Technology Adoption and Career Concerns: Evidence from the adoption of digital technology in motion pictures

By

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This paper shows the impact of career concerns on technological change by studying the adoption of digital cameras in the US motion picture industry in the early 2000. This setting allows us to collect rich data on the adoption of this new technology at project level (i.e., movie) as well as on the career of the main decision maker (i.e., the director). We find that less experienced directors played a leading role in the adoption of digital cameras, and that this effect appears to be explained by career concerns, rather than alternative motives. To discuss the validity of our results outside the specific setting studied, we present a simple conceptual framework which highlights the key trade-offs faced by a decision maker. This discussion shows that our results can generalize to other contexts and industries.

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1 Introduction

The adoption of new technologies is often slow, even when these new technologies can bring important benefits to the adopter (Geroski, 2000). Several theories have been offered to explain this slow diffusion process. For instance, some papers show that the speed and depth of technology adoption depends on organizational and incentive constraints (Atkin et al, 2017). Other papers focus on learning and informational frictions (e.g. Munshi, 2004, Conley and Udry, 2010, Gupta et., 2019), coordination (Caoui, 2022, Crouzet et al., 2022, Feigenbaum and Gross, 2022); or the extent of financial development (e.g. Comin and Nanda, 2019; Bircan and De Haas, 2019).

This study examines a new potential mechanism which may explain adoption patterns of new technologies: manager career concerns. Since the adoption decision is made by individuals, their individual career incentives should matter for technology adoption in firms.[1] Research has shown that career concerns affect day to day decision making (e.g., Chevalier and Ellison, 1999; Hong, Kubik, and Solomon, 2000; Lamont, 2002, Li, Low and Makhija, 2011). However, little is known about how this mechanism affects technology adoption.

A major obstacle to studying this issue is the lack of project-level data that would allow the researcher to connect information about the agent who makes a decision (i.e., the manager) with actual adoption behavior. We also seldom know who makes specific adoption decisions. This paper overcomes these limitations by examining the adoption of digital film making in the motion picture industry in the US during the early 2000s. We observe the decision making at the film-director level. Thus, we know who is making the decision to adopt a new technology for a specific film as well as the entire trajectory of her career. This makes it possible to assess whether career considerations are important for this decision.

Within this setting, our paper makes two important contributions. First, empirically we show that inexperienced directors played a major role in the adoption of digital film making, and that this effect is likely related to specific career incentives faced by directors. More generally this may suggest that newcomers play a particularly important role in the adoption of new technologies in creative and other industries. Second, with the help of a simple model, we provide a conceptual framework to assess how this relationship may hold in contexts different than the one studied. This can help scholars interested in extending our analysis to other areas.

While the idea that career concerns may influence agents' behavior in the workplace is well-established, its effect on technology adoption has not been studied. In fact, technology adoption differs from traditional investment decisions or corporate actions in several ways. First, the adoption of a new technology naturally involves the abandonment of an older technology where experienced managers may have extensive knowledge. Second, a new technology is generally characterized by a higher-level of risk,[2] which can either come from the new nature of the technology or the uncertainty about its commercial applications. Third, a new technology is

[1] Some of the major papers in the career concerns literature include Holmstrom and Ricart i Costa, 1986; Gibbons and Murphy, 1992, Prendergast and Stole, 1996; and Holmstrom, 1999.

[2] While we would argue that this is a crucial feature of most new technologies, we will also show empirical evidence that is consistent with this hypothesis in the specific setting studied here.

generally not introduced at its full potential, which may imply that early adopters may benefit from joining at the early stages of development.

This paper focuses on the adoption of digital photography in the U.S. movie industry. While available, digital technology was very rarely used to produce movies in the late 1990s. There were two main constraints to the diffusion of digital film making. First, the quality of the early devices was still low relative to traditional cameras that were recording on film. Second, the economic benefits from switching to digital were limited. As long as movie theaters were equipped with traditional projection technologies, production companies could not realize any significant cost savings when filming a movie digitally because they were still required to print and distribute a movie on film. While the quality of digital cameras had been constantly improving over time, the second issue was not solved until after 2007, when movie theaters and production companies reached a financial agreement to allow the widespread installation of digital projection. Our core focus will be on the period before this shift, when the lack of a strong economic benefit in adoption digital implies that directors had very large autonomy to decide the technology employed for shooting.

This setting has two main advantages for us. First, directors' career is risky and starts at a late age, hence career concerns are of paramount importance (See John et al, 2017, Han and Ravid, 2021). Second, this setting allows us to collect data on both the adoption decision at movie level as well as the full career of directors.

We show that the experience of a director at the time of the movie is a strong predictor of her probability of using digital: more experienced directors – measured by the number of past movies – are less likely to use digital. A one standard-deviation increase in experience translates into a roughly 20% decline in the average probability of using digital during this period. Furthermore, we find that the largest drop in probability happens between directors that are first-timers relative to directors with some experience. These results are robust to a variety of different modeling choices and not driven by differences in genres or ratings as well as other confounding factors.

We then show that these effects are likely related to career concerns by directors. First, we show that this effect is mostly driven by the period between 2002 and 2006, which is exactly when the first wave of adoption happened. When the use of digital becomes more widespread and economic incentives in favor of this option became stronger, the gap in adoption between experienced and inexperienced directors disappears.

We also reject some of the leading alternative interpretations of this relationship. We show that this result does not reflect differences in technical expertise between experienced or inexperienced directors, as well as differences in movie budget or production company preferences. We also rule out that our results reflect a preference for "digital" content among inexperienced directors. Our data collection allows us to identify movies that were shot on film but were later transferred at least in part into digital during the post-production phase.[3] This set of movies was shot on film,

[3] This step could be taken to incorporate special effects or other changes that are easier to conduct in digital format. Notice that this "digital intermediate" technology was already used at the end of the 1990s and it did not present the same risks as shooting directly in digital, since the original material was always available in film.

but they could have had comparable "digital" content in post-production. We then replicate our findings when we use this sub-sample as control group.

This evidence suggests that inexperienced directors played a leading role in the introduction of new technologies in this setting. A natural question at this point is the extent to which this result can be generalized outside the context studied. To examine this issue, we develop a simple model and use it to highlight the fundamental trade-offs that may be relevant for a manager facing the decision to keep an old technology versus switching to a new one. The model does not aim to give a full characterization of the problem, but rather to provide a parsimonious framework to think about this issue. In the model, a manager's level of experience affects her decision problem in two ways. First, more experienced managers are relatively more productive when using the old technology. Second, the less experienced managers must prove themselves and can keep working in the future only if the next project is sufficiently successful. These features generate career concerns in our case.

Our paper contributes to several areas of economics and finance. Broadly, our paper provides a showcase for the importance of managerial incentives in understanding the patterns of technology adoption within an industry.

These contributions add to our understanding of frictions that prevent the adoption of valuable technologies (e.g., Atkin et al, 2017; Bircan and De Haas, 2019; Comin and Nanda, 2019; Conley and Udry, 2010; Crouzet et al., 2022; Feigenbaum and Gross, 2022; Gupta et., 2019; Munshi, 2004). In terms of context, the closer paper in this area is Caoui (2022), which studies the adoption of digital projections for movie theaters in France. This paper finds that the presence of network effects between movie theaters adopting digital projections and production companies selling digital movies can generate significant excess inertia.[4]

This paper also contributes to the literature in finance that has focused on empirically studying the extent to which career concerns affect managers' behavior. Focusing largely on the investment industry, several papers have documented that younger managers tend to avoid bold decision making, and instead try to align their behavior with the most common strategy in the market (e.g., Chevalier and Ellison, 1999; Hong, Kubik, and Solomon, 2000; Lamont, 2002). Our paper finds a different result: among movie directors, less experienced directors are more willing to take risky strategies, in our case regarding adoption of new technology. We think that our conceptual framework may help explain the difference between these finding: as we discuss in Section 4, risk taking makes sense for less experienced managers only when the level of competition is high, and therefore success is defined by only an exceptionally positive result. When competition is lower, inexperienced managers that still need to build their reputation may prefer to play it safe, as indeed found in the literature focused on the investment industry.[5]

[4] Yang et al. (2021) also studies the adoption of digital projection by theaters, and show that digitization of movies and projection technology creates flexibility in scheduling.

[5] This discussion is also related to the branch of literature focused on herding behavior (Hirshleifer and Teoh, 2003), and in particular how this type of behavior relates to seniority (Ottaviani and Sorensen, 2001).

This paper is organized as follows. In Section 2, we present the empirical setting studied as well as discuss the data collection and the type of technology studied. In Section 3, we present the empirical analysis. In Section 4, we present a simple model and discuss our conceptual framework. In Section 5, we conclude.

2 Conceptual and Empirical Framework

In this section, we provide a discussion of our framework. First, we describe the introduction of digital cameras and the main forces affecting this process. Second, we discuss the data used in this study. Third, we discuss how this work differs from other studies on career concerns.

2.1 Digital Movies

Movies have been shot on film since the beginning of the motion pictures entertainment era. Digital technology started as an expensive toy in the 1980s although the potential for cost savings and simplification of the film making process was clear from the beginning. The first full length movie to be shot in Sony High-Definition video system was Julia and Julia (1987) with Kathleen Turner and Sting. However, the movie had to be converted back to film to be shown in theaters.

In fact, one of the key constraints to the mass adoption of digital filming was economic: as long as movie theaters were equipped with traditional projection technologies, production companies could not realize any significant cost saving when filming a movie digitally. While using a digital technology might have sometimes allowed directors to save on costs during the recording phase, the digital output had to be transferred to film when distributing to theaters. As a result, the net economic benefit of filming a move digitally was limited, if any.

