Management Science

Publication details, including instructions for authors and subscription information:
http://pubsonline.informs.org

Deadlines in Product Development

Juanjuan Zhang

To cite this article:
Juanjuan Zhang (2016) Deadlines in Product Development. Management Science 62(11):3310-3326. http://dx.doi.org/10.1287/mnsc.2015.2300

MANAGEMENT SCIENCE
Vol. 62, No. 11, November 2016, pp. 3310–3326
ISSN 0025-1909 (print) | ISSN 1526-5501 (online)

https://doi.org/10.1287/mnsc.2015.2300

Deadlines in Product Development

Juanjuan Zhang
MIT Sloan School of Management, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, jjzhang@mit.edu

Deadlines are common in product development and are often felt to be too harsh—many development efforts are still worth continuing at the time of mandated termination. We examine the value of deadlines from the agency-theoretic perspective. We consider a firm that pays an agent to lead product development activities. The chance of success depends on the viability of the project and the effort of the agent. As the project proceeds without success, doubts grow as to whether the project is viable. To motivate continued effort, the firm must promise the agent a generous reward if success is achieved during the late stage of development. However, rewarding late success undermines effort incentives in the early stage. The firm may find it more profitable to impose a hard, early deadline to eliminate the agent's dynamic incentive to procrastinate. We derive conditions under which the firm should impose such deadlines.

Keywords: deadline; product development; incentive; learning; dynamic moral hazard; agency theory
History: Received July 30, 2012; accepted May 7, 2015, by Pradeep Chintagunta, marketing. Published online in *Articles in Advance* April 4, 2016.

1. Introduction

Deadlines are commonly used in the product development process (e.g., Gersick 1988, 1989; Eisenhardt and Tabrizi 1995, Lindkvist et al. 1998, Kerzner 2013). In an empirical study of the global computer industry, Eisenhardt and Tabrizi (1995) find that frequent deadlines help accelerate product development. In a case study of Ericsson, Lindkvist et al. (1998, p. 939) document strict enforcement of deadlines, highlighting a project manager's comments: "If we said that it was to be ready by Friday, we did not accept anything else."

Deadlines are often felt to be "too harsh." Many projects would benefit from having more time when deadlines hit. Product Development Advantage Group, a Massachusetts-based management consulting company, emphasizes the inability to meet deadlines as a central problem in product development.[1] *Quality Digest* questions the frequent exertion of aggressive and wasteful deadlines (Himmelfarb 2008). Sean Ellis, a start-up guru, laments the high likelihood of missing deadlines when product development is susceptible to random factors (Nivi 2009). The Standish Group's survey of 8,000 software projects indicates that more than 80% failed to meet their respective deadlines (Wu et al. 2004).[2]

In this paper, we aim to understand the value of deadlines from the agency-theoretic perspective. We consider a firm that pays an agent to lead product development activities. Product development is fraught with uncertainty (Urban and Hauser 1993). Oftentimes neither the firm nor the agent knows for sure whether an idea would eventually lead to a successful product. The agent's development effort thus serves dual purposes in this uncertain environment. It not only contributes to success but also generates information about the project's inherent chance for success, because the quality of an idea is often learned through trials. As time passes without success, pessimism grows as to whether the project is inherently fruitful. To motivate continued effort during the late stage of product development, the firm must offer the agent a generous reward for achieving success. However, rewarding late success undermines the agent's incentive to work diligently in the early stage of product development. Imposing a hard, early deadline thus helps the firm battle procrastination in the workforce, even if the project is still worth continuing when the deadline hits—that is, even if the

[1] See http://pd-advantage.com/images/7_Steps_to_Improve_RD_thruput.pdf, accessed July 30, 2012.

[2] To further assess the prevalence of deadlines, in spring 2015 we surveyed 105 professionals with self-reported product development experience. We asked each survey participant to evaluate the statement "the company I work(ed) with enforces hard deadlines in the product development process" on a five-point Likert scale, with 1 being "never" and 5 being "always." Figure A.1(a) of the appendix presents the results. The average response is 3.619, which is significantly higher than the neutral value of 3 ($t = 5.545$, $p < 0.0001$). We also asked survey participants to evaluate the statement "some of the products are still worth continuing at the time of the deadline" on a five-point Likert scale, with 1 being "strongly disagree" and 5 being "strongly agree." Figure A.1(b) shows the results. The average response is 3.829, which is also significantly higher than 3 ($t = 9.037$, $p < 0.0001$).

project still generates positive expected values for the firm given the latest belief about its chance of success.

