rule advances the revelation of patents' technical details to the public by about 20 months, a significant advance in the disclosure of firms' innovative activities. Applications can be disclosed before 18 months if applicants submit an early disclosure request or if they claim a priority over previous applications.[7] In fact, 68.7% of patents with 18-month disclosures were disclosed within one year after the application date and the average gap between filing and 18-month disclosure was 300 days.

Figure 2 plots annual U.S. patent grants and the 18-month disclosures from 1996 to 2005. The difference between the number of 18-month disclosures (including eventually granted applications and abandoned ones which are voluntarily withdrawn by applicants or rejected by patent examiners) and the number of grants grew substantially in later years. This difference is largely due to an increase in the 18-month disclosures of subsequently abandoned applications, from which investors learn about inventions which are abandoned for good (fail to overcome patent examiner's rejection) or later improved upon by the applicants (drop the focal application and file a continuation application), a unique source of information that was not available before AIPA.

The 18-month patent disclosures are posted on the USPTO website every Thursday, easily accessible and searchable by applicant name, technology class, or keywords describing the invention. The entire patent document is revealed to the public, including a detailed description of the invention, technological claims which define the scope the invention, as well as technical

[6] Our sample includes only patents that are assigned to public companies. Graham and Hedge (2015) examine all patents filed with the USPTO from 1996 to 2005 and document a similar 18-month disclosure propensity.
[7] Among the patent applications filed after AIPA and before 2014, only 6,828 (0.2%) applications filed an early 18-month disclosure request.

drawings that illustrate the mechanisms of the invention. These patent documents are easily accessible not only through the USPTO's website but freely through other sites such as google patents and justia. Appendix B provides an example of an 18-month disclosure of a recent patent application filed by Amazon.

Examining the consequences of AIPA, several studies have documented that the law indeed facilitates knowledge diffusion among inventors. For example, Hegde, Herkenhoff, and Zhu (2018) examine sets of "twin patents," which are parallel applications in both the USPTO and the European Patent Office, and show that U.S. patents receive more and timelier "forward citations" (citations made by subsequent patents to a given patent, indicating technological impact) in the post-AIPA period than their European twins. They also find that the 18-month patent disclosures decrease the technological similarity between the disclosed patent and subsequent patents, consistent with policymakers' claim that early disclosures will reduce duplicative research. Focusing on biomedical patents, Hegde and Luo (2017) report that licensing deals are advanced by approximately 10 months after AIPA's enactment, suggesting that the 18-month disclosures ease information frictions in the patent licensing market.

Several studies examine the impact of the 18-month disclosures on capital markets. Kogan, Papanikolaou, Seru, and Stoffman (2017) report that trading volumes in the disclosing firms increase significantly on days with such disclosures. Using AIPA as a shock to information on innovation, Saidi, and Zaldokas (2017) document that firms in industries with greater acceleration in the revelation of patent documents are significantly more likely to switch lenders, suggesting that borrowers and lenders use the information made available by the 18-month disclosures. Mohammadi and Khashabi (2016) focus on venture capitalists and show that 18-month disclosures by startups significantly enhance the likelihood and size of corporate venture capital investment relative to independent venture capital investment. Focusing on the interaction between mandatory and voluntary disclosures, Wang (2017) reports that the mandatory R&D-related disclosures under AIPA are associated with more voluntary R&D-related press releases.

In contrast with the extant research on 18-month disclosures in capital markets, we focus in this study on the impact of expedited patent disclosure on the *speed of share price discovery* and on investors' *uncertainty concerning R&D*. In Appendix B, we provide an illustrative case study of Amazon's 18-month disclosures to clarify the path from the 18-month patent disclosures to investors' assessment and perceptions.

III. Hypotheses Development

It is widely held that R&D is a complex and risky activity, making it difficult for investors to understand and evaluate (Arrow 1962; Lev 2001; Kothari et al. 2002). The technological and commercialization uncertainty about R&D projects is further exacerbated by the absence of meaningful disclosure requirements about R&D activities in corporate financial reports, except for the total quarterly spending amount.

In contrast, an 18-month patent disclosure contains extensive information about the scope and potential of the R&D activities undertaken by the applicant. It informs investors about the applicant's R&D strategy and development priorities, enabling investors to gauge the applicant's technological edge and the commercial potential of the underlying technology. Moreover, the 18-month disclosures are standardized and systematically cataloged by the USPTO and therefore comparable across applicants, making it easier for analysts and investors to identify the next industry leader by peer comparison. Lastly, these disclosures are easily searchable and free to be downloaded from the USPTO's website.[8] Several widely visited innovation websites, such as *Google Patents*, *Free Patents Online*, and *freshpatents.com*, routinely extract these disclosures, process them, and disseminate them to investors, thereby reducing investors' information acquisition and processing costs. Taken together, we predict that AIPA's 18-month disclosures provide important information to investors, thereby accelerating the process by which stock prices incorporate value-relevant information, and unraveling the uncertainty about R&D investments. Accordingly:

***H1**: 18-Month patent disclosures accelerate share price discovery.*

Firms can always voluntarily disclosure more information about their R&D projects, but they are generally guarded about their R&D activities due to proprietary concerns (Verrecchia 1983). Merkley (2013) documents that R&D-intensive firms, on average, include 30.87 sentences with keywords, such as "research and development," "R&D," or "product development" in their 10-K filings, mainly discussing prior R&D expenses and seldom providing information on current R&D progress and prospects. Studying companies' press releases on product development, Cao, Ma, Tucker, and Wan (2018) report that, on average (median), firms only disclose 1142 (152) words related to R&D activities in press releases during a year, approximately one to two pages of information. To the extent that voluntary disclosures preempt 18-month disclosures, 18-month disclosures provide more useful information to investors when alternative R&D-related information is scarce.

[8] The machine readable bulk data of 18-month disclosures are updated weekly by the USPTO (https://bulkdata.uspto.gov/) and other web portals (e.g., *Reed Tech Patents* and *PatentsView*). Investors can search for patent applications of interest without reading the entire database through USPTO's Patent Full Text Databases (http://appft.uspto.gov/netahtml/PTO/search-bool.html) or other databases such as Google Patents.

***H2a**: The acceleration of share price discovery associated with the 18-month disclosures is more pronounced for firms with less alternativeR&D-related disclosures.*

Prior to the enactment of AIPA, detailed information about inventions only become available to the public when the applications are approved by the patent office. For such successful applications, AIPA advances the information release by 20 months, on average. Such an advance in timing is particularly advantageous to investors in industries characterized by fast-moving technologies (e.g., information technology), and less so for slow technological-development sectors (e.g., textiles). To the extent that the information in the 18-month disclosures is more novel and relevant in fast-moving industries, it will be more useful for investors in these industries, thereby resulting in faster price discovery.

***H2b**: The acceleration of share price discovery associated with the 18-month disclosures is more pronounced for firms in fast-moving industries.*

Scientifically-qualified financial analysts likely have the required knowledge to process the information contained in the 18-month disclosures. The larger the number of analysts following a firm, the higher the likelihood that some scientifically-qualified analysts will be among them. For example, Li (2016) finds that analysts' long-term earnings growth forecasts are revised upon patent grants and long-term forecast errors are negatively associated with grants. Anecdotal evidence of the Amazon case discussed above suggests that analysts indeed pay close attention to firms' 18-month patent disclosures. We, therefore, expect that the impact of 18-month disclosures on price discovery will increase with the number of analysts following the firm.

***H2c**: The acceleration of price discovery due to early patent disclosure is more pronounced for firms followed by a larger number of financial analysts.*

Institutional investors are likely to exploit some of the information in the 18-month patent disclosures due to their relative sophistication and considerable research resources. Unlike individual investors who largely lack the technical background to fully understand complex disclosures (Miller 2010), institutional investors can hire experts to process the information in patent documents. For example, Haeussler, Harhoff, and Mueller (2014) interviewed venture capitalists (VC) investing in British biotechnology companies and found that VCs indeed hired technology experts in the field to evaluate companies' patent portfolios. One interviewee even pointed out that granted patents are preferred but not particularly important as VCs "*are able to decide whether there is something valuable based on the patent application document*." This leads to the final hypothesis:

***H2d**: The acceleration of price discovery associated with the 18-month disclosures is more pronounced for firms with a larger institutional investor ownership.*

IV. Sample and Data

Our sample includes firm-year observations from 1996 to 2005, namely 10 years surrounding the AIPA's effective date (November 29, 2000).[9] We require that data be available from the Compustat, CRSP, IBES, and Thomson Reuters databases and that the sample firms existed both before and after the effective date of AIPA. Following prior research, we exclude firms in the financial (SIC between 6000 and 6999) and utility (SIC between 4900 and 4999) industries as only a small fraction on firms in these industries file for patent applications.

Our first measure of price discovery is the *intra-period timeliness* (IPT), which quantifies the speed of price discovery over a fiscal year (Butler et al. 2007). Specifically, we first compute

[9] We end the sample period in 2005 to mitigate data truncation concerns. Our patent data, described below, include patents granted by 2010 and their citations received through 2016, so we allow five years for disclosed patent applications to be granted and another six years to accumulate citations to measure their value.

a share's monthly abnormal return as its raw return minus the value-weighted return for a portfolio of firms matched on 5 × 5 classes of firm size and market-to-book ratio. We then plot the fraction of the annual cumulative abnormal return that has been reflected in the stock price as of the end of each month, thereby generating the price discovery curve. The standard IPT measure is the area under this curve, and a larger value of IPT indicates a faster price discovery.[10]

In addition to IPT, we also use the *stock price informativeness*, as defined by Bai et al. (2016), to quantify the information efficiency of the stock price. Specifically, we use the stock price six months after the current fiscal year-end to predict next fiscal year's earnings,[11] and interpret the regression coefficient on the stock price as an indicator of its informativeness.

We measure investors' R&D uncertainty by the association between R&D intensity and idiosyncratic realized volatility of stock returns or the idiosyncratic implied volatility based on option prices. Idiosyncratic realized volatility is the annualized standard deviation of residuals from firm-specific annual time-series regressions of daily individual stock returns on the value-weighted index returns. We obtain the implied options volatility of 30-day at-the-money standardized options from OptionMetrics, following Billings, Jennings, and Lev (2015). To adjust for market-wide systematic factors, we follow Dennis, Mayhew, and Stivers (2006) to decompose the implied volatility, using the market model, and remove the systematic component associated with the market volatility (measured by VIX which is available on the CBOE website). Please

[10] Blankespoor et al. (2017) point out that if the intermediate cumulative return *exceeds* the annual return followed by a reversal during the year, the standard IPT measure will increase with the magnitude of over-reaction. We follow their suggestion and subtract twice the area of the over-reaction from the standard IPT. The first subtraction removes the over-reaction and the second one penalizes the over-reaction for the inefficiency. Due to the penalty, this adjusted IPT could be negative if the over-reaction is substantial.