Things improved at the beginning of the new millennium. In 1999, George Lucas and others introduced the first digital projectors. Initially, digital projectors cost around $250,000 and theater owners in a declining market claimed they could not afford them without the support from producers. In 2002 major movie studios formed a committee to develop standards ("All things considered," NPR, Mark Uryck, May 13, 2002). However, as of October 2003 there were only 80 digital cinemas in the US and 200 around the world (Eric Taub New York Times, October 13, 2003). In November 2004 the Association of theater owners publicly agreed to digital projection, stating that costs of the new systems should be split between exhibitors and studios (UPI.com, November 22, 2004).

Despite these coordination efforts, the downstream impact was still limited. By 2007 some theater chains had started converting to digital on a larger scale, but only 2200 screens out of 38,000 in the US were digital. The financial breakthrough that year was that studios agreed to pay a fee for every digital copy they shipped (Virtual Print Fee or VPF) to help in financing the initial purchase of digital projectors (NPR, "All Things Considered," Laura Seidel, March 21, 2007). By 2012 the cost of digital projectors had come down to $75,000 and financial agreements such as VPI allowed theaters to engage in digital projection. By 2015, 4900 of 5700 theaters in the US used digital projection, with different financing agreements. In 2019 only 602 out of over 40,000 screens were not digital. Therefore, from an economic standpoint, shooting digital was not necessarily a superior

option at least until after 2007, when the ability to distribute digitally significantly improved the payoff of digital movies. A similar adoption pattern was also present outside the US (Caoui, 2022).

Another important aspect of digital shooting is the impact of the medium on quality. Slumdog Millionaire (2008) became the very first movie with digital cinematography to win an Academy Award for Best Cinematography as well as the best film award. In recent decades, digital technology has become progressively cheaper and digital effects more accessible. However, even in 2019, although the quality of film and digital was very similar, and more than 90% of movies were shot on digital, there were still directors who argue that film has some advantage in terms of quality.

For instance, Quentin Tarantino famously suggested that he "might retire" if forced to shoot digital and said, "I can't stand this digital stuff" and that digital was "TV in public".[6] Indeed, even Tarantino's most recent film, in 2019 was shot on film (and converted to digital for distribution). The well-known director Steve McQueen, a supporter of films told the New Republic in 2014: "all this technology, it's changing every five minutes because someone's making some money out of it." Other directors supporting film include academy award nominee Christopher Nolan. Nolan's Tenet, one of the very few films to be released in the pandemic year of 2020, was shot on film.

On the other end of the spectrum, some well-known and experienced directors were early adopters. Oscar winner Steven Soderbergh was one of the first to shoot with a "red camera." Similarly, Danny Boyle, the director of Slumdog Millionaire was one of the early adopters, and Martin Scorsese, a leader in the directing field, shot the Wolf of Wall Street in a digital format in 2012.

This very short history shows that the process of technology adoption in the creative industries can be far from linear and that throughout the process, leaders in the industry have had very different views of the new technology. Our data allows us to track individual project managers and characterize their actions vis a vis an evolving technology.

2.2 Data on Directors and Technologies

The key pieces of information we need to study technology adoption in the movie industry are the type of equipment chosen by directors as well as various other film- and director-level characteristics. Most of the data used in the analysis is collected from the Internet Movie Database (IMDb). IMDb is an online database owned by Amazon. IMDb maintains a unique webpage for films as well as for individuals associated with the production of movies, such as film directors. The film webpages contain information on production, the content of the film such as genre and rating, and various measures of the film's success such as reviews and box office revenue as well as importantly, technical information on the production. Individual webpages contain detailed information on the individual's participation in filmed entertainment in a variety of roles. We focus on directorial roles for theatrical films, defined below.

[6] https://www.digitalspy.com/movies/a441960/quentin-tarantino-i-cant-stand-digital-filmmaking-its-tv-in-public/

We start by obtaining from IMDb a list of all films released in the United States from 1975 to 2018 with gross box office revenue of at least $10,000 (2018 inflation-adjusted USD).[7] From the IMDb page we collect film-level data about how the film was created, its content, and various measures of success such as user ratings and box office revenue. The most important information for our purposes relates to the film's production process found in the "Technical Specifications" section on the film web page, which allows us to categorize the equipment used to shoot the film as either film or digital.

We focus on the "Camera" and "Cinematographic Process" fields of the technical specifications section. We create a comprehensive dictionary of all unique cameras and cinematographic processes used in the filming of movies in our sample. Then we attempt verify whether the camera or cinematographic process use film or digital processes using online internet searches as well as discussions with professionals. To illustrate the categorization process, consider the 2013 film Dallas Buyers Club. The technical specifications page shows that the camera used to shoot the film was an Arri Alexa, a popular digital camera. Furthermore, the cinematographic process "ProRes 4:4:4 (1080/24P)" is associated with digital filming. Given this information, Dallas Buyers Club is categorized as a digitally shot film. In some instances, a film's technical specifications suggest both digital and film cameras were used in production. We consider these films as digital given that the director chose to adopt digital film technology for at least part of the filming process.

While we collect films in IMDb from 1975 to 2018, we begin film categorization in 1995 since there were practically no digital productions prior to that year. For films that can be categorized Figure 1 shows the proportion of film and digitally shot movies from 1995 to 2018. The story depicted by this figure matches the anecdotal evidence discussed above. In early 2000s, the share of digital films was extremely limited. However, adoption started to change during the 2000s, and the share of digital films increased steadily, reaching approximately 21% in 2008. As discussed before, after that year the adoption of digital photography increased even more rapidly as digital projectors were being installed in theaters shifting the incentives of the studios further in favor of digital. Indeed, we see that by 2018, over 94% of movies are digital. Our categorization process depicted in figure 1 is consistent with the work of Stephen Follow, a data journalist who specializes in the film industry. In a blog post, Follow categorizes the camera type for the top 100 grossing films in the United States from 2000-2015.[8] The trend in adoption of digital cameras he documents is nearly identical to our categorization.

In addition to film characteristics collected from the film's webpage, we obtain information about the directors of the films. For each person involved in the entertainment industry, the IMDb page provides detailed career information listing the complete history of the films which this individual had directed, as well as a range of other roles they may have had in film production and in television. This career information is useful for controlling for other potential mechanisms affecting the decision to adopt digital technology. For example, having experience in technical

[7] The following link displays films released in the United States in 2000 contained in IMDb: https://www.imdb.com/search/title/?title_type=feature&year=2000,2000&sort=boxoffice_gross_us,desc&ref_=adv_nxt

[8] For more information on Stephen Follow's categorization of camera types see: https://stephenfollows.com/film-vs-digital/

roles (e.g., as a cinematographer, DP) might have exposed directors to digital film techniques therefore lowering the cost of adopting the new technology once they became directors. The resulting dataset is at the film-director level containing all films with U.S. box office revenue of at least $10,000 from 1975 to 2018.

2.3 Career Concerns and Technology Adoption

We are interested in studying this context to provide new insights about how a manager's career concerns can affect the incentive to adopt a new technology. As we discuss more extensively below, directors can be thought as project managers who need to decide which technology to adopt in order to maximize their career prospects in an uncertain labor environment.

The idea that career considerations can affect the decisions of managers is not new: a large theoretical literature has shown that a firm's investment planning can be affected by a manager's career incentives (e.g., Holmstrom and Ricart i Costa, 1986; Gibbons and Murphy, 1992, Prendergast and Stole, 1996; and Holmstrom, 1999). As discussed in Li, Low and Makhija (2017), the empirical tests of these models usually find that younger managers tend to avoid bold decision making, and instead prefer to align their behavior to what is considered the most common strategy in their relevant market (e.g., Chevalier and Ellison, 1999; Hong, Kubik, and Solomon, 2000; Lamont, 2002).[9]

However, previous studies focus on core business decisions, and do not specifically examine how career incentives affect technology adoption. In general, we think that the decision process affecting the adoption of a new technology should be different than actions that are closer to the core tasks of a job assignment and are likely to be repeated frequently over a regular work life (e.g., selecting stocks for a portfolio manager). If this is the case, it is unclear whether the type of conceptual framework and empirical results that were developed previously can be easily applied to our question.

As discussed earlier, we think that the adoption of a new technology differs from a typical investment decision (e.g., buying some equipment) across three dimensions.[10] First, a new technology is a product or process for which no one has extensive experience. This does not necessarily imply that experience with the old technology is not important to operate the new one. However, the benefits in terms of experience are less valuable for the new technology than for the old one. As a result, established managers may face a higher hurdle than newcomers when using the new technology.

[9] Among the others, an exception to this is indeed Li, Low and Makhija (2017), which studies CEO behavior. Interestingly, the authors explain the difference in results because the previous literature in finance has focused mostly on highly specialized labor market (e.g. mutual fund managers), where the need to herd could be stronger. Interestingly, our paper focuses on a very specialized labor market, but still find results that are inconsistent with these papers. Our discussion in Section 5 will try to explain the motivation behind this result.

[10] We provide this characterization to help the reader thinking through our conceptual context and provide a benchmark to differentiate the adoption of a digital technology from other investment. Clearly, we do not see this characterization to be universal. Furthermore, we do not think that each new technology will be characterized by all three features with the same strength.

Second, new technologies are usually not introduced at their full potential: adjustments and improvements are common in the early life of a new technology. As a result, if we consider the net benefit (cost) of adopting a new technology, this is likely to increase (decrease) over time relative to the old technology. One implication of this feature is that adopting early may be valuable, at least in some cases. Early adopters – by learning how to use the new technology – may be able to reap some of these improvements over the long run. This feature will depend on the specific nature of the technology, and the extent to which this is likely to generate a "first-mover advantage" in the market.

Third, a new technology is not necessarily better than an old one - in particular early on -, but it is generally characterized by a higher level of risk. In other words, a new technology presents both higher upsides and lower downsides. Generally, a new technology is introduced to overcome some of the limitations of the status quo. While ex-post this push could be extremely rewarding, it also presents potential downside risks. This risk can come from technological or market risk. For instance, in our specific application one concern was about viewers, and whether they would have liked more (or less) the output produced with the new technology.