[11] We use the stock price at the end of the sixth month after the current fiscal year to ensure that the earnings of the current year are released to the public. We also try the stock price three months after year-end and obtain consistent results. Earnings are measured as EBIT, or income before extraordinary items.

refer to Appendix A for detailed variable definitions. We also proxy for investors' information uncertainty by the bid-ask spread of stocks.

We obtain the patent data from Kogan et al. (2017) whose dataset contains all U.S. patents granted from 1926 to 2010. They match each patent to a CRSP firm based on the assignee names listed in the bibliographic text of the patent. To complement this database, we obtain *citations* made by U.S. patents through 2016 as well as *patent claims* and *technology classes* from the bulk data maintained by the USPTO, using textual analyses techniques. We also extract 18-month disclosures of abandoned patent applications from the USPTO's bulk data products and match these disclosures to public firms following the procedure described in Kogan et al. (2017).

Summary statistics are reported in Table 1. IPT is highly skewed (negative median) and volatile. To reduce the noise in IPT due to small denominators, we eliminate IPTs when the absolute value of the annual abnormal return is less than 2%, and denote these IPTs as IPT2. The average firm in our sample has an idiosyncratic realized return volatility of 0.55 and an idiosyncratic implied volatility of 0.48. The sample mean (median) of relative effective spread is 2.2% (1.0%). Both our return volatility measures and the relative spread are slightly larger than those reported in previous research (for example, Billings et al. 2015), mainly because our sample period largely overlaps with the tech bubble and its subsequent burst (2000). The average R&D intensity (R&D spending scaled by total assets) is 7.6% and the mean patent stock (weighted average number of patents granted in the recent 5 years) is 50. The average sample firm is 18 years old, is followed by 3 analysts, and has a 41.5% institutional ownership. 40.6% of the sample firms issued at least one management earnings forecast (guidance) during the year. The average ROA (income before extraordinary items and R&D expenditures, scaled by total assets) is positive

(0.04), with 23.1% of firm-years in a financial loss. On average, our sample firms have considerable growth potential, as indicated by the average (median) Tobin's Q of 2.04 (1.34).

Panel A of Table 2 classifies the sample by the Fama-French 12-industry grouping. Business Equipment (computers, software, and electronic equipment), as well as healthcare, medical equipment, and drug companies, have a higher R&D intensity, larger relative effective spreads, and slower price discovery than firms in other industries. In terms of patent stock, consumer durables companies have the largest patent portfolios, consistent with the statistics reported by the National Science Foundation in 2010, indicating that the manufacturing sector files for more patents than other sectors.[12]

Panel B of Table 2 breaks down the sample by year. Column 1 (2) reports the number of firm-years that are not yet "treated" (already "treated") by the 18-month disclosure rule under AIPA, respectively. Once a firm has an 18-month disclosure, we consider it as "treated" and it remains so for the rest of the sample period, even if it didn't have an 18-month disclosure in some of the subsequent years. 525 firms (20.1% of the sample firm-years) had their first 18-month disclosure in 2001, and the average number of 18-month disclosures in 2001 is 2.63.[13] Gradually, more and more firms had 18-month disclosures and the average annual count of 18-month disclosures per firm increased, reaching 31 disclosures per firm in 2005 on average. Because firms applied for patents at different points in time, they were affected by the 18-month disclosure requirement differently in time, as shown in Figure 3. This *de facto* staggered phase-in of the 18-

[12] https://www.nsf.gov/statistics/infbrief/nsf11300/

[13] The earliest 18-month disclosure was issued on March 15, 2001, about 3.5 months after the effective date of AIPA. As discussed in Section II, 18-month disclosures can be issued before 18 months either because the applicant requests early disclosures or the application claims priority from a previous application.

month disclosure rule enables us to isolate the impact of patent disclosures from other concurrent changes, as elaborated in the next section.

V. 18-Month Disclosures and Price Discovery

Baseline Results

To visually examine the change in share price discovery associated with the 18-month patent disclosures, we plot the average IPT curve for the sample firm-years in Figure 4. The horizontal axis indicates the month during the fiscal year and the vertical axis reflects the fraction of annual abnormal return that has been incorporated into the stock price by the end of the month. A larger area under the IPT curve means that firm-specific information (proxied by the annual abnormal stock return) is impounded into stock prices more quickly. The solid IPT curve represents treated firm-years (firms in the year when they had the first 18-month disclosure and the subsequent years), whereas the dashed IPT curve represents all other firm-years of non-patenting firms, or of patenting firms before they had the first 18-month disclosure. It is evident that the solid curve dominates the dashed one, indicating that firms had a faster price discovery after issuing the first 18-month disclosure.

To formally examine the impact of 18-month disclosures on price discovery, we use a generalized difference-in-differences (DID) methodology, following Betrand and Mullainathan (2003). The baseline empirical model is as follows:

$$IPT_{i,t} = \alpha_0 + \alpha_1 PostAIPA_{i,t} + W_{i,t} + \gamma_t + \eta_i + \epsilon_{i,t} \quad (1)$$

where i stands for firm and t for year. The dependent variable, *IPT*, measures the speed of price discovery during the year. The key variable of interest, *PostAIPA*, indicates the phase-in of the 18-month disclosure rule. It equals one when the firm had its first 18-month disclosure and remains one until the end of the sample period. In addition to this dummy indicator, we use the number of

18-month disclosures issued by the firm each year to measure the differential treatment effect of AIPA. The control vector *W* contains the following set of common firm characteristics: patent stock (5-year weighted average number of granted patents), R&D intensity (*RD*), capital expenditures (*CAPX*), firm size, firm age, leverage, and financial performance (ROA and a dummy variable indicating whether the firm reported a loss for the year). We also include Tobin's Q to control for the impact of growth opportunities.

Prior research suggests that a firm's information environment is influenced by information intermediaries and outside monitors, such as financial analysts and institutional investors (e.g. Lang and Lundholm 1993). To capture this influence, we control for the number of analysts following the firm, the percentage of institutional ownership, and the issuance of earnings guidance by managers (additional information disclosures). Lastly, we control for firm fixed effects (η_i) and year fixed effects (γ_t). Firm fixed effects capture the time-invariant firm-specific heterogeneity, while year fixed effects capture the aggregate fluctuations in the price discovery efficiency over time. Just like Betrand and Mullainathan (2003), our DID estimation essentially compares firms that had their first 18-month disclosure in year t to all other firms that haven't had 18-month disclosures in that year or already had 18-month disclosures in prior years.

Due to the staggered phase-in of the 18-month rule (namely, some firms had their first 18-month disclosure in 2001, others in 2002, 2003, and so on), the change in price discovery documented in this study isn't likely to be caused by other concurrent market-wide or macroeconomic changes, since it is unlikely that such concurrent changes follow the same staggered timing and cross-sectional variation of the 18-month disclosures.

The estimates of Model 1 are reported in Columns 1-2 of Panel A of Table 3. Consistent with the graphic evidence in Figure 4, the coefficient on *PostAIPA* is positive and significant at

1% level, indicating that price discovery is significantly accelerated in the post-AIPA period. Economically, AIPA increases IPT by 7.9% (=26.51/33.352) of the sample standard deviation or raises the median firm to the 80th percentile. These results are unlikely to have been driven just by firms' innovativeness, as we control for the stock of patents granted in the previous five years. In unreported results, we use the number of patents granted during the year to proxy for firms' innovativeness and find almost identical results (similar to the coefficient on the patent stock, the coefficient on patent grants is 0.461, statistically insignificant, with a p-value of 0.36). The coefficients on the other control variables are generally consistent with our expectations. Higher capital expenditures (R&D expenses) are associated with a faster (slower) price discovery, although the coefficients are statistically insignificant. Consistent with conditional conservatism implying that poor earnings news is recognized more quickly than good news, ROA is negatively associated with IPT. Firms with greater growth potential (measured by Tobin's Q) or followed more analysts have faster price discovery, probably due to closer attention by investors.

To capture AIPA's heterogeneous effect across firms, we examine the relationship between the firm-specific count of 18-month disclosures and price discovery. Specifically, we count the disclosures of successful applications (eventually granted patent applications) and set the count to zero when such disclosures are absent. By construction, all firms in the pre-AIPA periods have zero 18-month disclosures. We then take the natural logarithm of one plus the disclosure count to deal with the skewness in the count (*Ln(Disclosure)*). As shown in Columns 3-4 of Table 3, the coefficient on *Ln(Disclosure)* is significantly positive, indicating that the improvement in price discovery increases with the number of 18-month disclosures.

We expect that the 18-month disclosures of subsequently abandoned (or rejected) patent applications provide investors with useful information regarding the firm's R&D activities such as the deficiencies in the applicant's R&D program. Firms also abandon patent applications of preliminary inventions which are later improved and covered by new applications. The disclosures of such preliminary inventions provide investors with information about on-going R&D progress. Consistent with this expectation, we find that the 18-month disclosures of subsequently abandoned applications (*Ln(Dis-Abn)*) also contribute to the efficiency of price discovery, as shown in Column 1 of Panel B of Table 3. When we run a horse race between *Ln(Disclosure)* and *Ln(Dis-Abn)* in Column 2, the coefficient on *Ln(Dis-Abn)* becomes insignificant while that on *Ln(Disclosure)*—the 18-month disclosures of eventually granted patents—remains significantly positive, suggesting that the information on successful inventions is more useful than that on failed or preliminary inventions in evaluating R&D activities.

Finally, within patent disclosures of subsequently granted applications, we distinguish between those providing more useful information on innovation and those with less useful information. We first identify *stale disclosures* as those disclosing patent applications that claim priority over prior applications which cover the same invention and were already disclosed to the public.[14] These stale disclosures convey scant new information hence are expected to have a smaller impact on price discovery than the disclosures of brand new inventions. Consistent with this expectation, as reported in Column 3 of Panel B, we find that IPT is positively associated with both stale disclosures (*Ln(Disclosure-Stale)*) and new disclosures (*Ln(Disclosure-New)*), but only the association with new disclosures is statistically significant.

[14] One requirement for the "child" application to claim the priority over the "parent" application is that the child application repeats a substantial portion of its parent (Hegde, Mowery, and Graham 2009). Although not all parent applications are revealed to the public before their child applications (parent applications can be abandoned before 18 months or opt out of the 18-month disclosure requirement), 21.2% of the sample 18-month disclosures are preempted by parent patent publications (parent applications' 18-month disclosures or grant documents), according to the USPTO's comprehensive record of continuing applications (Patent Examination Research Dataset).

We then classify patents into two categories based on their scientific value, measured by forward citations, and expect that disclosures of influential inventions (more forward citations) have a larger impact on price discovery. To deal with technology heterogeneity, we identify influential inventions as those with forward citations above the technology class-grant year median (Hall, Jaffe, Trajtenberg 2005; Seru and Lerner 2015).[15] The results, reported in Column 4, show that only disclosures of influential inventions (*Ln(Disclosure-Imp)*)) significantly contribute to the efficiency of price discovery. The surprising thing about our findings is that despite the considerable complexity of patent documents, investors' reaction to the 18-month disclosures is not simply a response to the fact that an invention is attempted to be patented, but rather a nuanced reaction to the prospective value and technological contribution of the invention.