We think that the digital transition in movies fits this conceptual framework well. First, directors consider shooting on digital to be different than shooting on film. Not only does the result look different, but the process of creating a digital film is different, for example, it allows virtually costless repetitions of scenes and instant access to results. Second, as the first wave of adoption in early 2000s progressed, the perception was that digital cameras still had a relatively wide margin for improvements and were generally considered of lower quality than film. As we discuss further in Section 4, it is not clear that in this specific case adopting early will put a director on a much better trajectory over the long run, given that switching later is still available at low penalty.

Lastly, recording a movie with a digital camera was perceived as a high-risk endeavor. As discussed, the process is different and there were also widespread concerns about the quality of digital output as well as concerns about the viewers' and critics' perception of digital movies.

Our first empirical step is to verify that as we suggest, the new (digital) technology is riskier. For that purpose, we calculate returns on each film, i.e. revenues divided by the production budget. Returns data indeed confirms this idea that digital movies are characterized by relatively higher risk. In Table 1, we classify movies by their family friendliness MPAA rating (G, PG, PG13, R, or Unrated) and by the process – digital or film. We split by rating since prior work suggests that ratings categories provide different returns on average (Ravid, 1999, Basuroy and Ravid, 2004). We then compare the standard deviation of the movie's returns between these categories for movies produced between 1998-2009, as a proxy of the ex-post realized risk for each category.[11] Across essentially all rating groups digital movies show systematically higher risk than movies recorded on films. For instance, PG movies recorded on films have a standard deviation of 8.93, while the SD for digital is 48.9. Given the highly skewed nature of movies' returns, we also show that this regularity does not depend on the tail of the distribution: in fact, we find the same pattern

[11] We define returns based on the reported cost and revenues. Notice that this information is not available for all movies used in our analysis.

when we winsorize returns at 1%. The only partial exception to this pattern is movies rated as "PG-13:" The level of realized risk is similar across the two groups, but when we winsorize returns, again, digital movies have a significantly higher risk.

Altogether, while there may be other characteristics of new technologies we may not capture in our setting, we think that differences in ex-ante expertise, expected benefits, and risks are crucial features that help separating the adoption of a new technology from another corporate action. Indeed, we will incorporate these features in our conceptual framework in section 4.

3 Adoption of digital filming and Experience

3.1 Empirical Setting – movie directors' careers

Our empirical setting is characterized by several features that make this analysis unique and useful.

Movie directors can be viewed as managers in charge of large projects. The director is responsible for completing the film on time and within budget as well as for the artistic merit of the project. As a result, the movie industry provides a very natural project-level data set, where both the career of the manager of the project (i.e., the director) as well as all the project's characteristics are available to the researchers, and we can discern the career stage of directors adopting the new technology (see John et al, 2017 Han and Ravid, 2021).

A second issue is that it is often difficult to isolate the incentives related to career concerns from those coming from a typical principal-agent relationship. For instance, in a large organization, the adoption of a technology by one branch may reflect both the incentives of a local manager and the authority of the headquarters. Our context is much cleaner in this dimension. Furthermore, the transition to digital had occurred during a relatively well defined period of time: thus, we are able to study the entire adoption process, with clear start and end points. As discussed, until the late 1990s there were virtually no digital films, whereas 20 years later there were very few non-digital productions.[12]

Third, directors' career is risky and starts at a late age, hence career concerns are of paramount importance. Han and Ravid (2021) as well as John et al. (2017) find that the average director enters the profession at age 39 makes only one film before dropping out and returning to their previous profession. In Han and Ravid (2021) 84% of male directors who had entered the profession between 1995 and 2015 and 90% of the female directors in the same cohort made 2 films or fewer before they dropped out. Given that the average budget in that sample was over $40 million in 1998 dollars it is not surprising that failure or mild success is not sufficient to allow directors to be hired again and control projects worth tens of millions of dollars.[13]

[12] This obviously has changed as digital became much more profitable, as discussed earlier. According to discussions we had with an experienced top movie executive with stints in several major studios, by 2019 only top directors could still request to shoot on film.

[13] The situation is different for experienced directors – both papers (Han and Ravid, 2021 and John et al., 2017) show that previous success (average return or the number of movies) is a strong predictor of obtaining another assignment. Thus, more experienced directors with a good track record can afford to experiment and even fail while still being able to continue their career.

In other words, this context allows us to observe clearly both the decision to adopt and the career of the director; directors are mostly in charge of the adoption decision, and career concerns are extremely salient. With this framework in mind, we test whether the ex-ante experience of a director increases her incentive to use digital versus films. We estimate an equation of this form:

$$1\{Digital_{mdt}\} = \alpha_t + \beta Experience_{dt} + \gamma X_{mdt} + \varepsilon_{mdt}$$

where $1\{Digital_{mdt}\}$ is a dummy equal to one if the movie m directed by d in year t was recorded using a digital camera, and zero otherwise, α_t is a year fixed-effect, $Experience_{dt}$ is a proxy for the experience of director d in year t, and X_{mdt} are various controls at the movie- or director-level.[14]

There are four features of this model that we want to highlight. First, as our main proxy for experience, we use the inverse hyperbolic sine (IHS) transformation of the past number of movies directed, but we show consistent results with alternative approaches.[15] Second, for simplicity we estimate the main specification using a linear probability model (LPM), but we also show results are qualitatively identical using alternatives (i.e., probit). Third, given our assumption of linearity in the relationship between adoption probability and experience, we reduce the skewness of experience by excluding from the analyses directors at the tail of the distribution of experience (i.e. directors with ten or more movies by 1999). However, we show consistent results with the full sample or using a non-parametric approach. Finally, our main analyses include movies between 1997 and 2009, but we examine different sub-samples in later analyses. [16]

3.2 Main Results

The main question we are trying to answer is whether the level of experience of a director affects the initial wave of adoption of digital filming. Before estimating the regression, we can test whether any difference can be observed in the raw data, without controls. Figure 2 compares the probability of adoption of digital filming across directors with different levels of experience. For simplicity, we divide directors into four groups depending on the number of movies they had directed before the one considered. The findings are striking: directors making their first movie (group 0) have about a 10% probability of using digital technology which is about double that of directors with one (group 1) or two (group 2) movies behind them, and three times the probability of adoption of directors with even more experience (group 3).

This effect can be replicated in a regression framework. The main result is presented in Table 2: column 1. We find that higher experience translates into a lower probability of using digital over this period. A one-standard-deviation increase in experience translates to a 2% lower probability of doing digital, which corresponds to a roughly 20% decline over the average probability during

[14] Notice that this equation is estimated with a director-level data set: a director is in the sample for the number of movies she has directed or co-directed.

[15] The IHS transformation is conceptually similar to adding one to a normal logarithmic transformation, but presents better properties as shown in recent research.

[16] Notice that we also drop movies that are rated as "TV" or "X". We also removed animated movies, since the use of digital was fundamentally different. For obvious reasons, we also exclude a relatively small number of movies for which we cannot identify whether they were shot on digital or film cameras because of a lack of data.

this period. Across the different columns, we show that results are similar when – on top of year fixed-effects – we also include controls for the genre of the movie (column 2) or its rating (column 3) or both (column 4).[17]

In Table 3, we examine the same results when defining experience in two alternative ways. First, rather than looking at the simple count of past movies, we proxy this dimension with the IHS of the aggregate amount of revenue generated by that director before the movie considered. This measure allows us to adjust previous movies effectively weighting them by the level of success.[18] As we show in columns 1 and 2, we find very similar results. In the other two columns, we examine the effect non-parametrically, essentially splitting the sample into four groups based on experience, following the same approach discussed previously for Figure 2. In addition to confirming that lower experience is generally associated with higher adoption probability, this test also gives us a better sense of the relationship between adoption probability and experience. In particular, we find that being a first-time director explains a large share of the effect: on average, this group is more likely to use digital than any other group of directors. However, directors with one previous movie are still roughly twice more likely to use digital than those with two movies. This relationship does not appear monotonic since we find that directors with three or more movies are roughly equally likely to use digital than those with a few movies. The same result holds both without and with controls for genre and rating.

The effects we find are robust to several tests. First, we find similar effects when we use a probit model rather than the LPM. Table A1 reports the same results of the previous two tables combined presenting the marginal effects of probit. Despite the expected differences in magnitudes, we find qualitatively identical results from what we presented before. Second, in Table A2 we show that our results are also almost identical when we exclude movies rated as "G." As discussed earlier, there are no digital movies during this early period that were rated "G". This robustness test confirms that this imbalance does not affect our results. In general, this category is relatively small.

Third, in Table A3, we show consistent results when controlling for past adoption of digital. While essentially no film had been shot digitally before our sample period, as we move past 2000 our sample contains directors that might have already filmed a movie digitally and are not considering the technology to use for a follow-up movie. To adjust for this dynamic dimension, we also include past adoption decision by the director.[19] The inclusion of this control does not generally alter our conclusions: if anything, we find a marginal increase in the size of the coefficients. Fourth, in Table A4, we consider the full sample of directors, in particular also including directors with an

[17] The genre is defined by including non-mutually exclusive dummy variables that identify whether the reported list of genres in IMDb lists whether the film is action, drama, comedy, thriller, horror, or other (when this information is missing). As discussed previously, our analyses also excludes animation movies, for which the meaning of digital is different.

[18] This measure effectively combines intensive and extensive margins in proxying experience. A caveat of this measure is that the revenue is strongly predicted by costs. This is why we generally prefer focusing on past movie count as a better measure.

[19] To be clear, the control is a dummy equal to one if the director has used digital in the past movie. This variable is zero by construction for first timers.

exceptional level of experience. This inclusion slightly increases the overall sample, but again, it does not significantly affect our magnitude or statistical significance.

Lastly, we also examine the role of the age of the director. Examining this dimension is difficult for two reasons. First, from a statistical standpoint, we find a very strong relationship between age and experience. While there are cases of directors entering the profession much later in life, the data also suggests a very systematic relationship between age and experience. Second, from a conceptual standpoint, the incentive coming from career concerns may also come from differences in age, and therefore it is difficult to separate the role of age as a mechanism from its role as a confounding factor. Indeed, several other career concerns papers focus on age as their main treatment variable (e.g. Li, Low and Makhija, 2011).

With these limitations in mind, we can reject the idea that our results are simply capturing the effects of younger and inexperienced directors. In Table A5, we focus specifically on the subset of directors that are forty year or older in 2000.[20] This corresponds to roughly the median age of directors in our sample. Despite the sample being much smaller than the main one, we still find results that are consistent with our previous results.

Before moving forward, we also examine the timing of our effects. We divide the sample period in three parts: (1) before 2002, when digital productions were extremely rare; (2) between 2002 and 2006, which is when digital was still a small share of all movies, but the technology was starting to be adopted more broadly; (3) after 2006, which is when the technology started becoming more prevalent.

The result of this analysis is reported in Table 6: in particular, we report separately the coefficient of our main treatment effect across the three periods. We find that the effect of experience is completely driven by the initial phase of large adoption, between 2002 and 2006.[21] After 2006, the effect is smaller in size and not significantly different from zero. This evidence is consistent with our interpretation of the differences in adoption as resulting from career concern incentives. In fact, this result suggests that the gap in adoption rates is related to experience only during the early phase of the technology, when the uncertainty and risk related to digital is high.

Altogether, this set of results shows that career considerations were important for the adoption of digital filming. On average, more experienced directors were less likely to adopt the new technology, and this effect is not explained by differences in the type of movie, as well as other confounding factors. Our result also highlights that these effects are in large part explained by the difference between directors at their first movie versus the rest, and experience appears less important as it accumulates. We also find that this effect is specific to the first wave of digital adoption, and it disappears as digital becomes more widely employed.

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[20] This analysis also drops those directors for which we cannot confirm the birth year. Notice that birth year was missing for a significant number of directors from IMDb. To supplement this information, we manually searched directors on Wikipedia and identify the birth year for almost 60% of them.

[21] We also find a null effect on the first period: we are not surprised by this result, since this period has very few digital movies in our sample (around 3%). We include it to provide a benchmark or "pre-period" to the time when adoption has actually significantly increased.

3.3 Alternative Interpretations

Our interpretation of these results is that differences in experience matter for the adoption of digital recording because of career concerns. However, experience may also affect technology adoption through other channels. In this sub-section, we examine some of the leading alternative interpretations and empirically discuss their importance in the data.

One may be concerned that the experience is related to the level of technical expertise. Given the results, the worry is that inexperienced directors may have more familiarity with the digital medium, at least relative to their experience with film. If differences in technical expertise explain the heterogeneity in behavior between directors at different parts of their career, then we should expect to find that part of the career's effect should be explained by technical expertise.[22]

We conduct this analysis in Table 4. First, we add controls for technical expertise (columns 1 and 2). Importantly, we find that technical expertise has a significant positive impact on the probability of adopting the digital technology. This supports the idea that our measure of expertise captures a significant dimension of a director's skill set. However, our main effects remain qualitatively and quantitatively unchanged: while technical expertise matters, this channel seems to run parallel to the one based on experience.

In column 3, we test for differential effects of the career's variable depending on the level of technical expertise. The idea is that – to the extent that the heterogeneity in behavior comes even just in part from differences in technical expertise – we should find that our effects should be higher for more technically skilled. However, our results reject this hypothesis. In general, our effects are orthogonal to the director's level of technical expertise. Technical expertise may however, be a proxy for the ease of learning, and we explore this idea further in our conceptual framework below.

A second hypothesis is that a director's experience may influence the budget constraint of a film production, which in turn may affect the type of recording technology used. In particular, this explanation suggests that inexperienced directors have tighter budgets and also that this condition will systematically lead to the use of digital. We address this concern both conceptually and empirically. To start, while plausible, we do not think that this interpretation is likely to be important ex-ante. As discussed before, the large economic advantage of filming a movie digitally is in the distribution process. However, until roughly the end of the first decade of the 21st century, most movie theaters were not equipped for digital films, and therefore the distribution happened on film for most movies. This implies that the incentive to go digital to overcome a financial constraint is unlikely to be first order.

As an alternative way to look at this hypothesis, we can use films' budget data. Like age, there is a very strong relationship between a movie's budget and a director's experience. Another issue is that budget is missing for a substantial share of movies: however, missing values are not randomly distributed. As we were able to check manually, budget is generally available for medium and

[22] We define a director to be more technically skilled, if he had experience on technical roles within the movie industry. Using data on the director's IMDb page we look at whether the director had previous work in the following roles: (1) camera and electrical department; (2) cinematographer; (3) special effects; (4) visual effects.

large productions, while missing for smaller productions. To rule out the possibility that our results stem simply from differences in financial ability, we replicate our main results looking at the sample of small productions, defined as movies with missing budgets or confirmed budgets lower than $5M. Results in Table 5 confirm that despite the significantly smaller sample size, our findings do not simply reflect the differences in budget between experienced and less experienced directors. Even within small productions our earlier findings hold.

Another related interpretation is that larger studios prefer digital shooting, and their ability to impose their preference on the creative team is greater when it is led by an inexperienced director. While it is plausible that more experienced directors have more freedom to choose their teams and technology, the implication of this statement is hard to square with the timing of the effects discussed earlier. As we discussed before, the economic benefit of using digital for producers increased over time, and it was particularly high after 2007, when digital movies could be distributed directly without going through films. Therefore, if our results were to reflect differences in bargaining power between a director and producers, we should expect our results to become larger – and not disappear- at the end of the sample period.

Lastly, we also want to discuss the possibility that directors with different level of experience may prefer digital versus film simply because they tend to direct different types of movies or have preferences for different types of digital content. In general, it is possible that the style of filmmaking of inexperienced directors – in particular first timers – may be different in ways that would require more extensive use of digital filming. For instance, inexperienced directors may focus on making movies that require more special effects, which in turn makes them more likely to benefit from digital filming for reasons that are orthogonal to career concerns. This is not a plausible explanation in the context of the industry, since if anything, expensive films with digital wizardry are rarely directed by an inexperienced director, but we examine this potential story empirically below.

We consider this hypothesis by comparing movies that are shot digitally to others that were recorded originally on film but were later transferred into digital forms in post-production ("digital intermediary"). The idea of this test is the following: during our period, a director who wanted to shoot the movie in film but still wanted to take advantage of digital technologies to include special effects of various forms could do this by adding an intermediate digital transfer of the movie. In other words, it could transfer the movie (or part of it) into digital format, undertake all the intermediate steps in this format, and then move it back to film for distribution. Importantly, this "digital intermediate" technology was already used at the end of the 1990s and it did not present the same risks as shooting directly in digital, since the original material was always available in film.

Leveraging this feature, in Table 7, we compare movies that were shot digitally to other movies that were not shot digitally but that undertook a digital intermediate step during production.[23] The idea is that these two sets of movies are more comparable than the entire population of movies,

[23] Data on whether a film used a digital intermediate is also included in the technical specifications section of the IMDb page that we used to categorize the movie cameras as either digital or film.

since they both can access the same type of post-production features. When focusing on this sub-sample, we still confirm our main results. If anything, the magnitude of the effects is now larger.

While partial in nature, this discussion helps rule out several leading alternative interpretations to our career concerns hypothesis. In particular, our findings that differential adoption is based on past experience level is robust to other possible mechanisms such as variation in technical expertise, financial slack, pressure from production companies, or movie type.

Section 4 A Conceptual Framework of Technology Adoption and Career Concerns

The empirical evidence in the previous section shows that career concerns may affect the relative incentives to adopt a new technology: during the first adoption wave of digital cameras in the motion picture industry the utilization of this new technology was largely driven by inexperienced directors. This suggests that managers in their early career may play a particularly important role in the propagation of new technologies in the workplace.

However, a natural question is whether this result can be extended outside the specific context studied. To try and frame our results in a more general setting, we consider a simple model of technology adoption and use it to present the economic forces that are likely to play a role in our case. To be clear, the model does not aim to fully characterize the decision problems of managers, instead, we consider it a parsimonious framework that helps to highlight the key trade-offs faced by a manager. The outline of the model is presented here, and a more complete formulation is presented in Appendix B. After developing the model, we use its results to discuss the external validity of our results.

Section 4.1 A Simple Model

In this model a director with experience level i where $i \in (Exp, Inex)$ chooses whether to use the old (f) or new (d) technology $t \in (f, d)$ for her next project. Each director is assumed to be maximizing the lifetime utility from her work:

$$U_i = E(r_{it}) + Prob\{r_{it} > k_i\}V_t + c1\{t = d\}$$

This lifetime utility is made up of three terms. The first term captures the expected return of the next project, which depends on the level of experience i, the chosen technology t, and a random component. Specifically, we assume that $r_{it} = \mu_{it} + \varepsilon_t$, where μ_{it} is the expected return on the movie which is dependent on both experience and technology. Returns also have a random component that is normally distributed with variance that can vary by technology: $\varepsilon_t \sim N(0, \sigma_t^2)$.

The second term captures the career's continuation value: the first component is probability that the director is allowed to continue making movies given the return on her previous film – $Prob\{r_{it} > k_i\}$ – it is multiplied by the value of continuing to direct movies conditional on the choice of the technology today V_t.