We also conduct two sensitivity tests. First, to mitigate the concern with industry-specific shocks, we replace the year fixed effects with industry-year fixed effects in Model 1. The results, reported in Columns 5-6, are very similar to the baseline results in Panel A. Second, to reduce the influence of the noise in the IPT measure, we exclude firm-years with annual returns between -2% and 2%, following Blankespoor et al. (2017), and find similar results as shown in Columns 7-8.[16]

Alternative Explanations

A concern may arise that our estimates reflect *pre-existing* trends, unrelated to AIPA. For example, the introduction of the SEC Regulation Fair Disclosure (2001)[17] and the Sarbanes–Oxley Act (2002) may have enhanced price discovery in general and the impact of these regulations could have been larger for R&D-intensive firms which tend to be more opaque to begin with. As we

[15] We also use patent scope (the number of claims) to identify influential inventions and find consistent results.

[16] Based on the estimates in Column 7, AIPA increases IPT by 8.4% (=1.261/15.005) of the sample standard deviation, or the 50th percentile firm to the 80th percentile. This economic magnitude is similar to the magnitude of the baseline regression (7.9% of the sample standard deviation).

[17] SEC Regulation Fair Disclosure prohibits managers from disclosing material information in a non-public manner. Sarbanes–Oxley Act was enacted to improve corporate governance and enhance investor confidence.

have argued above, such impacts are minimized by the unique feature of our empirical setting—the *de facto* staggered phase-in of the 18-month disclosure rule—but perhaps the impacts of these or other factors are not eliminated altogether.

To address this concern, we follow Betrand and Mullainathan (2003) and investigate the dynamic impact of the 18-month disclosures on IPT. Specifically, we replace *PostAIPA* in Model 1 with a set of dummy variables reflecting the implementation process of the 18-month disclosure rule: *before[x]* and *post[x]*, with *x* indicating the years relative to year 0—the year with the first 18-month disclosure by the firm. The model is specified as follows:

$$IPT_{i,t} = \alpha_0 + \alpha_1 Before[-3]_{i,t} + \alpha_2 Before[-2]_{i,t} + \alpha_3 Before[-1]_{i,t} + \alpha_4 Post[0]_{i,t} + \alpha_5 Post[1]_{i,t} + \alpha_6 Post[2]_{i,t} + \alpha_7 Post[3+]_{i,t} + W_{i,t} + \gamma_t + \eta_i + \epsilon_{i,t} \quad (2)$$

The "before indicators" (*Before[-3]*, *Before[-2]*, and *Before[-1]*) allow us to directly detect changes in price discovery prior to the phase-in of the 18-month disclosure rule. Finding such changes would suggest that something other than the 18-month disclosures (e.g., the SEC Regulation Fair Disclosure) is affecting price discovery. The results, reported in Columns 1-2 of Table 4 and in Figure 5 show that the coefficients on the "before indicators" are statistically and economically insignificant, casting doubt on the possibility of pre-existing trends affecting price discovery. In contrast, the coefficients on the "post indicators" (*Post[1]*, *Post[2]*, and *Post[3+]*) are significantly positive, indicating that the 18-month disclosures indeed enhance price discovery. The coefficient on *Post[0]* is positive but insignificant, meaning that the AIPA impact on price discovery is small when the first few 18-month disclosures just become public, likely because only a few 18-month disclosures were available in year 0 and they are difficult to interpret since there were no prior disclosures.

We also examine the differential treatment effects of the 18-month rule in each event year and report the results in Columns 3-4 of Table 4. Specifically, we count the 18-month disclosures and construct the variable *Ln(Disclosure[x])* as the natural logarithm of one plus the number of 18-month disclosures in event year x, and set it to be 0 in all other years. The coefficients on *Ln(Disclosure[x])* are all positive for x equal 0, 1, 2, 3+, although the statistical significance varies. Overall, this evidence suggests that within each year after the phase-in of the 18-month disclosure rule, the AIPA impact on price discovery increases with the amount of information released under AIPA, as measured by the number of 18-month disclosures.

Lastly, one may argue that firms with more 18-month disclosures are more successful in their R&D activities, thereby having faster price discovery because managers are more willing to provide voluntary information on R&D success or because investors spend more effort acquiring private information on these firms. The fact that we already controlled for patent grants and that these innovative firms do not enjoy a faster price discovery in the year immediately before the first 18-month disclosure mitigates the plausibility of this alternative explanation. However, to further address this concern, we construct placebo disclosures by applying the 18-month disclosure rule to patents filed *before* AIPA's enactment. When these patents were granted in later years, we observe their application dates and fabricate their placebo disclosure dates as 18 months after the application dates.[18] We then add these *placebo* disclosure counts (*Ln(PlaceboDis[x])*) in each event year prior to the first *actual* 18-month disclosure to the regression. Both placebo and actual 18-month disclosures reflect the success of R&D, but only the actual disclosures reveal new R&D-related information to investors. If the faster price discovery is attributable to firms' innovativeness or R&D success rather than the 18-month disclosures, we should observe that the placebo

[18] Specifically, the placebo disclosure date is 550 days (i.e. 18 months) after the first filing date (i.e., priority date documented in the bibliographic text of each patent), according to the detailed provision in AIPA. If the patent's first filing date is 18 months earlier than the actual filing date, we designate its placebo disclosure date to be 180 days after the actual filing date based on the post-AIPA average time lag between disclosure date and filing date for patents with priority claims. For a few patents that were granted before 18 months, we set the placebo disclosure date to be the grant date.

disclosures also positively correlate with IPT. The results, reported in Columns 5-6 of Table 4, show that none of the coefficients on placebo disclosures is statistically significant, largely ruling out the innovativeness-based alternative explanation. We thus establish that it is the 18-month disclosures under AIPA rather than prior trends or firms' innovativeness that enhances price discovery.

The Demand of 18-Month Disclosures

To strengthen our finding that 18-month disclosures boost the speed of price discovery, we examine whether such a boost is more pronounced when the demand for R&D-related information in 18-month disclosures is higher. Considering that 18-month disclosures contain highly technical and complex information on firms' recent inventions, we conjecture that this information is more useful for investors when alternative sources of information are more limited, when firms operate in fast-moving and dynamic industries, or when investors are better equipped to process the technologically complex information.

First, we expect that the 18-month disclosures are an important source of R&D-related information when alternative information is scarce. We proxy for the abundance of alternative R&D-related information by the R&D-related word count in 10-Ks, arguably the most comprehensive and authoritative source of information for public companies. Specifically, we obtain the list of R&D-related words from Merkley (2013), count the R&D-related words using Python, and scale the R&D-related word count by the 10-K filing's total word count. We then estimate Model 1 for firms whose scaled R&D-related word count is above FF48-year median and below the median, respectively. The results, reported in Columns 1-2 of Table 5, show that only for below-median firms the coefficients on *PostAIPA* or *Ln(Disclosure)* are significantly positive, suggesting that the faster price discovery in the post-AIPA period we documented above is primarily driven by firms with more limited alternative R&D-related information.

Next, we focus on technology cycles. We posit that the18-month disclosures are more effective in enhancing investors' understanding of R&D undertaken by firms operating in industries with fast-moving technologies. Following Gu and Wang (2005), we use the average time lag of backward citations (citations in the patent document to previous patents) to measure the speed of innovation. That is, for each patent granted during our sample period, we calculate the time gap between its own application date and the average application dates of its backward citations. To minimize noise, we use the average time lag across all patents assigned to public firms in each of the Fama-French 48 industries every year and construct an industry-year measure of technology speed. According to our computations, industries characterized by fast innovation include computers (FF48 code=35), communication (FF48 code=32), electronic equipment (FF48 code=22). Industries with slow innovation speed include textiles (FF48 code=16), utilities (FF48 code=31), and tobacco products (FF48 code=5). We then estimate Model 1 using the two subsamples split by the innovation speed and report the results in Columns 3-4 of Table 7. Consistent with our expectation that the impact of 18-month disclosures on price discovery increases with the innovation speed, we find *PostAIPA* and *Ln(Disclosure)* are significantly associated with IPT only for firms in the fast-moving industries.

Financial analysts, particularly those in the science-based and technology sectors, likely have the technological and scientific knowledge required to interpret and disseminate the information contained in patent disclosures. The Amazon case discussed earlier (Section I) demonstrated such information dissemination by analysts. To empirically explore the role of financial analysts, we split the sample based on the median analyst coverage by FF 48 industry and year and reestimate Model 1 for each subsample. We report the estimates in Columns 5-6 of Table 5 and find that the coefficients on *PostAIPA* or *Ln(Disclosure)* are significant for firms followed by an above-median number of financial analysts only. Financial analysts are thus an important conduit of the information in patent disclosures, enabling investors to incorporate this information into their investment decisions.

Institutional investors generally have considerable research capabilities and technical expertise. We, therefore, expect that the enhancement of price discovery attributable to the 18-month disclosures will be more pronounced for firms with a larger share of institutional ownership. As quasi-index or transient institutional investors likely make their decisions based on index composition or momentum strategies and spend less effort in analyzing firm fundamentals, we exclude them in our institutional ownership measure and focus on dedicated institutional investors (Bushee 1998).[19] We then split the sample based on the FF48 industry-year median dedicated institutional ownership and repeat the regressions for both subsamples. The results, reported in Columns 7-8 of Table 5, show that the impact of the18-month disclosures on IPT is only significant in firms with above-median ownership of dedicated institutional investors. This evidence indicates that dedicated institutional investors play an important role in speeding up the process of incorporating patent information into the stock price.

Alternative Proxy for Price Discovery: Price Informativeness

The previous analyses used IPT as a proxy for the efficiency of price discovery to capture the process through which value-relevant information is incorporated into the price. The implicit assumptions of IPT are that the arrival of information within the year is identical across firms (thus IPT captures the speed with which the stock price incorporates the information while holding the

[19] When we split the sample based on total institutional ownership, the results are weaker.

information arrival process constant) and that the annual return represents all information made available throughout the year. Violations of these assumptions undercut the validity of IPT. To mitigate this concern, we use an alternative price discovery proxy, *price informativeness*, as defined by Bai et al. (2016). The price informativeness measure captures the ability of the stock price to predict future earnings. A high predictive power implies that the stock price incorporates more of the future earnings, hence a faster price discovery in the current year. However, this price informativeness measure is not a panacea because it essentially considers the subsequent earnings as the ultimate yardstick to gauge the informativeness of the stock price. Nevertheless, we believe it is a reasonable complement to IPT as it takes inter-period information into account and does not make assumptions about the information arrival process.