Two aspects regarding this second term are worth elaborating. First, we assume that the probability of being able to continue directing movies is less dependent on current results for experienced

directors. For simplicity, we assume that an experienced director can always continue her career irrespective of the results of the current movie (i.e., $Prob\{r_{Exp,t} > k_{Exp}\} = 1$). For inexperienced directors the probability of continuation is strictly less than 1. This generates a fundamental difference in career concerns between directors. Second, the ratio V_d/V_f captures the relative value of being an early adopter in digital versus continuing with the use of film. As we discuss further below, this parameter depends on both the actual expected value of using digital and the benefit of starting to use this technology early on versus switching to the new technology later. For instance, if industry experts expect digital to be much better than film over the long run, it could still be that V_d/V_f is low to the extent that switching later to digital has a small penalty.

The third term captures a director-specific preference for using the new technology. We assume this parameter can vary by director and is drawn from a uniform distribution defined between 0 and some large value C.[24]

Following the discussion in Section 2, we assume that the new and old technology differ across two dimensions. First, there is a difference in familiarity between the two technologies: experienced directors have already used the old technology and therefore are relatively more productive at using it. In our context, an experienced director producing a movie using film will have $\mu_{it} = \mu_{Hf}$, while for the inexperienced director $\mu_{it} = \mu_{Lf}$, such that $\mu_{Hf} > \mu_{Lf}$. Since no one has experience with the new technology, their level of familiarity in that case is μ_{Ld} irrespective of the level of experience. Notice that our model can accommodate different assumptions regarding how director experience is related the type of technology, but we think that these assumptions are the most relevant for our case. Second, we assume that the new technology is characterized by higher level of risk, such that $\sigma_d^2 > \sigma_f^2$. This assumption is consistent with our general definition of a new technology, and it is also in line with the empirical evidence provided in Table 1 showing that the standard deviation in returns for digital movies was higher than film.

In this context, it is easy to show that inexperienced directors are more likely to adopt than experienced if:

$$\mu_{Hf} - \mu_{Lf} > \Big(1 - Prob\big(r_{In,d} > k_{In}\big)\Big) V_d - \Big(1 - Prob\big(r_{In,f} > k_{In}\big)\Big) V_f$$

From this formula, we can observe that three parameters are crucial in understanding how the level of experience will affect adoption (the proofs for these statements are provided in Appendix B):

(a) The value of experience $\mu_{Hf} - \mu_{Lf}$: If being experienced with the old technology generates a significant payoff, experienced directors will be less likely to experiment with the new technology.[25]

(b) The long-term value of adopting the new technology today V_d/V_f: if we expect that adopting the new technology early will be better in the long-run, experienced directors will be more likely

[24] The inclusion of an idiosyncratic parameter allows us to do comparative statics on the relative probability of adoption by the two types of directors.

[25] Notice that this difference could also be negative: for instance, sometimes a new technology could be so much better that – despite a lack of experience with it – a user can be more productive than with the old technology.

to adopt early, all else equal. By assumption, experienced directors are more likely to be active in the future since their ability to keep working does not depend on the outcome of the current project. Therefore, they internalize more extensively the future benefit of switching to the new technology, if any. We further discuss how to interpret this prediction below.

(c) The interaction between the threshold to continue (k_{Inex}), in other words the competition in the labor market, and the risk of the new technology (σ_d^2): the fact that inexperienced directors need to prove themselves in the current project implies that risk is an important variable when deciding which technology to use. However, the direction of the impact of risk depends on the level of competition in the market.

When the level of competition is low (i.e., most inexperienced directors will be able to become experienced), then an inexperienced director will generally be risk-averse and therefore avoid adopting the new technology. However, when competition is high, new directors will tend to prefer the riskier technology. In this case, picking the high variance option maximizes their chance of clearing the high bar in the market. Appendix B provides the formal proof of these results.

Section 4.2 Discussion

Despite the simplicity of the model, we think that this framework provides some useful insights to think about how our findings could be extended outside our specific setting.

The first observation is that – given our knowledge of the directors' career – it is not surprising that inexperienced directors played a leading role in the adoption of digital filming. As discussed in Han and Ravid (2021), the market for directors is extremely competitive, and early career directors can continue directing movies only if they are extremely successful. This is akin to inexperienced directors facing a high continuation threshold k_{Inex}. As a result, we should expect inexperienced directors to have a strong incentive to be risk-takers so they can pass this threshold, which is exactly what we find. This aspect of the model can also explain why in other industries inexperienced players tend to be more conservative. If the threshold is low, then inexperienced players tend to herd and go with proven technologies, as for example, in Chevalier and Ellison, 1999; Hong, Kubik, and Solomon, 2000; Lamont, 2002).[26]

The value of continuing with future technologies relative to current technologies can also matter and change behavior. In our case, V_d/V_f may not be particularly high. As we discussed in Section 2, many directors appear to reject the use of digital for artistic reasons, therefore suggesting that for some directors, digital will always be a low-quality option irrespective of the technical improvements. In other words, the presence of artistic preferences for film in this industry suggests that there will be always some scope for using film relative to digital.

[26] Among the others, an exception to this is indeed Li, Low and Makhija (2017), which studies CEO behavior. Interestingly, the authors explain the difference in results because the previous literature in finance has focused mostly on highly specialized labor market (e.g. mutual fund managers), where the need to herd could be stronger. Interestingly, our paper focuses on a very specialized labor market, but still find results that are inconsistent with these papers. Our discussion in Section 5 will try to explain the motivation behind this result.

Furthermore, as we discussed early, this ratio depends on both the actual value of the technology as well as the extent to which the current decision to use digital will be beneficial relative to someone that adopted later. In this case, it is not very plausible that the benefits for early adopters are very high: the movie industry is characterized by large and infrequent projects, and therefore a director that does not adopt immediately is likely to be able to switch to digital later, if the value of switching is high. This idea is also consistent with our findings: in our data, we find evidence of persistence in adoption. Early adopters are relatively more likely to keep using digital in the future, but we also see many directors switching across film and digital later in the sample.

This discussion highlights how our result is consistent with what we should expect in this industry. However, this framework also suggests that this result can vary depending on specific parameters. In other industries with different technologies the relationship between early adoption and experience may differ from our context.

A particularly interesting aspect to understand is the nature of competition for promotions. In many highly competitive areas, it is reasonable to expect that the need to "stand out from the crowd" can generate a strong incentive for newcomers to adopt new technologies or business methods, as we find for directors. However, the same mechanism should not work in areas where the career progression is more linear and the bar to clear for promotion is low. In this sense, public administration may represent an interesting case to study, since in several developed countries career progression is mostly tied to tenure and the benefits of "outperforming" peers can be more limited. In this situation, it is plausible to expect that managers may prefer "to play it safe" and therefore avoid taking any initiative that would generate downside risk, irrespective of the upside that can be captured.

Another important parameter embedded in (V_d/V_f) is the long-run benefit of adopting. As we discussed early, this parameter depends on both the actual value of the technologies over the long-run and the benefit that accrues to early adopter. As a result, an important dimension to consider is the presence of large reputational benefits to early adopters. All else equal, if adopting early will generate strong reputation, we should expect experienced agents to be more active in experimenting with the new technology. The importance of these reputational benefits will depend on the specific nature of the industry. Lastly, while experience with the old technology will generate a preference among established managers to keep the old technology, this channel may be more or less important across different fields.

Altogether, the relationship between career concerns and technology adoption is ex-ante ambiguous, and a detailed analysis of the competitive landscape is necessary to assess the type of frictions that career concern may generate. In this context, our analysis is important for two reasons. First, it represents one of the first attempts to study carefully how career concerns and technology adoption interact. In this context, our empirical and conceptual framework may provide a useful starting point for future research in other contexts. Other industries and technologies may differ across dimensions in our conceptual framework – such as the threshold for being able to continue, the long-run value in adopting the new technology, or the inherent riskiness in the new technology – and this may lead to different outcomes related to how career concerns impact technology adoption.

Second, despite the limitations discussed above, we believe that the leading role of inexperienced agents in the adoption of a new technology is a result that likely extends to many important areas of our economy – like artistic or intellectual professions – which share many similarities with the film industry.

Section 5 Conclusion

This paper studies how career concerns may affect the adoption of new technologies. To examine this question, we first focus on the adoption of digital filming in the motion picture industry and then present a simple conceptual model to discuss how our findings may extend outside this context.

The first two decades of the twenty first century saw a dramatic shift in the technology used in films. Focusing on this period, we find that inexperienced directors played an important role in this transition. These results do not appear to be explained by differences in the movie genre, rating, or technical expertise. We also argue that this relationship is likely explained by a difference in career concerns rather than other mechanisms, like differences in funding or preferences for digital content between more and less experienced directors.

At face value, these results suggest that managers in their early career may play a particularly important role in the propagation of new technologies in the workplace. We then present a simple conceptual framework to discuss how career concerns may affect technology adoption outside the motion picture context discussed here. The theory suggests that this relationship is likely to be context dependent. Three features appear to be particularly salient: the degree to which experience with the old technology accumulated by more experienced managers may generate sizable benefits; the long-term value of switching to the new technology early; and the extent to which high levels of competition may incentive early-career managers to take riskier options, therefore favoring the adoption of a new technology.

While we think that our results are likely relevant to important areas like creative or intellectual professions, this discussion also acknowledges that the actual incentives provided by career concern may differ across industries or types of technologies. Our discussion provides a simple conceptual framework to think about this issue in a more general way. In this regard, we hope that future research will examine the relationship between career concerns and technology adoption across areas where the set of incentives and aspects of the technology differ from our setting.

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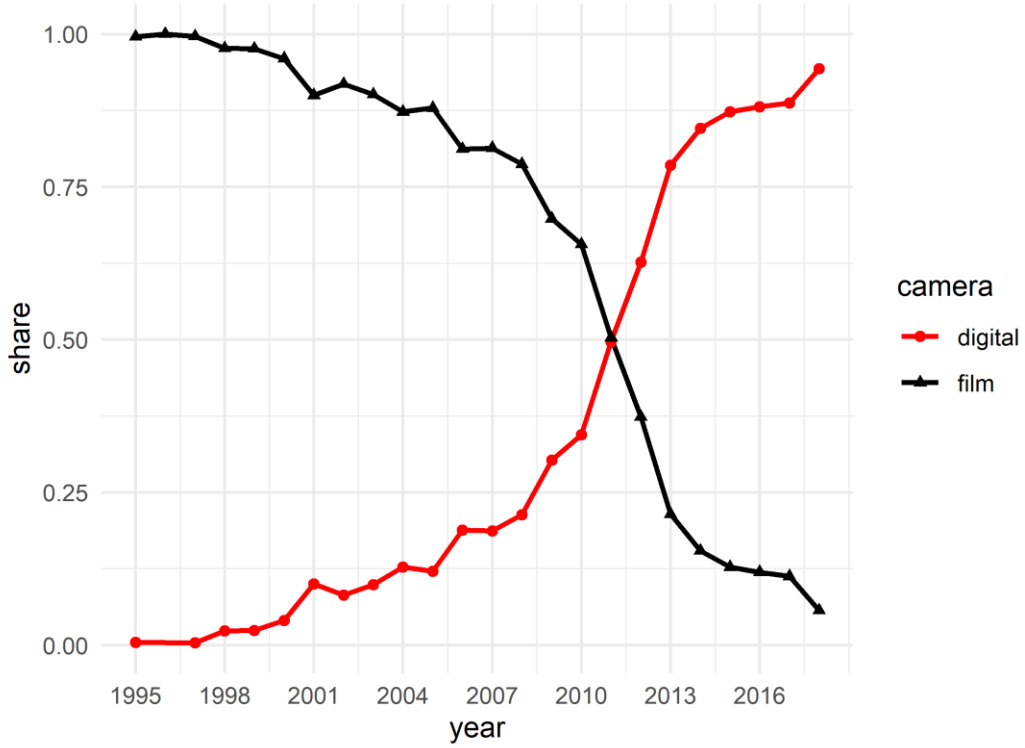
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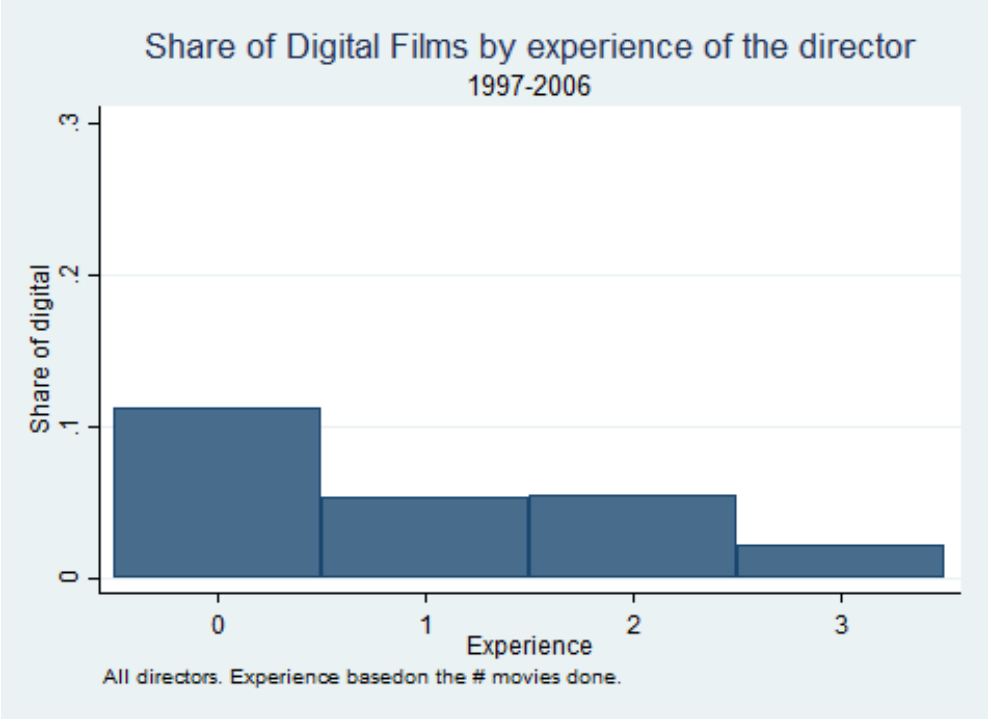
Figures

Figure 1



Notes: this figure reports the share of films that were categorized as being films with either a digital or film camera in a year. A film was categorized using the "Technical Specifications" information on the film's IMDb page.

Figure 2



Notes: this figure reports the probability that a director will choose a digital camera conditional on different levels of previous experience. Group 0 are directors that have directed no previous films. Group 1 are directors with one previous film. Group 2 are directors with two previous films. Groups 3 are directors with more than two previous films.

Tables

Table 1: Standard Deviation of Film Returns

Period		1998-2009	2001-2009	Winsor 1998-2009	Winsor 2001-2009
G	SD Film	4.71	5.53	4.71	5.53
	SD Digital	NA	NA	NA	NA
PG	SD Film	8.93	9.83	3.06	3.41
	SD Digital	48.96	49.97	8.12	9.57
PG13	SD Film	4.76	5.14	2.92	3.21
	SD Digital	4.84	4.85	4.52	4.84
R	SD Film	122.84	9.49	3.75	3.98
	SD Digital	1048.77	1066.57	5.56	6.11
Unrated	SD Film	6.53	6.91	3.97	4.56
	SD Digital	9.51	9.76	6.02	6.64

Notes: this table reports the standard deviation of move returns for each camera type by film rating and time period. Film returns are defined as the difference between worldwide gross revenue and the budget relative to the budget, as reported in IMDb. The last two columns winsorize the data at the top and bottom one percent.

Table 2: Probability of Adoption (Baseline Results)

	(1)	(2)	(3)	(4)
	digital	digital	digital	digital
# Previous films (IHS)	-0.017***	-0.017***	-0.012**	-0.011**
	(0.005)	(0.005)	(0.005)	(0.005)
Genre F.E.	No	Yes	No	Yes
Rating F.E.	No	No	Yes	Yes
Observations	3776	3776	3776	3776
Adjusted R^2	0.057	0.059	0.070	0.073

Notes: year fixed effects included, robust errors in parenthesis. This table reports the results from the main specification. The outcome is a dummy for whether the director used a digital or film camera. The main variable of interest is the inverse hyperbolic sine of the number of previous movies the director had directed.

* p<0.10, ** p<0.05, *** p<0.01

Table 3: Probability of Adoption (Alternative Measures of Experience)

	(1) digital	(2) digital	(3) digital	(4) digital
Previous Movie Revenue (IHS)	-0.009***	-0.005**		
	(0.002)	(0.002)		
Only One Prev. Movie			-0.039***	-0.033**
			(0.014)	(0.014)
Only two previous movies			-0.068***	-0.058***
			(0.016)	(0.016)
>2 Prev. Movies			-0.043***	-0.030**
			(0.012)	(0.013)
Genre F.E.	No	Yes	No	Yes
Rating F.E.	No	Yes	No	Yes
Observations	3776	3776	3776	3776
Adjusted R^2	0.059	0.073	0.060	0.075

Notes: year fixed effects included, robust errors in parenthesis. This table presents regression results for two alternative measures of director's past experience. Columns 1 and 2 include the cumulative gross revenue of past movies. Columns 3 and 4 consider a non-parametric measure of experience using bins of total previous films. The outcome is a dummy for whether the director used a digital or film camera.

* p<0.10, ** p<0.05, *** p<0.01

Table 4: Probability of Adoption (Controlling for Previous Technical Expertise)

	(1) digital	(2) digital	(3) digital
# Previous films (IHS)	-0.015***		-0.016***
	(0.005)		(0.006)
Only One Prev. Movie		-0.032**	
		(0.014)	
Only two previous movies		-0.059***	
		(0.016)	
>2 Prev. Movies		-0.037***	
		(0.013)	
Technical Expertise=1	0.077***	0.076***	0.072***
	(0.013)	(0.013)	(0.021)
Technical Expertise=0 # # Previous films (IHS)			0.000
			(.)
Technical Expertise=1 # # Previous films (IHS)			0.004
			(0.013)
Genre F.E.	Yes	Yes	Yes
Rating F.E.	Yes	Yes	Yes
Observations	3776	3776	3776
Adjusted R^2	0.083	0.085	0.083

Notes: year fixed effects included, robust errors in parenthesis. This table presents regression results controlling for a director's past experience in the technical production of films. Data on a director's technical expertise is taken from the "Filmography" section of the director's IMDb page. The technical expertise variable is a dummy that is equal to 1 if the director was listed as being in the "Camera and Development", "Cinematographer", "Special Effects", or "Visual Effects" departments on a previous film. Column 1 uses the inverse hyperbolic sine of the number of previous movies whereas column 2 uses dummy bins for the number of previous movies. Column 3 includes the interaction between past experience and past technical expertise. The outcome is a dummy for whether the director used a digital or film camera.