Specifically, we run the following regression to test the impact of 18-month disclosures on price informativeness:

$$Earnings_{i,t+1} = \beta_0 + \beta_1 Earnings_{i,t} + \beta_2 Ln\left(\frac{MV6}{AT}\right)_{i,t} + \beta_3 PostAIPA_{i,t}$$

$$+\beta_4 Ln\left(\frac{MV6}{AT}\right)_{i,t} * PostAIPA_{i,t} + W_{i,t} + \gamma_t + \eta_i + \epsilon_{i,t+1} \quad (3)$$

Earnings are earnings before interest and tax scaled by total assets (*EBIT*) or income before extraordinary items scaled by total assets (*IB*).[20] *Ln(MV6/AT)* is the market value of equity as of the sixth month of the current fiscal year scaled by total assets. The coefficient on *Ln(MV6/AT)* measures the ability of the stock price to predict next year's earnings. The variable of interest is the interaction term between *Ln(MV6/AT)* and *PostAIPA*, which measures the impact of the18-

[20] In unreported analysis, we use earnings three years ahead as the dependent variable and find consistent results. Following Bai et al. (2016), we adjust earnings for inflation with inflation index and for survival biases by filling the earnings of delisted firms with the industry weighted average (specifically, we invest the delisting proceeds into a portfolio of firms with the same SIC 2-digit code and take the share of total industry earnings accruing to the delisting proceeds as the survival bias-adjusted earnings for the delisted firm).

month disclosures on price informativeness. We include in Model 3 the same set of control variables used in Table 3, except for *ROA* and *TobinQ* as they overlap with the key variables *EBIT, IB,* and *Ln(MV6/TA).* We also code *Loss* to indicate the negative value of *EBIT* or *IB*, respectively.

We report the estimates of Model 3 in Panel A of Table 6. For brevity, we do not report the coefficients on the control variables. Earnings are measured by EBIT in the first four columns. The coefficient on current *EBIT* is significantly positive even with firm fixed effects, indicating earnings persistence. Consistent with Bai et al. (2016), *Ln(MV6/TA)* has a significant positive association with next year's earnings. The coefficient on the interaction of *Ln(MV6/TA)* and *PostAIPA* is also significantly positive, indicating that the predictive power of the current stock price for next year's earnings has improved post-AIPA. The results hold when we use the 18-month disclosure count to quantify the differential treatment effects of AIPA. In addition, we obtain similar results when we measure earnings by income before extraordinary items (*IB*), as reported in the last four columns of Table 6.

In Panels B and C of Table 6, we conduct cross-sectional analyses. As before, we expect the improvement in price informativeness to be more pronounced for firms with more limited alternative R&D-related disclosures, more dynamic industry environment, a larger analyst coverage, or a higher ownership of dedicated institutional investors. Overall, we find consistent results, although the coefficients on *Ln(MV6/AT)*PostAIPA* or *Ln(MV6/AT)*Ln(Disclosure)* are not always significant across the two sub-samples.[21] Collectively, the results are consistent with the hypotheses that 18-month disclosures improve stock price informativeness, and such improvement is more pronounced when investors have a stronger demand and capability to process R&D-related information in the 18-month disclosures.

[21] The price informativeness more than doubles after AIPA (increase by 0.014 from 0.013) for the high-tech subsample, whereas it only increases by 0.009 from 0.039 for the non-high-tech subsample.

VI. Investors' R&D Uncertainty

So far, we have shown that the 18-month disclosures are associated with more efficient share price discovery. Following this finding we expect that if patent disclosures provide investors with useful information about R&D activities, then such information should reduce investors' uncertainty about R&D. To test this expectation, we examine AIPA's impact on improving investors' information through two measures: (i) a measure based on differences between buyers' and sellers' bids for a certain stock, and (ii) a measure of mispricing for a firm's stock.

We first proxy for investors' uncertainty by the trading volume weighted *effective bid-ask spread* using the TAQ data (Holden and Jacobsen 2014). We use both the dollar effective spread (*Spread$*) as well as the relative effective spread (*Spread%*, the dollar effective spread scaled by the bid-ask midpoint). We then regress next year's spread on the current 18-month disclosures (the dummy variable *PostAIPA* or the count variable of 18-month disclosures *Ln(Disclosure)*). We use here the same set of control variables as in Model 1.

The estimates in Table 7 show a significantly negative association between the18-month disclosures and the bid-ask spread. In Column 1, for example, the coefficient on *PostAIPA* is -0.018, indicating that the dollar effective spread decreases by 11.4% (=-0.018/0.158) after AIPA. When we use the relative effective spread (*Spread%*), the coefficient on *PostAIPA* is -0.388, implying that the relative effective spread decreases by 17.7% (=-0.388/2.188) after AIPA. When we replace the *PostAIPA* with the number of 18-month disclosures per firm (*Ln(Disclosure)*), we find consistent results.

One may be concerned that enactment of AIPA coincided with the decimalization of stock trading which significantly reduced bid-ask spreads (Fang, Noe, and Tice 2009). To address this concern, we add a control variable which measures the annual average effective tick size based on the decimalization schedule documented in Fang et al. (2009).[22] The results are unaffected. Overall, we find consistent evidence that the 18-month disclosures reduced investors' uncertainty as proxied by the bid-ask spread.

We use share price volatility as an alternative proxy for investors uncertainty. Specifically, we regress next year's idiosyncratic volatility of stock returns on the 18-month disclosures (the dummy variable *PostAIPA*, or the per-firm count variable *Ln(Disclosure)*), using the same set of control variables as in Model 1. To examine whether patent disclosures mitigate the uncertainty *arising from R&D activities*, we interact the 18-month disclosures with R&D intensity. If timely patent disclosures improve investors' understanding of firms' R&D activities, we should see a reduction in the association between R&D and return volatility in the post-AIPA period, all else equal.

We report the results in Table 8. The dependent variable in the left four columns is the annual *realized* idiosyncratic volatility (*Real_Vol*). Across the four regression specifications, we see that, as expected, *RD* positively correlates with *Real_Vol*, significant at the 1% level, consistent with the prior literature (Kothari et al. 2002; Pandit et al. 2011). The coefficients on *PostAIPA* or *Ln(Disclosure)* are negative, although statistically insignificant. Interestingly, the interaction terms between *RD* and *PostAIPA* or *Ln(Disclosure)* are significantly negative, suggesting that the return volatility associated with R&D is significantly reduced after AIPA. We obtain similar results when we use the implied *idiosyncratic volatility* (*Imp_Vol*) as the dependent variable in Columns 5-8, although the sample size becomes smaller. Collectively, these findings indicate that the 18-month patent disclosures are associated with a decrease in investors' risk perceptions of R&D activities, an important finding considering the generally high uncertainty concerning firms' R&D activities.

[22] We thank Vivian Fang for sharing the data on the schedule of decimalization with us.

Next, we examine AIPA's effect on stock mispricing, using the mispricing score as pricing errors based on 11 anomalies, constructed by Stambaugh, Yu, and Yuan (2015). The score ranges from 1 to 100 with higher values indicating greater degree of overpricing relative to other public companies.

Figure 6 plots histograms of the distribution of mispricing scores for firm-months before and after AIPA and suggests a closer clustering of the distribution around the center of the distribution after AIPA, which in turn implies a reduction in mispricing. In order to more formally examine whether AIPA affects the overpricing or underpricing of stocks, we create: (1) a dummy treatment indicator PostAIPA which equals one when the firm has its first 18-month disclosure and remains so in subsequent years; and (2) a continuous treatment measure Ln(Disclosure) which is the natural logarithm of one plus the number of 18-month disclosures. We then interact these variables with an indicator of whether the firm was relatively underpriced in the year prior to the disclosure. Table 9 shows the corresponding results which confirm that AIPA leads to the recovery of under-priced stocks. We thus establish that early patent disclosures reduce investors' R&D uncertainty and improves the general underpricing of the shares of R&D-intensive firms.

Our findings are particularly relevant to corporate managers of R&D intensive firms concerned with the general underpricing of their shares, and the consequent increased cost of capital. Many of these managers would like to disclose certain non-GAAP data to alleviate investors' R&D uncertainty but are not sure which data to disclose. Our findings indicate that information included in patent applications indeed alleviate investors' R&D uncertainty, so to the extent that the discourse of such information will not harm the firm's competitiveness it will be advisable to disclose to investors.

VII. Conclusions

We examine in this study the impact of patent disclosures on share price discovery and investors' uncertainty about R&D. Our first main findings are that price discovery has been significantly improved after firms started disclosing their patent applications under AIPA. The improvement in share price discovery is stronger when patent disclosures reveal successful, new, or important inventions. We further demonstrate that our results cannot be explained by concurrent macroeconomic changes, pre-determined trends, or firms' innovativeness. We also find that the AIPA effect is mainly driven by firms with little R&D-related disclosures in 10-Ks, in fast-moving industries, followed by more analysts, or endowed with a larger dedicated institutional ownership. Our second finding relates to investors' R&D uncertainty. Proxying for this uncertainty by the bid-ask spread and by the stock return volatility (realized and implied), we find that 18-month patent disclosures are associated with a significant reduction in R&D uncertainty. AIPA also reduces the mispricing of stocks, in particular by helping recover underpriced stocks.

The relevance of our findings is in their implications for voluntary managerial disclosures concerning firms' innovative activities. Namely, details of the technological attributes will alleviate investors' information uncertainty surrounding R&D activities. For managers who are interested in reducing investors' R&D uncertainty and enhancing share price discovery, the information disclosed by the 18-month patent publications is the type of information capable of achieving these two goals.

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Figure 1. R&D-related Words in 10-K filings

The left figure plots the average R&D-related words (*R&D-Words*) in 10-K filings by year. The right figure plots the annual average percentage R&D-related words (*R&D-Words%*). R&D-related words are identified based on the keyword list developed by Merkley (2013). We exclude tables, exhibits, titles, and subtitles from the word count.

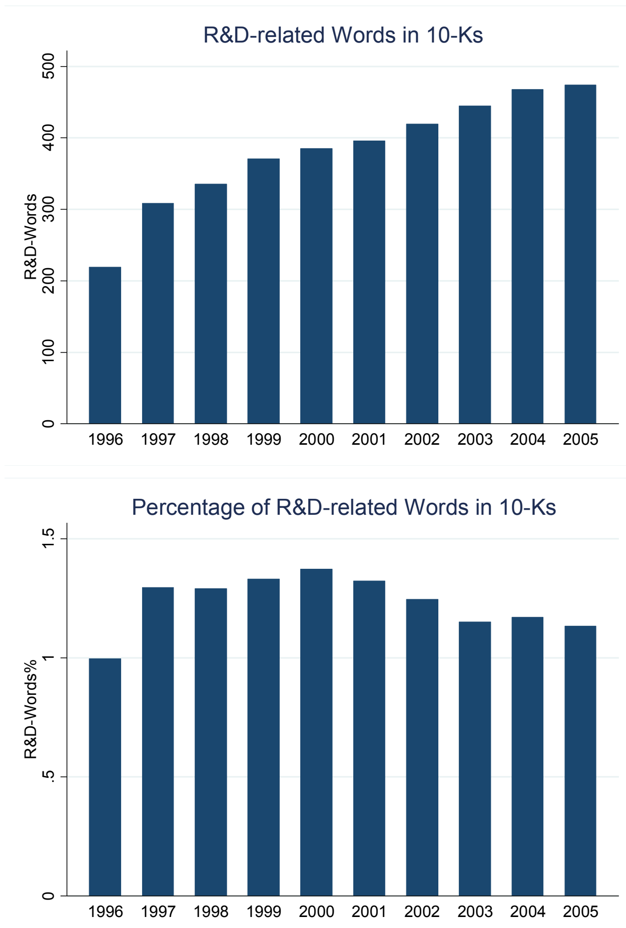

Figure 2. Patent Grants and 18-Month Disclosures

This figure plots the annual count of the universe of U.S. patent grants and 18-month disclosures. The red bar represents 18-month disclosures of all patent applications (abandoned, pending, or granted), while the green bar represents 18-month disclosures of those that are eventually granted by the end of 2014.

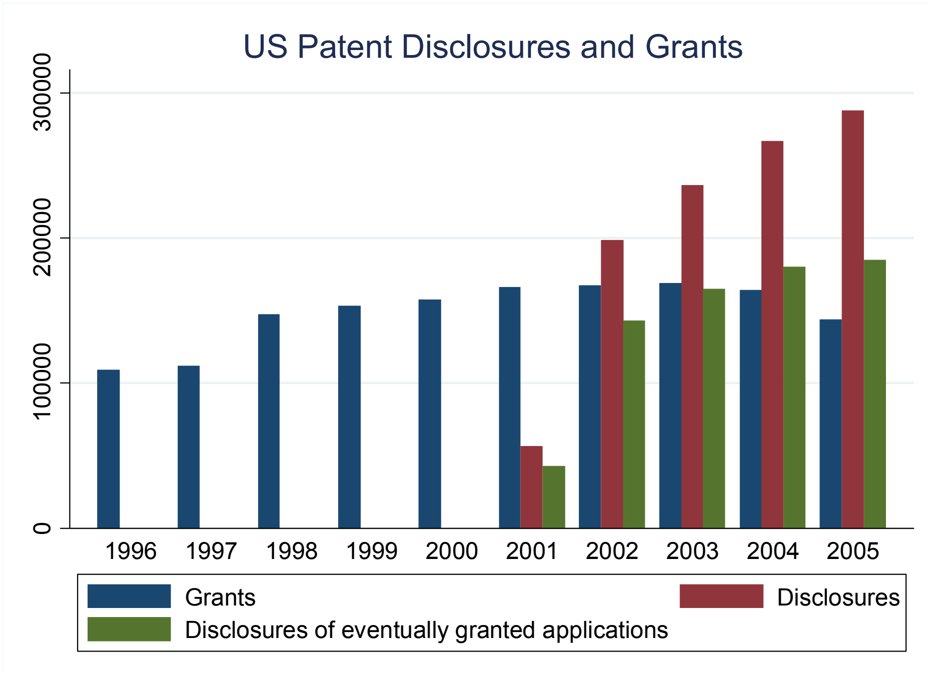

Figure 3. Sample firm composition

The left figure plots the percentage of treated and untreated firm-years, respectively. The right figure plots the average number of patent grants (blue bar) and 18-month disclosures of eventually granted applications (red bar) per firm during each year of the sample period.

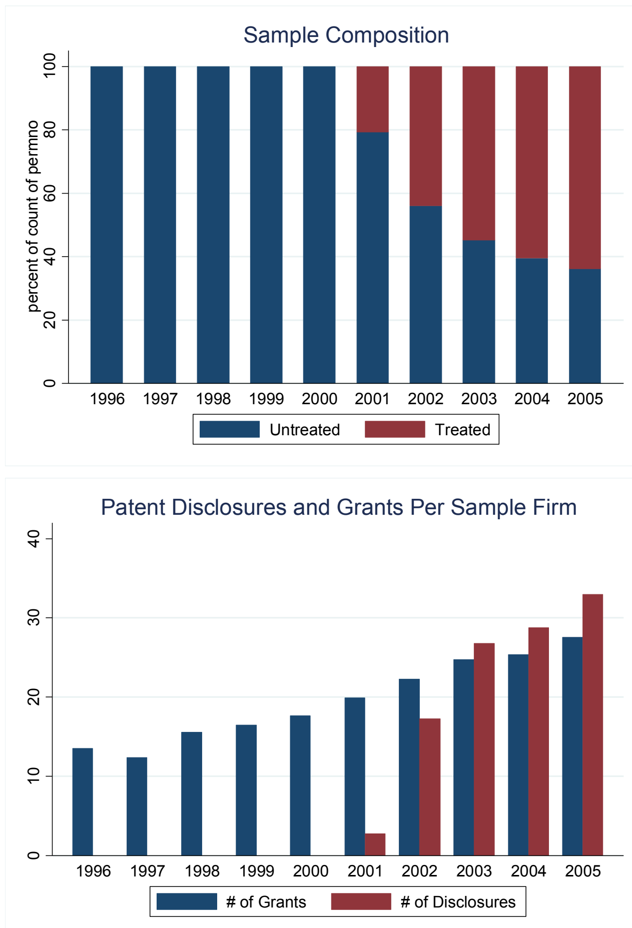

Figure 4. Intra-period timeliness

This figure plots the average fraction of annual abnormal return as of the end of each month during the fiscal year for firms treated and untreated by AIPA, respectively. Treated firm-years include firms in the year they had the first 18-month disclosure and the subsequent years. All other firm-years are considered untreated. Monthly abnormal return for each individual stock is computed as its raw monthly return minus the value-weighted return for a portfolio of firms matched on 5 × 5 sorts of size and market-to-book. Data on individual stocks' monthly returns are obtained from CRSP (msf) and monthly portfolio returns are download from Kenneth French's website.

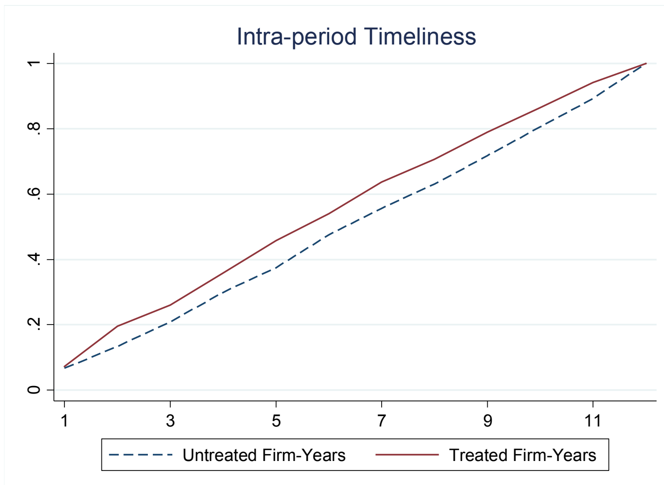

Figure 5. Dynamic effects of AIPA on IPT

This figure shows the dynamic impact of AIPA on IPT along event years based on estimates reported in Column 1 of Table 4. Both the point estimate and its 95% confidence intervals are plotted. Event year 0 is the fiscal year in which firms have the first 18-month disclosure. Event year 3+ includes the third year after the year with the first 18-month disclosure as well as all other years after if available.

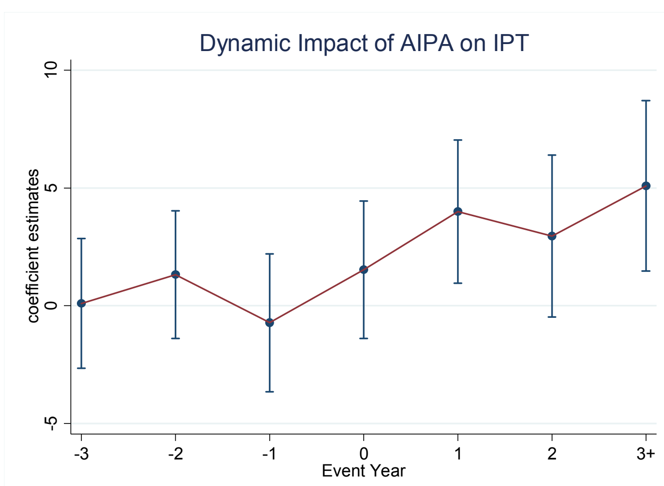

Figure 6. Mispricing score distribution

This figure plots the distribution of mispricing score for firm-months in the pre-AIPA (red bars) and post-AIPA period (green bars), respectively. The brown area indicates the overlapped distribution. Mispricing score is a monthly rank based on 11 anomalies constructed by Stambaugh, Yu, and Yuan (2015). The score ranges from 1 to 100 with the higher value indicating the greater degree of overpricing relative to other public companies.

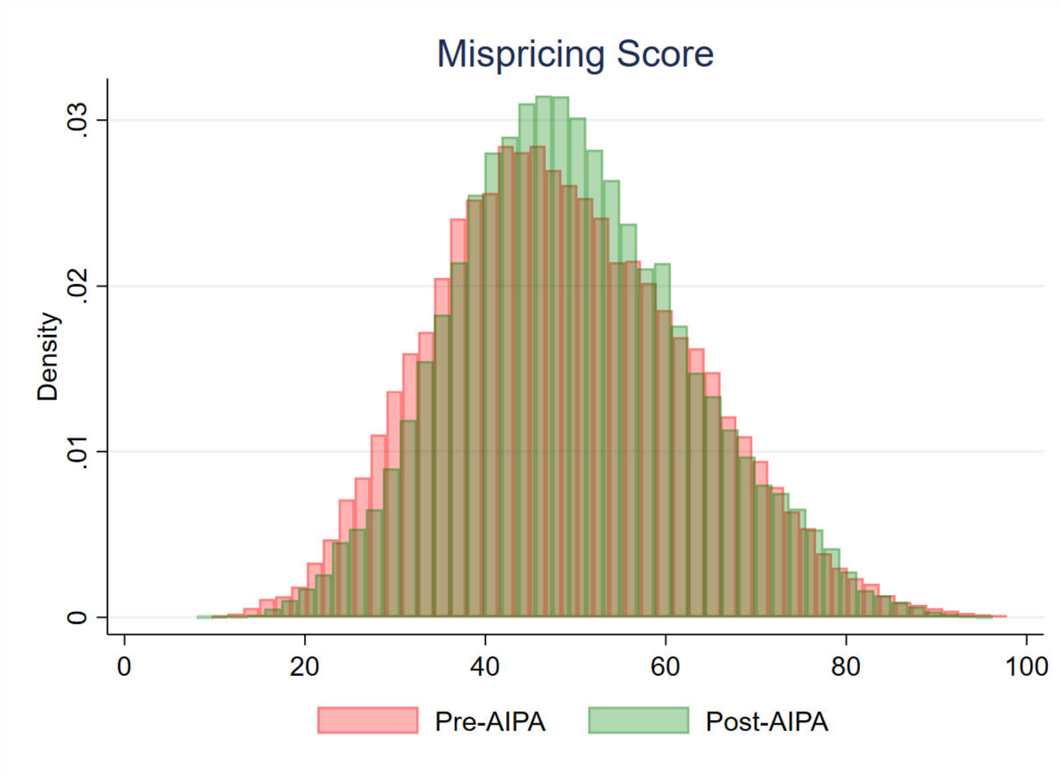

Table 1. Summary statistics

This table reports the summary statistics for firm-year observations in our sample. Intra-period timeliness (*IPT*) measures the efficiency of the price discovery process. To reduce noises in this measure, *IPT2* modifies *IPT* by setting the value of *IPT* to be missing for firm-years with the absolute value of annual abnormal returns smaller than 2%. Volatility (*Real_Vol* for idiosyncratic realized volatility and *Imp_Vol* for average idiosyncratic implied volatility) and effective spread (*Spread$* for effective spread in dollars and *Spread% fo*r relative effective spread in percentages) are measured one fiscal year ahead (year t+1) and all other variables are measured in year t. Please refer to Appendix A for detailed variable definitions.