* p<0.10, ** p<0.05, *** p<0.01

Table 5: Probability of Adoption (Films with Small Budget)

	(1) digital	(2) digital	(3) digital	(4) digital	(5) digital	(6) digital
# Previous films (IHS)	-0.016***	-0.011*				
	(0.006)	(0.006)				
Only One Prev. Movie					-0.049***	-0.043***
					(0.016)	(0.016)
Only two previous movies					-0.076***	-0.066***
					(0.017)	(0.017)
>2 Prev. Movies					-0.046***	-0.034**
					(0.014)	(0.014)
Previous Movie Revenue (IHS)			-0.007***	-0.004*		
			(0.002)	(0.002)		
Genre F.E.	No	Yes	No	Yes	No	Yes
Rating F.E.	No	Yes	No	Yes	No	Yes
Observations	2981	2981	2981	2981	2981	2981
Adjusted R^2	0.065	0.081	0.066	0.080	0.069	0.084

Notes: year fixed effects included, robust errors in parenthesis. This table presents regression results restricting the sample to small budget films. Films must have a confirmed budget less than $5 million or missing budget information since the vast majority of these films are small productions. The different columns present the results for the three alternative measures of a director's past experience. Columns 1 and 2 use the inverse hyperbolic sine of the number of previous films. Columns 3 and 4 use the cumulative revenue of past directed films. Columns 4 and 5 use dummy bins for the previous number of films. The outcome is a dummy for whether the director used a digital or film camera.
* p<0.10, ** p<0.05, *** p<0.01

Table 6: Probability of Adoption (Effect Over Time)

	(1) digital	(2) digital
Prev. Films X 1997-2001	-0.005	0.001
	(0.005)	(0.005)
Prev. Films X 2002-2006	-0.035***	-0.028***
	(0.008)	(0.008)
Prev. Films X 2006-2010	-0.002	0.000
	(0.014)	(0.014)
Genre F.E.	No	Yes
Rating F.E.	No	Yes
Observations	3776	3776
Adjusted R^2	0.059	0.075

Notes: year fixed effects included, robust errors in parenthesis. This table presents regression results examining the effect of past director experience on adoption over time. The variables of interest interact the inverse hyperbolic sine of the number of previous films directed with different time periods. The outcome is a dummy for whether the director used a digital or film camera.

* p<0.10, ** p<0.05, *** p<0.01

Table 7: Comparing Digital vs. Digital Intermediary

	(1) digital	(2) digital	(3) digital	(4) digital
# Previous films (IHS)	-0.062***	-0.042***		
	(0.012)	(0.012)		
Only One Prev. Movie			-0.140***	-0.111***
			(0.034)	(0.034)
Only two previous movies			-0.200***	-0.164***
			(0.036)	(0.036)
>2 Prev. Movies			-0.167***	-0.116***
			(0.029)	(0.030)
Genre F.E.	No	Yes	No	Yes
Rating F.E.	No	Yes	No	Yes
Observations	1436	1436	1436	1436
Adjusted R^2	0.063	0.109	0.072	0.116

Notes: year fixed effects included, robust errors in parenthesis. This table presents regression results with films that were not shot digitally but undertook a digital intermediary post-production process. The different columns present the results for the two alternative measures of a director's past experience. Columns 1 and 2 use the inverse hyperbolic sine of the number of previous films. Columns 3 and 4 use dummy bins for the previous number of films. The outcome is a dummy for whether the director used a digital or film camera.
* p<0.10, ** p<0.05, *** p<0.01

Appendix A: Additional Tables

Table A1: Probability of Adoption (Main Specification Using Probit)

	(1) digital	(2) digital	(3) digital	(4) digital	(5) digital	(6) digital
digital # Previous films (IHS)	-0.098***	-0.071**				
	(0.029)	(0.030)				
Previous Movie Revenue (IHS)			-0.050***	-0.030**		
			(0.012)	(0.013)		
Only One Prev. Movie					-0.222***	-0.191**
					(0.079)	(0.081)
Only two previous movies					-0.394***	-0.361***
					(0.100)	(0.102)
>2 Prev. Movies					-0.248***	-0.182***
					(0.067)	(0.069)
Genre F.E.	No	Yes	No	Yes	No	Yes
Rating F.E.	No	Yes	No	Yes	No	Yes
Observations	3776	3766	3776	3766	3776	3766

Notes: year fixed effects included, robust errors in parenthesis. This table presents regression results for the main specification using probit instead of a linear probability model. The different columns present the results for the three alternative measures of a director's past experience. Columns 1 and 2 use the inverse hyperbolic sine of the number of previous films. Columns 3 and 4 use the cumulative revenue of past directed films. Columns 4 and 5 use dummy bins for the previous number of films. The outcome is a dummy for whether the director used a digital or film camera.
* p<0.10, ** p<0.05, *** p<0.01

Table A2: Probability of Adoption (Dropping Rated G movies)

	(1) digital	(2) digital	(3) digital	(4) digital	(5) digital	(6) digital
# Previous films (IHS)	-0.017***	-0.011**				
	(0.005)	(0.005)				
Previous Movie Revenue (IHS)			-0.009***	-0.009***		
			(0.002)	(0.002)		
Only One Prev. Movie					-0.039***	-0.032**
					(0.014)	(0.014)
Only two previous movies					-0.067***	-0.057***
					(0.016)	(0.016)
>2 Prev. Movies					-0.043***	-0.030**
					(0.013)	(0.013)
Genre F.E.	No	Yes	No	No	No	Yes
Rating F.E.	No	Yes	No	No	No	Yes
Observations	3742	3742	3742	3742	3742	3742
Adjusted R^2	0.057	0.073	0.059	0.059	0.060	0.075

Notes: year fixed effects included, robust errors in parenthesis. This table presents regression results for the main specification dropping the sample of films that are rated G since no rated G films in are sample were filmed digitally. The different columns present the results for the three alternative measures of a director's past experience. Columns 1 and 2 use the inverse hyperbolic sine of the number of previous films. Columns 3 and 4 use the cumulative revenue of past directed films. Columns 4 and 5 use dummy bins for the previous number of films. The outcome is a dummy for whether the director used a digital or film camera.

* p<0.10, ** p<0.05, *** p<0.01

Table A3: Probability of Adoption (Controlling for Past Adoption)

	(1) digital	(2) digital	(3) digital	(4) digital	(5) digital	(6) digital
# Previous films (IHS)	-0.027***	-0.022***				
	(0.005)	(0.005)				
Previous Movie Revenue (IHS)			-0.012***	-0.012***		
			(0.002)	(0.002)		
Only One Prev. Movie					-0.053***	-0.047***
					(0.014)	(0.014)
Only two previous movies					-0.083***	-0.073***
					(0.016)	(0.016)
>2 Prev. Movies					-0.065***	-0.052***
					(0.012)	(0.012)
Top Production						
1Past Adopt	0.315***	0.306***	0.309***	0.309***	0.314***	0.306***
	(0.043)	(0.042)	(0.043)	(0.043)	(0.043)	(0.042)
Genre F.E.	No	Yes	No	No	No	Yes
Rating F.E.	No	Yes	No	No	No	Yes
Observations	3776	3776	3776	3776	3776	3776
Adjusted R^2	0.090	0.104	0.091	0.091	0.092	0.106

Notes: year fixed effects included, robust errors in parenthesis. This table presents regression results for the main specification controlling for whether the director had previously adopted digital filming. The past adopt variable is a dummy for whether any of the director's previous films were filmed using a digital camera. The different columns present the results for the three alternative measures of a director's past experience. Columns 1 and 2 use the inverse hyperbolic sine of the number of previous films. Columns 3 and 4 use the cumulative revenue of past directed films. Columns 4 and 5 use dummy bins for the previous number of films. The outcome is a dummy for whether the director used a digital or film camera.
* p<0.10, ** p<0.05, *** p<0.01

Table A4: Probability of Adoption (Results Using the Full Sample)

	(1) digital	(2) digital	(3) digital	(4) digital	(5) digital	(6) digital
# Previous films (IHS)	-0.015***	-0.009**				
	(0.005)	(0.005)				
Previous Movie Revenue (IHS)			-0.008***	-0.004**		
			(0.002)	(0.002)		
Only One Prev. Movie					-0.039***	-0.033**
					(0.014)	(0.014)
Only two previous movies					-0.068***	-0.058***
					(0.016)	(0.016)
>2 Prev. Movies					-0.043***	-0.029**
					(0.012)	(0.012)
Genre F.E.	No	Yes	No	Yes	No	Yes
Rating F.E.	No	Yes	No	Yes	No	Yes
Observations	3937	3937	3937	3937	3937	3937
Adjusted R^2	0.060	0.075	0.061	0.075	0.062	0.077

Notes: year fixed effects included, robust errors in parenthesis. This table presents regression results for the main specification for the full sample of directors. This includes exceptional directors with ten or more previous films directed. The different columns present the results for the three alternative measures of a director's past experience. Columns 1 and 2 use the inverse hyperbolic sine of the number of previous films. Columns 3 and 4 use the cumulative revenue of past directed films. Columns 4 and 5 use dummy bins for the previous number of films. The outcome is a dummy for whether the director used a digital or film camera.

* p<0.10, ** p<0.05, *** p<0.01

Table A5: Probability of Adoption (Restricting to Directors At Least Years Old)

	(1) digital	(2) digital	(3) digital	(4) digital	(5) digital	(6) digital
# Previous films (IHS)	-0.016**	-0.014**				
	(0.007)	(0.007)				
Previous Movie Revenue (IHS)			-0.006**	-0.003		
			(0.003)	(0.003)		
Only One Prev. Movie					-0.045**	-0.042**
					(0.021)	(0.021)
Only two previous movies					-0.041*	-0.035
					(0.024)	(0.024)
>2 Prev. Movies					-0.049***	-0.043**
					(0.018)	(0.019)
Genre F.E.	No	Yes	No	Yes	No	Yes
Rating F.E.	No	Yes	No	Yes	No	Yes
Observations	1668	1668	1668	1668	1668	1668
Adjusted R^2	0.042	0.052	0.041	0.050	0.043	0.052

Notes: year fixed effects included, robust errors in parenthesis. This table presents regression results for the main specification restricting to directors that are at least forty years old. The different columns present the results for the three alternative measures of a director's past experience. Columns 1 and 2 use the inverse hyperbolic sine of the number of previous films. Columns 3 and 4 use the cumulative revenue of past directed films. Columns 4 and 5 use dummy bins for the previous number of films. The outcome is a dummy for whether the director used a digital or film camera.