Variable	N	mean	sd	p25	p50	p75
IPT	22831	-4.145	33.352	-0.038	4.411	6.623
IPT2	22025	0.656	15.005	0.777	4.586	6.696
Real_Vol	21962	0.549	0.317	0.313	0.473	0.706
Imp_Vol	11217	0.484	0.252	0.294	0.432	0.625
Spread$	21997	0.158	0.113	0.084	0.131	0.198
Spread%	21997	2.188	3.046	0.399	0.998	2.616
PostAIPA	22831	0.235	0.424	0.000	0.000	0.000
Disclosure	22831	9.892	106.410	0.000	0.000	0.000
Patent-Grant	22831	18.902	123.566	0.000	0.000	3.000
Patent-Stock	22831	50.650	331.700	0.000	1.000	8.200
RD	22831	0.076	0.121	0.000	0.027	0.104
CAPX	22831	0.051	0.048	0.020	0.037	0.066
Size	22831	5.703	2.112	4.088	5.502	7.124
Age	22831	17.953	16.192	6.845	12.173	25.085
Leverage	22831	0.177	0.172	0.009	0.143	0.294
ROA	22831	0.039	0.182	0.006	0.062	0.124
Loss	22831	0.232	0.422	0.000	0.000	0.000
EBIT	22824	0.007	0.224	-0.021	0.066	0.123
TobinQ	22831	2.037	2.082	0.873	1.340	2.315
AF	22831	3.042	4.357	0.000	1.250	4.000
IO	22831	0.416	0.279	0.160	0.405	0.656
MF	22831	0.409	0.492	0.000	0.000	1.000

Table 2. Sample breakdown

This table breaks down the sample by the Fama-French 12 Industry (Panel A) and by year (Panel B). The liquidity measures (*Spread%*) is measured one year ahead (year t+1) and all other variables are measured in year t. Firms become *"Treated"* when firms they have the first 18-month disclosure and remain so afterward. *UnTreated* firm-years are those that have not had 18-month disclosures yet or never have any patent disclosure throughout the sample period.

Panel A: By Industry

Industry (FF12)	# Obs	% Obs	# Firm	IPT	IPT2	Spread%	RD	Patent-Stock
Consumer Non-Durables	1,528	6.6%	201.00	-4.09	1.00	1.98	0.01	7.39
Consumer Durables	1,036	4.5%	139.00	-5.44	1.29	1.71	0.04	242.63
Manufacturing	4,023	17.4%	500.00	-4.09	1.40	1.92	0.03	65.24
Oil, Gas, Coal Extraction and Products	837	3.6%	107.00	-3.91	1.62	1.30	0.01	35.54
Chemicals and Allied Products	771	3.3%	97.00	-4.11	1.22	1.46	0.04	87.56
Business Equipment	7,234	31.3%	998.00	-3.95	0.01	2.52	0.12	57.13
Telephone and Television Transmission	464	2.0%	77.00	-0.88	1.52	1.84	0.03	60.16
Wholesale, Retail, and Some Services	1,692	7.3%	223.00	-3.35	1.09	2.29	0.02	6.71
Healthcare, Medical Equipment, and Drugs	3,158	13.7%	422.00	-5.82	-0.21	2.55	0.16	23.19
Other	2,390	10.3%	342.00	-3.37	1.07	2.05	0.05	7.12

Panel B: By Year

Year	#UnTreated	#Treated	Disclosure	Disclosure-New	Disclosure-Stale	Dis-Abn	Patent-Grant	Patent-Stock
1996	1,853	0.00					13.10	35.64
1997	2,149	0.00					12.58	34.87
1998	2,369	0.00					15.73	36.34
1999	2,585	0.00					15.81	38.78
2000	2,745	0.00					16.74	43.86
2001	2,091	525.00	2.63	1.60	1.04	0.35	19.16	51.00
2002	1,367	1036.00	16.31	12.65	3.68	2.95	21.09	56.55
2003	1,031	1218.00	25.66	21.08	4.65	5.55	23.74	64.99
2004	865	1293.00	26.87	21.70	5.23	5.86	24.09	69.43
2005	713	1293.00	31.95	25.28	6.75	7.59	26.63	75.86

Table 3. Baseline results of the AIPA effect on IPT

This table reports the DID estimates of the impact of AIPA on IPT. IPT is the adjusted intra-period timeliness, which measures the speed of price discovery during the fiscal year. The key variables of interest are two treatment variables: (1) a dummy treatment indicator *PostAIPA* which equals one when the firm has its first 18-month disclosure and remains so in subsequent years; (2) a continuous treatment measure *Ln(Disclosure)* which is the natural logarithm of one plus the number of 18-month disclosures. Panel A reports the baseline regressions and Panel B reports the robustness checks. In Columns 1-4 of Panel B, we examine the impact of 18-month disclosures of abandoned applications versus granted applications, stale versus new inventions, technologically valuable versus less valuable inventions. In Columns 5-6, we control for Fama-French 48 industry-year fixed effects to control for time-variant industry shocks. In Columns 7-8, we require the absolute value of annual abnormal return to be above 2% to avoid noises due to a small denominator in the computation of IPT. We include the same set of control variables in Panel B as in Panel A but do not report the coefficients for simplicity. See Appendix A for detailed variable definitions. Standard errors are clustered by firm and *** indicates significance at 1%, ** at 5%, and * at 10%.

Panel A: Baseline results

VARIABLES	(1) Coeff.	(2) S.E.	(3) Coeff.	(4) S.E.
PostAIPA	2.651***	0.999		
Ln(Disclosure)			1.110***	0.367
Ln(Patstock)	0.356	0.532	0.228	0.548
RD	-1.795	5.242	-1.913	5.242
CAPX	8.187	7.747	8.504	7.749
Size	-0.688	0.675	-0.725	0.676
Ln(Age)	-1.268	1.773	-0.547	1.790
Leverage	-0.946	2.801	-0.880	2.803
ROA	-8.303***	2.043	-8.336***	2.044
Loss	0.472	0.894	0.461	0.893
TobinQ	0.373**	0.151	0.383**	0.152
LnAF	1.278*	0.712	1.260*	0.712
IO	0.391	2.533	0.702	2.525
MF	1.126	0.690	1.108	0.690
Year FE	Yes		Yes	
Firm FE	Yes		Yes	
Observations	22,831		22,831	
R-squared	0.133		0.133	

Panel B: Robustness checks

VARIABLES	(1) IPT	(2) IPT	(3) IPT	(4) IPT	(5) IPT	(6) IPT	(7) IPT2	(8) IPT2
PostAIPA					2.787***		1.261***	
					(0.983)		(0.401)	
Ln(Disclosure)		0.937**				1.357***		0.443***
		(0.418)				(0.372)		(0.145)
Ln(Dis-Abn)	1.186***	0.264						
	(0.451)	(0.595)						
Ln(Disclosure-New)			0.907*					
			(0.546)					
Ln(Disclosure-Stale)			0.250					
			(0.760)					
Ln(Disclosure-Imp)				1.447**				
				(0.667)				
Ln(Disclosure-Unimp)				-0.346				
				(0.713)				
Excluded obs.	None	None	None	None	None	None	<+/-2%	<+/-2%
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
FF48-Year FE	No	No	No	No	Yes	Yes	No	No
Observations	22,809	22,809	22,809	22,809	22,809	22,809	21,999	21,999
R-squared	0.131	0.131	0.131	0.131	0.152	0.152	0.151	0.151

Table 4. Dynamic effects of AIPA on IPT

This table reports the dynamic impact of AIPA on contemporaneous IPT. IPT is the adjusted intra-period timeliness, which measures the speed of price discovery during the fiscal year. The year with the first 18-month disclosure is indicated by *Post[0]* and other years relative to that year are indicated by *Before[x]* and *Post[x]*, respectively. *Post[3+]* indicates the third year after the first 18-month disclosure and all subsequent years if available. *Ln(Disclosure[x])* is the natural logarithm of one plus the number of patent disclosures in event year x and it is set to be 0 in all other years. For years before AIPA, we construct placebo 18-month disclosures by applying the 18-month disclosure rule to patents filed before (*Ln(PlaceboDis[x])*). We include the same set of control variables used in Panel A of Table 3 but do not report the coefficients for simplicity. See Appendix A for the variable definitions. Standard errors are clustered by firm and *** indicates significance at 1%, ** at 5%, and * at 10%.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Before[-3]	0.099	1.409				
Before[-2]	1.319	1.380				
Before[-1]	-0.726	1.495				
Post[0]	1.530	1.487				
Post[1]	3.990**	1.550				
Post[2]	2.956*	1.749				
Post[3+]	5.085***	1.847				
Ln(PlaceboDis[-3])					0.637	0.582
Ln(PlaceboDis [-2])					0.876	0.553
Ln(PlaceboDis [-1])					-0.854	0.687
Ln(Disclosure[0])			0.783	0.655	0.793	0.781
Ln(Disclosure[1])			1.877***	0.462	1.917***	0.561
Ln(Disclosure[2])			0.565	0.584	0.609	0.651
Ln(Disclosure[3+])			1.082**	0.435	1.127**	0.517
Controls	Yes		Yes		Yes	
Year FE	Yes		Yes		Yes	
Firm FE	Yes		Yes		Yes	
Observations	22,831		22,831		22,831	
R-squared	0.133		0.133		0.133	

Table 5. Cross-sectional analyses

This table reports the cross-sectional analyses of the impact of AIPA on contemporaneous IPT. The key variable of interest is a dummy treatment indicator *PostAIPA* in Panel A and a continuous treatment measure *Ln(Disclosure)* in Panel B. We first split the sample based on the FF48-industry-year median percentage of R&D-related words in 10-Ks and repeat the baseline regressions in the two subsamples of in Columns 1-2. In Columns 3-4, we repeat the analyses for fast-moving industries as defined in Gu and Wang (2005) and other industries. In Columns 5-6 (7-8), we split the sample based on FF48-industry-year median analyst following (institutional ownership). We include the same set of control variables used in Panel A of Table 3 but do not report the coefficients for simplicity. See Appendix A for detailed variable definitions. Standard errors are clustered by firm and *** indicates significance at 1%, ** at 5%, and * at 10%.

Panel A: Cross-sectional analysis I

VARIABLES	(1) Below-median R&D-Words%	(2) Above-median R&D-Words%	(3) Fast-moving	(4) Slow-moving	(5) Above-median AF	(6) Below-median AF	(7) Above-median IO	(8) Below-median IO
PostAIPA	3.629**	0.730	2.748**	1.240	2.727*	2.166	4.084**	2.314
	(1.445)	(1.782)	(1.219)	(2.047)	(1.655)	(1.518)	(1.612)	(1.556)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13,132	9,699	15,603	7,206	10,897	11,934	11,303	11,528
R-squared	0.204	0.209	0.174	0.207	0.167	0.191	0.216	0.240

Panel B: Cross-sectional analysis II

VARIABLES	(1) Below-median R&D-Words%	(2) Above-median R&D-Words%	(3) Fast-moving	(4) Slow-moving	(5) Above-median AF	(6) Below-median AF	(7) Above-median IO	(8) Below-median IO
Ln(Disclosure)	1.953***	-0.047	1.143***	0.020	1.247**	0.677	1.218**	0.952
	(0.565)	(0.607)	(0.421)	(0.834)	(0.518)	(0.666)	(0.565)	(0.630)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13,132	9,699	15,603	7,206	10,897	11,934	11,303	11,528
R-squared	0.204	0.209	0.174	0.207	0.167	0.191	0.216	0.240

Table 6. Price informativeness

This table reports the changes in stock price informativeness around AIPA. We measure price informativeness as the predictive power of stock price (*Ln(MV6/TA)*) for earnings before interest and tax scaled by total assets (EBIT) following Bai et al. (2016). As a robustness check, we also report the results with income before extraordinary items scaled by total assets (IB). Panel A reports the baseline results and Panel B and C report the cross-sectional analyses. We include the same set of control variables used in Table 3 except *ROA* and *TobinQ* as they are similar concepts of the key variables *EBIT, IB* and *Ln(MV6/TA)* and that *Loss* corresponds to the negative value of *EBIT* or *IB*, respectively. See Appendix A for the variable definitions. Standard errors are clustered by firm and *** indicates significance at 1%, ** at 5%, and * at 10%.

Panel A: Main results

Dep VAR:	$EBIT_{t+1}$				IB_{t+1}			
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
EBIT	0.392***	0.024	0.392***	0.024				
IB					0.154***	0.020	0.154***	0.020
Ln(MV6/TA)	0.020***	0.003	0.021***	0.003	0.031***	0.004	0.032***	0.004
PostAIPA	0.004	0.004			0.002	0.004		
Ln(MV6/TA)#PostAIPA	0.012***	0.004			0.014***	0.005		
Ln(Disclosure)			0.000	0.001			0.002	0.001
Ln(MV6/TA)#Ln(Disclosure)			0.003***	0.001			0.005***	0.002
Controls*	Yes		Yes		Yes		Yes	
Year FE	Yes		Yes		Yes		Yes	
Firm FE	Yes		Yes		Yes		Yes	
Observations	22,826		22,826		22,834		22,834	
R-squared	0.761		0.761		0.663		0.663	

Panel B: Cross-sectional analysis I

VARIABLES	(1) Below-median R&D Words	(2) Above-median R&D Words	(3) Fast-moving	(4) Slow-moving	(5) Above- median AF	(6) Below- median AF	(7) Above- median IO	(8) Below- median IO
EBIT	0.357***	0.396***	0.340***	0.454***	0.367***	0.337***	0.383***	0.389***
	(0.039)	(0.036)	(0.029)	(0.048)	(0.040)	(0.034)	(0.038)	(0.036)
Ln(MV6/TA)	0.024***	0.018***	0.019***	0.030***	0.031***	0.014***	0.023***	0.020***
	(0.005)	(0.005)	(0.004)	(0.006)	(0.004)	(0.005)	(0.005)	(0.005)
PostAIPA	0.005	0.001	0.002	0.007	0.005	0.003	0.007	0.001
	(0.005)	(0.006)	(0.005)	(0.005)	(0.004)	(0.006)	(0.005)	(0.006)
Ln(MV6/TA)#PostAIPA	0.016***	0.005	0.018***	-0.004	0.011**	0.005	0.011*	0.011
	(0.005)	(0.006)	(0.005)	(0.006)	(0.004)	(0.007)	(0.006)	(0.007)
Controls*	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13,138	9,688	15,616	7,188	10,943	11,883	11,350	11,476
R-squared	0.776	0.799	0.755	0.858	0.766	0.790	0.809	0.788

Panel C: Cross-sectional analysis II

VARIABLES	(1) Below-median R&D Words	(2) Above-median R&D Words	(3) Fast-moving	(4) Slow-moving	(5) Above- median AF	(6) Below- median AF	(7) Above- median IO	(8) Below- median IO
EBIT	0.358***	0.396***	0.340***	0.454***	0.368***	0.337***	0.384***	0.389***
	(0.039)	(0.036)	(0.029)	(0.048)	(0.040)	(0.034)	(0.038)	(0.036)
Ln(MV6/TA)	0.025***	0.018***	0.021***	0.029***	0.032***	0.014***	0.024***	0.021***
	(0.005)	(0.005)	(0.004)	(0.006)	(0.004)	(0.005)	(0.005)	(0.005)
Ln(Disclosure)	0.003*	-0.002	-0.000	0.003**	-0.000	0.002	0.000	0.001
	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)	(0.003)	(0.001)	(0.002)
Ln(MV6/TA)# Ln(Disclosure)	0.004***	0.002	0.003**	0.002	0.003**	0.002	0.003**	0.004
	(0.001)	(0.002)	(0.001)	(0.003)	(0.001)	(0.003)	(0.001)	(0.002)
Controls*	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13,138	9,688	15,616	7,188	10,943	11,883	11,350	11,476
R-squared	0.776	0.799	0.755	0.858	0.765	0.790	0.809	0.788

Table 7. Uncertainty (bid-ask spread)

This table reports the impact of AIPA on uncertainty. We measure uncertainty using the annual average trading volume weighted dollar effective spread (*Spread$*) or relative effective spread (*Spread%*) in year t+1. The key variables of interest are two treatment variables: (1) a dummy treatment indicator *PostAIPA* which equals one when the firm has its first 18-month disclosure and remains so in subsequent years; (2) a continuous treatment measure *Ln(Disclosure)* which is the natural logarithm of one plus the number of 18-month disclosures. See Appendix A for detailed variable definitions. Standard errors are clustered by firm and *** indicates significance at 1%, ** at 5%, and * at 10%.

VARIABLES	(1) Spread$	(2) Spread$	(3) Spread%	(4) Spread%
PostAIPA	-0.018***		-0.388***	
	(0.003)		(0.071)	
Ln(Disclosure)		-0.011***		-0.135***
		(0.001)		(0.019)
Ln(Patstock)	-0.006***	-0.003	-0.037	-0.032
	(0.002)	(0.002)	(0.032)	(0.033)
RD	-0.020	-0.019	-1.201***	-1.188***
	(0.014)	(0.014)	(0.449)	(0.449)
CAPX	-0.000	-0.004	-0.701	-0.730
	(0.020)	(0.020)	(0.501)	(0.501)
Size	-0.023***	-0.023***	-0.956***	-0.952***
	(0.002)	(0.002)	(0.054)	(0.054)
Ln(Age)	-0.042***	-0.051***	0.358***	0.284**
	(0.006)	(0.006)	(0.131)	(0.136)
Leverage	-0.003	-0.003	1.301***	1.285***
	(0.008)	(0.008)	(0.204)	(0.204)
ROA	0.037***	0.037***	-0.987***	-0.983***
	(0.005)	(0.005)	(0.148)	(0.149)
Loss	0.000	0.000	0.592***	0.592***
	(0.002)	(0.002)	(0.058)	(0.058)
TobinQ	0.007***	0.007***	-0.226***	-0.226***
	(0.000)	(0.000)	(0.012)	(0.012)
LnAF	-0.044***	-0.046***	-0.871***	-0.918***
	(0.008)	(0.008)	(0.151)	(0.152)
IO	-0.013***	-0.013***	-0.092**	-0.089**
	(0.002)	(0.002)	(0.038)	(0.038)
MF	-0.007***	-0.007***	-0.207***	-0.205***
	(0.002)	(0.002)	(0.035)	(0.035)
Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Observations	22,318	22,318	22,318	22,318
R-squared	0.663	0.666	0.717	0.716

Table 8. Uncertainty (volatility-R&D sensitivity)

This table reports the impact of AIPA on investors uncertainty of R&D. The dependent variable is realized idiosyncratic volatility (*Real_Vol*) in year t+1 in the left four columns and implied idiosyncratic volatility (*Imp_Vol*) in year t+1 in the right four columns. *RD* is R&D intensity, measured by R&D expense scaled by total assets. *PostAIPA* (a dummy variable equal one when the firm has its first 18-month disclosure and remains so in subsequent years) and *Ln(Disclosure*) (the natural logarithm of one plus the number of 18-month disclosures) are two variables indicating the treatment of AIPA. We include the same set of control variables as in Table 3 but do not report their coefficients for brevity. See Appendix A for the variable definitions. Standard errors are clustered by firm and *** indicates significance at 1%, ** at 5%, and * at 10%.

VARIABLES	(1) Real_Vol	(2) Real_Vol	(3) Real_Vol	(4) Real_Vol	(5) Imp_Vol	(6) Imp_Vol	(7) Imp_Vol	(8) Imp_Vol
PostAIPA	-0.008		0.009		-0.002		0.004	
	(0.005)		(0.006)		(0.006)		(0.006)	
PostAIPA#RD			-0.187***				-0.081*	
			(0.038)				(0.046)	
Ln(Disclosure)		-0.001		0.008***		0.005***		0.007***
		(0.002)		(0.002)		(0.002)		(0.002)
Ln(Disclosure)#RD				-0.117***				-0.040**
				(0.020)				(0.020)
RD	0.176***	0.176***	0.215***	0.206***	0.138***	0.140***	0.154***	0.152***
	(0.035)	(0.035)	(0.036)	(0.036)	(0.034)	(0.034)	(0.035)	(0.035)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	22,264	22,264	22,264	22,264	11,354	11,354	11,354	11,354
R-squared	0.799	0.799	0.800	0.800	0.856	0.856	0.856	0.856

Table 9. AIPA's impact on mispricing

This table reports the DID estimates of the impact of AIPA on mispricing. The dependent variable (*Misp_Score*) is an annual average mispricing score which quantifies the relative mispricing of 11 anomalies. The key variables of interest are two treatment variables: (1) a dummy treatment indicator *PostAIPA* which equals one when the firm has its first 18-month disclosure and remains so in subsequent years; (2) a continuous treatment measure *Ln(Disclosure)* which is the natural logarithm of one plus the number of 18-month disclosures. In Columns 3 (4), we interact *PostAIPA* (*Ln(Disclosure)*) with the *UnderPriced* dummy which indicates whether the firm is relatively underpriced in the previous year. We include the same set of control variables as Table 3 but do not report the coefficients for simplicity. See Appendix A for detailed variable definitions. Standard errors are clustered by firm and *** indicates significance at 1%, ** at 5%, and * at 10%.