* p<0.10, ** p<0.05, *** p<0.01

Appendix B: Model

In this Appendix, we discuss more formally the simple model presented in Section 4.

General Setting

The model considers a director of experience level i who can either be experienced (Exp) or inexperienced ($Inex$). They choose to film a movie using camera technology t which can either be digital (d) or film (f). To make this choice, the director maximizes its lifetime expected utility of the following form:

$$E(U) = E(r_{it}) + \Pr(r_{it} > k_i)\, V_t + c1\{t = d\}$$

Lifetime utility includes three terms. The first term captures the expected return of the next project, which depends on the director's level of experience i, the chosen technology t, and a random component. Specifically, we assume $r_{it} = \mu_{it} + \epsilon_t$ where $\epsilon_t \sim N(0, \sigma_t^2)$. The parameter μ_{it} captures the level of experience with a specific technology. We assume that u_{it} can be either high or low for each technology based on the previous experience with the specific medium. For instance, for directors using film, this parameter can take values μ_{Hf} (high experience with film) or μ_{Lf} (low experience with film) such that $\mu_{Hf} > \mu_{Lf}$. Notice that the expected returns depend on both the level of experience and the technology choice (i.e. the experienced director will have a different payoff if they choose the old versus new technology), while the variance depends solely on the technology choice.

The second term captures the continuation value for a director's career which is the product of the probability that a director will be able to continue directing movies – $\Pr(r_{it} > k_i)$ – and the value of continuing to direct movies conditional on the choice of the technology today V_t. The idea behind the first part is that a director will be able to continue directing movies only if the returns are above a certain level k_i. This threshold k_i captures the level of competition in a specific field: higher k_i implies that the director is less likely to ex-ante continue in their current career of directing movies. Importantly, we assume that the probability of continuing to direct movies is less dependent on current results for experienced directors. For simplicity, we assume that an experience director can always continue directing films: $\Pr(r_{Exp,t} > k_{Exp}) = 1$. As a result, we relabel: $k_{Inex} = k$.

We also want to briefly discuss the intuition behind V_d/V_f. This captures the relative value of being an early adopter in digital versus continuing with the use of film. This will depend on both the actual value of the technology and how much benefit there is from adopting early versus later. In fact, even if digital will be much more valuable in the long run, if a director that uses film in this period can switch to digital in the future at no penalty relative to early adopters, then V_d/V_f will be low.

The third term captures a director-specific preference for using the new technology. We assume this parameter is director specific and is drawn from a uniform distribution defined between 0 and

some large value C. The distribution is the same between experienced and inexperienced directors. This is a technical assumption to allow us to estimate the share of directors using the technology.

We make two assumptions regarding the nature of the technology. First, there is a difference in learning. The new technology is unknown to everyone: so whenever any director uses it, regardless of experience level, they will always start from low productivity. However, experienced directors know the old technology and therefore have a "knowledge advantage in the market." This is captured by $\mu_{Hf} > \mu_{Lf}$ and μ_{Hf} is only available to experienced directors using film.

Second, there is a difference in risk between the two technologies. As we have shown in the data, we assume $\sigma_d > \sigma_f$. We think this feature is common among new technologies. In Section 2 we provide evidence consistent with the returns for films shot digitally having higher variance than movies shot using film cameras.

Model Solution

As discussed before, the utility of an inexperienced director choosing technology t is:

$$U_{Inex} = E\left(r_{Inex,t}\right) + \Pr\left(r_{Inex,t} > k\right) V_t + c1\{t = d\}$$

For an experienced director, their expected utility is:

$$U_{Exp} = E\left(r_{Exp,t}\right) + V_t + c1\{t = d\}$$

If you are an experienced director, then you would choose digital if:

$$E\left(r_{Exp,d}\right) + V_d + c > E\left(r_{Exp,f}\right) + V_f$$

$$\Rightarrow c > \left(\mu_{Hf} - \mu_{Ld}\right) + (V_f - V_d)$$

Given the uniform distribution assumption for c, the share of directors choosing digital is:

$$ExpShare = 1 - \frac{\left(\mu_{Hf} - \mu_{Ld}\right) + (V_f - V_d)}{C}$$

When a director is inexperienced, they choose digital if:

$$E\left(r_{Inex,d}\right) + \Pr\left(r_{Inex,d} > k\right) V_d + c > E\left(r_{Inex,f}\right) + \Pr\left(r_{Inex,f} > k\right) V_f$$

Labelling $\Pr(r_{it} > k) = \Phi_t$ and rearranging yields:

$$c > \left(\mu_{Lf} - \mu_{Ld}\right) + (\Phi_f V_f - \Phi_d V_d)$$

This implies that the inexperienced share is:

$$InexShare = 1 - \frac{\left(\mu_{Lf} - \mu_{Ld}\right) + (\Phi_f V_f - \Phi_d V_d)}{C}$$

We can now calculate when inexperienced directors are more likely to adopt the digital technology than experienced directors. This is defined by the expression:

$$1 - \frac{(\mu_{Lf} - \mu_{Ld}) + (\Phi_f V_f - \Phi_d V_d)}{C} > 1 - \frac{(\mu_{Hf} - \mu_{Ld}) + (V_f - V_d)}{C}$$

$$\Rightarrow (\mu_{Hf} - \mu_{Ld}) + (V_f - V_d) > (\mu_{Lf} - \mu_{Ld}) + (\Phi_f V_f - \Phi_d V_d)$$

$$\Rightarrow (\mu_{Hf} - \mu_{Lf}) > (1 - \Phi_d) V_d - (1 - \Phi_f) V_f$$

Results

This formulation suggests that there are three parameters that are important in understanding whether inexperienced managers will lead adoption or vice-versa.

(a) The value of experience $(\mu_{Hf} - \mu_{Lf})$: the higher the value of experience with the old technology, the higher the relative share of inexperienced directors among early adopters.

Proof: The proof of this statement is trivial, since by increasing $(\mu_{Hf} - \mu_{Lf})$ the condition above becomes less binding. The economic intuition is also simple: the more knowledge with the old technology is valuable, the more directors with experience will continue using it. As a result, adoption will be driven by those that have no knowledge of the old technology. For example, if you are in an industry where it is very hard for the inexperienced to catch up to the knowledge level of the experienced, you will tend to see adoption of new technologies driven by newcomers.

(b) The long-run value of adopting the new technology today V_d/V_f: if we expect the new technology to be better in the long-run, experienced directors will be more likely to adopt early, all else equal.

Proof: The proof also easily follows from the condition above. The economic intuition is that experienced directors are going to benefit from directing in the long-run with probability one, while the inexperienced may be forced to drop out. As a result, the experienced are more likely to internalize the long-run benefit that may arise from adopting the new technology early.

(c) The interaction between the level of labor market competition (k) and the risk of the new technology (σ_d^2): the fact that the inexperienced need to prove themselves in the current project, since they may not be able to continue producing, implies that risk is an important variable when deciding which technology to use. However, the director of the impact of risk depends on the level of competition in the market. When the level of competition is low (i.e., most inexperienced directors will be able to become experienced), then an inexperienced director will generally be risk-averse and avoid adopting the new technology. In contrast, when competition is high, new directors will tend to prefer the riskier technology.

Proof: the proof of this statement is a bit more demanding. To examine how risk affects the relative probability that inexperienced versus experienced dominates among early adopters,

we can conduct the following thought experiment. We can start from a condition in which the two technologies have the same level of risk, and then study how a marginal increase in risk (i.e. increasing σ_d^2) affects the condition above. Before doing this, we need to observe that:

$$\Phi_t = \Pr(r_{it} > k) = \Pr(\epsilon_t > k - \mu_{it}) = 1 - CDF_t(k - \mu_{it}) =$$

$$= 1 - \left[.5\left(1 + erf\left(\frac{k - \mu_{it}}{.5\sigma_t^2}\right)\right)\right]$$

This implies that the condition above can be rewritten as:

$$(\mu_{Hf} - \mu_{Lf}) > .5\left(1 + erf\left(\frac{k - \mu_{it}}{.5\sigma_d^2}\right)\right)V_d - .5\left(1 + erf\left(\frac{k - \mu_{it}}{.5\sigma_f^2}\right)\right)V_f = \Delta$$

Where we define Δ for convenience. Our problem then is essentially to sign $\frac{\delta\Delta}{\delta\sigma_d^2}$. We can start by writing:

$$\frac{\delta\Delta}{\delta\sigma_d^2} = .5V_d \frac{\delta erf\left(\frac{k - \mu_{Ld}}{.5\sigma_d^2}\right)}{\delta\sigma_d^2}$$

Which can be rewritten as:[27]

$$\frac{\delta\Delta}{\delta\sigma_d^2} = -.5V_d \frac{2}{\sqrt{\pi}} e^{-\left(\frac{k-\mu_{it}}{.5\sigma_d^2}\right)^2} \left(\frac{k - \mu_{Ld}}{.5\sigma_d^2}\right)$$

Now, the sign of this derivative depends on $k - \mu_{Ld}$. Notice that the sign of $k - \mu_{Ld}$ can be interpreted as the proxy for the level of competition in the market. When $k - \mu_{Ld} > 0$, this means that the majority of managers starting will fail to keep working in the future. If $k - \mu_{it} > 0$, then the sign is negative. This implies that if the variance increases, Δ decreases, and therefore it is more likely that we will have the inexperienced adopt. If $k - \mu_{it} < 0$, then the derivative is positive, and the intuition is the opposite.

This result is in line with the economic intuition: when the level of competition for the job is sufficiently high, taking a riskier option is optimal. On the other hand, when the baseline assumption is that the manager will be able to stay in the market, higher risk is bad and should be avoided.

[27] Since, $\frac{\delta \mathrm{erf}(x)}{\delta x} = \frac{2}{\sqrt{\pi}} e^{-x^2}$.