VARIABLES	(1) Misp_Score	(2) Misp_Score	(3) Misp_Score	(4) Misp_Score
PostAIPA	1.040***		0.079	
	(0.301)		(0.348)	
Ln(Disclosure)		0.301***		-0.038
		(0.115)		(0.130)
PostAIPA#UnderPriced_$_{t-1}$			1.406***	
			(0.325)	
Ln(Disclosure)#UnderPriced_$_{t-1}$				0.369***
				(0.119)
UnderPricing_$_{t-1}$			-4.293***	-4.101***
			(0.192)	(0.181)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Observations	17,346	17,346	15,622	15,622
R-squared	0.646	0.646	0.671	0.670

Appendix A. Variable Definitions

Variable	Definition
IPT	Intra-period timeliness is the area under the price discovery curve which is a plot of the fraction of annual cumulative abnormal returns that have been reflected in stock prices as of the end of each month. We compute monthly abnormal return as the raw return minus the value-weighted return for a portfolio of firms matched on 5 × 5 sorts of size and market-to-book. We adjust stock return over-reaction following Blankespoor et al. (2017) using the following equation where CAR represents cumulative abnormal return. $$IPT = \sum_{t=1}^{12} 1 - \left(\frac{\lvert CAR_{12} - CAR_t \rvert}{\lvert CAR_{12} \rvert}\right)$$
Spread$	The annual average daily trading volume weighted effective spread in dollars where the effective spread is the absolute difference between the price and midpoints of the national best bids and offers. The data are obtained from the TAQ dataset.
Spread%	The annual average daily trading volume weighted relative effective spread where the relative effective spread is the absolute difference between the log price and the log midpoints of the national best bids and offers, multiplied by 100. The data are obtained from the TAQ dataset.
Real_Vol	The standard deviation of idiosyncratic realized returns (the residuals from the firm-specific annual regression of daily individual stock returns on value-weighted market index returns), multiplied by the square root of 252. A minimum of 200 return observations per year is required to calculate the annualized standard deviation.
Imp_Vol	Average idiosyncratic implied volatility which is calculated as follows (Dennis, Mayhew, and Stivers, 2006) $$Imp\_Vol_{it} = \sqrt{Raw\_Imp\_Vol_{it}^{\ 2} - \beta_i^{\ 2} * VIX_t^2}$$ where *i* indexes for firm and *t* for day. Raw_Imp_Vol is the daily average implied volatility of 30-day standardized call and put options , β is the coefficient on the market return in the market model for each individual stock, and VIX is implied volatility of S&P 500 stock index option. Individual implied volatility is obtained from OptionMetrics, β is estimated using the CRSP dsf dataset, and VIX is obtained from the CBOE website.
PostAIPA	A dummy indicator of the treatment of AIPA. It is equal one when the firm has its first 18-month patent disclosure and remains one till the end of the sample period.
Disclosure	Number of 18-month disclosures during the year. We only count patents that are eventually granted by 2010 (i.e., ignore the disclosures of abandoned patent applications or applications granted after 2010). The variable is set to be zero for all firms before the enactment of AIPA. If the variable name is prefixed with "*Ln*", it means we take the natural logarithm of one plus the number disclosures, henceforth.
Dis-Abn	Number of 18-month disclosures of abandoned patent applications during the year.
Disclosure-New	Number of 18-month disclosures of eventually granted applications whose inventions are never disclosed to the public before.
Disclosure-Stale	Number of 18-month disclosures of eventually granted applications whose underlying inventions have been disclosed in the 18-month disclosure or grant document of their parent patent applications.
Disclosure-Imp	Number of 18-month disclosures of important applications whose forward citations are above the median of the patents with the same technology class and grant year.
Disclosure-Unimp	Number of 18-month disclosures of important applications whose forward citations are below the median of the patents with the same technology class and grant year.

PlaceboDis	Number of placebo 18-month disclosures which are constructed by applying the 18-month disclosure rule to patent applications filed before the enactment of AIPA.
Patent-Grant	The number of patents granted in each year. If the variable name is prefixed with "*Ln*", it means we take the natural logarithm of one plus the variable value.
Patent-Stock	The cumulative number of granted patents, assuming a 20% depreciation rate following Lev, Sarath, and Sougiannis (2005). If the variable name is prefixed with "*Ln*", it means we take the natural logarithm of one plus the variable value.
RD	R&D expenditures (xrd) scaled by total assets (at), replaced as 0 if R&D expenditures are missing.
CAPX	Capital expenditures (capx) scaled by total assets (at).
Size	Natural logarithm of total assets (at).
Age	Number of years that a firm has been on the CRSP database.
Leverage	Summation of short-term and long-term debt (dltt, dlc), scaled by the lagged book value of equity.
ROA	Income before extraordinary items (ib) and before R&D expenditures (xrd), scaled by total assets (at).
Loss	Dummy variable, one if ROA is negative.
EBIT	Earnings before interest and taxes (ebit) scaled by total assets (at).
IB	Income before extraordinary items (ib) scaled by total assets (at).
TobinQ	Summation of market value of equity (prcc_f*csho) and book value of debt (dltt, dlc), scaled by total assets (at).
Ln(MV6/TA)	Market value of equity at the end of 6 months after the fiscal year end, scaled by total assets (at).
AF	Number of analyst following. If the variable name is prefixed with "*Ln*", it means we take the natural logarithm of one plus the number disclosures.
IO	Ownership by institutional investors, obtained from Thomson Reuters database
IS	Innovation speed, minus one times the average time gap between the application dates of the citing patent and its backward patent citations. We then take the annual average of the time gap of all patents assigned to public firms in the same FF 48 industry.
MF	Dummy variable, one if the firm provides management earnings guidance of any horizon during the year.
R&D-Words	Number of R&D-related words in 10-K filings. R&D-related words are identified based on the keyword list developed by Merkley (2013). We exclude tables, exhibits, titles, and subtitles from the word count.
R&D-Words%	Percentage of R&D-related words in 10-K filings. We divide *R&D-Words* by total word and multiply it by 100.

Appendix B. The Amazon Case

Amazon is notoriously tight-lipped about its R&D efforts and strategic plans. The New York Times observed, "*Amazon is the most obscure large company in the tech industry. It isn't just secretive, the way Apple is, but in a deep sense, Jeff Bezos' e-commerce and cloud-storage giant is opaque. Amazon rarely explains either its near-term tactical aims or its long-term strategic vision*."[24] Amazon, however, is an aggressive patent applicant, having filed more than a thousand patent applications since it was founded in 1994. Early disclosure of these patents provide astute investors with a trove of information about expected strategic moves, as noted by *Forbes*: "*Retailing powerhouse Amazon.com seldom pulls back the curtain on its high-tech operating secrets…But there's one place where the online retailer is garrulous as can be: its filings with the U.S. Patent Office*."[25]

Consider, for example, Amazon's far-reaching strategic shift to open its e-commerce platform to third parties. This unannounced strategic move became clear with the 18-month patent disclosure titled "*Providing a marketplace for web services*." The patent application was filed on January 27, 2004, and disclosed 18 months later on July 28, 2005, more than three years before its grant on October 7, 2008. On the day of this18-month disclosure, CNet website covered it,[26] discussing the increased potential of Amazon as a marketplace for third-party web service providers. On October 26, 2005, Bear Stearns explicitly mentioned this 18-month disclosure in their report titled "*Investing for the Future*."

A more recent example is Amazon's move to drone delivery. When the idea was first introduced by Jeff Bezos in a "60 Minutes" interview in December 2013, it met with widespread skepticism. People claimed it is "crazy," a "pipe dream," and a "publicity stunt" to promote Amazon's online sales before Black Friday. However, when the 18-month patent disclosure titled "unmanned aerial vehicle delivery

[24] https://www.nytimes.com/2016/08/11/technology/think-amazons-drone-delivery-idea-is-a-gimmick-think-again.html
[25] https://www.forbes.com/sites/georgeanders/2013/11/14/amazons-1263-patents-reveal-retailings-high-tech-future/#25f791e3cd0d
[26] https://www.cnet.com/news/amazon-files-for-web-services-patent-1/

system" (US20150120094A1) came to light, people began to take the idea seriously. The patent application was filed on October 26, 2013, first published on April 30, 2015, and recently granted on February 21, 2017. The 18-month disclosure was 37 pages long and, had 17 images to illustrate how Amazon plans to use drones to deliver goods to customers. The first page of this publication is presented in Appendix B.

Amazon's unmanned delivery patent disclosure and related ones clearly demonstrated the company's seriousness in moving to develop the futuristic delivery system. It was well received by the media: On May 12, 2015, for example, CNN discussed this patent disclosure in detail and observed that "*Delivering packages wherever you want it, through the air, via drone in just 30 minutes—that's Amazon's vision and the company just made another step forward*."[27] CNN, in fact, dug into the *patent* filing and mentioned some of the invention's operating details, such as the option of "bring it to me"—letting drones deliver the goods to customers based on their GPS data from mobile phones. It also laid out Amazon's idea to exchange data among drones to optimize their routes and monitor people and animals in the path, which could potentially solve the biggest problem in the commercialization of drones—the safety concern. Forbes pointed out that "*the company's continuous stream of innovations, such as ... the use of drones to supply products could significantly bolster growth over the next 3-5 years*."[28]

A search of analyst reports on Amazon with the keyword "drone" within one year after the 18-month disclosure reveals 27 reports, which generally expressed a positive view. For example, an analyst from CrsipIdea Research wrote on May 26, 2015, that "*Sooner or later, drones will be acting as a local delivery boy and will be delivering goods at customers' footsteps and giving online retailer ship just another level*." Not surprisingly, investors reacted to the 18-month patent disclosure favorably.

[27] http://www.cnn.com/2015/05/12/politics/amazon-patent-drone-delivery/index.html
[28] https://www.forbes.com/sites/greatspeculations/2015/09/23/heres-why-amazon-will-continue-to-gain-market-share-in-the-u-s/#5e10cdc54f26

Amazon's stock price appreciated by 3% within the 8-day window from the disclosure date to the publication of the CNN article, while the S&P 500 index only increased by 0.65% during that period. Notably, the average implied volatility of Amazon's options during the 8-day was 72% of the average implied volatility during 2015. Thus, investors' reaction was quick and decisive to Amazon's 18-month patent disclosure of the unmanned delivery patent application.

Figure B1. Amazon's 18-month patent disclosure of Unmanned Aerial Vehicle Delivery System

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(54) **UNMANNED AERIAL VEHICLE DELIVERY SYSTEM**

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(57) **ABSTRACT**

This disclosure describes an unmanned aerial vehicle ("UAV") configured to autonomously deliver items of inventory to various destinations. The UAV may receive inventory information and a destination location and autonomously retrieve the inventory from a location within a materials handling facility, compute a route from the materials handling facility to a destination and travel to the destination to deliver the inventory.