This interpretation of deadlines relies on companies using extrinsic rewards to motivate product development efforts. The role of rewards on effort motivation has been widely recognized in the agency theory literature (e.g., Holmström 1979). Rewards are also frequently seen in real-world new product development processes. Pragmatic Marketing® surveyed more than 1,500 individuals responsible for product management and marketing in 2012. About 80% of respondents received a bonus (Pragmatic Marketing 2013). The qualitative study by Burroughs et al. (2011) of 20 companies finds that 15 offer incentive programs during new product development. Examples include employee bonuses for making a significant product development contribution, a trip to a desired destination for launching a promising new product, and annual merit raises contingent on meeting innovation expectations. Markham and Lee (2013) present the results of the Product Development and Management Association (PDMA)'s 2012 Comparative Performance Assessment Study. They find from a sample of 453 companies that a variety of incentives and rewards are used to motivate new product development personnel, among which the use of financial-based rewards saw the largest increase since the previous PDMA survey by Barczak et al. (2009). In particular, best-practice companies, compared with the rest, use significantly more rewards tied to project success such as project completion celebration and the opportunity to increase project responsibilities.

Empirical studies suggest that rewards can indeed motivate product development effort (e.g., Zenger and Lazzarini 2004).[3] It is also commonly accepted that larger rewards are needed to motivate effort on more challenging projects.[4] However, the effect of rewards in dynamics settings is more nuanced. A forward-looking employee's decision of whether to work and when to work will depend on the dynamics of the reward system, especially if his current effort affects his future earnings. There is empirical evidence that employees do engage in this type of strategic planning. For example, Misra and Nair (2011) find that salespeople shade current effort to convince the firm that sales quotas are difficult to attain (e.g., because of poor territory potential) so that the firm will lower its sales goals down the path. The mechanism in our paper can be similarly stated as the product development agent shirking current effort to convince the firm that success is difficult to reach (because of the low viability of the project) so that the firm will offer a more generous reward for success in the future.

The agent's dynamic incentive to shirk exacerbates the firm's payroll burden. The question is whether payroll cost is a first-order consideration for companies in managing new product development. The answer is yes for many. Companies participating in PDMA's 2012 survey list "total cost of new product effort" as one of the most important metrics to evaluate new product development projects, with best-practice companies putting significantly more emphasis on this metric than the rest (Markham and Lee 2013). In the Netherlands, the labor costs of research and development (R&D) personnel have drawn significant attention such that the government launched a policy instrument called WBSO, which allows companies to reduce development costs by receiving a tax credit for the wages of employees working on R&D projects.[5]

In short, the findings of this paper are relevant to companies who use rewards to motivate product development effort and who are interested in economizing the labor cost of product development. For these companies, we offer managerial recommendations on when to impose hard deadlines. We find that hard deadlines are more suitable if the agent's cost of effort is higher, if the firm's yield from success is lower, if the agent is more patient, if the firm is less patient, or if the prior belief of the project is more pessimistic. Interestingly, hard deadlines may be more useful when the agent is more productive. This is because delayed success, in spite of high productivity, signifies the project's pessimistic nature, which means the firm must offer a significant reward for success in the late stage of development to maintain the agent's incentive to work. Rewarding late success lavishly exacerbates the agent's tendency to procrastinate, and the firm will, in fact, be better off enforcing a hard deadline early on. On the basis of these findings, we discuss the applicability of hard deadlines to internal versus external agents, core versus ancillary products, cumulative development efforts, and successive development projects. We also discuss possible levers companies can use in place of hard deadlines.

2. Literature Review

Why do companies impose deadlines in the product development process? First, product development is

[3] In the sales domain, Chung et al. (2014) find that bonuses indeed enhance productivity.

[4] In the same survey described in Footnote 2, we asked each participant to evaluate the statement "the less likely the product is going to succeed, the greater incentives the company has to offer to motivate its product development workforce" on a five-point Likert scale, with 1 being "strongly disagree" and 5 being "strongly agree." As Figure A.1(c) of the appendix shows, participants tend to agree with this statement. The average response is 3.514, which is significantly higher than the neutral value of 3 ($t = 3.984$, $p = 0.00013$).

[5] See http://english.rvo.nl/subsidies-programmes/wbso-research-and-development-rd-tax-credit, accessed January 23, 2014.

often time sensitive. Deadlines signify that development must finish by natural stopping points such as the closing of the sales window (Cohen et al. 1996), a fixed launch date (Joglekar et al. 2001), or the end of the available time allocated to a specific development activity (Kerzner 2013). Second, product development may require teamwork. A deadline serves as a common focal point for all, which helps synchronize efforts and facilitate work flow (Kerzner 2013). Third, deadlines help mitigate product developers' tendency to procrastinate. Our model of deadlines focuses on the third effect. To abstract away from the first two effects, we will restrict attention to hard, "premature" deadlines that precede the end of the available time for development (to be defined in §3) and will focus on a single product development agent such that effort synchronization is irrelevant.

Past research has studied the source of procrastination and the value of deadlines in battling procrastination. O'Donoghue and Rabin (1999) posit that procrastination results from people's psychological tendency to overvalue current utilities. Ariely and Wertenbroch (2002) find that people recognize their self-control problems and try to combat them by committing to costly deadlines. Bonatti and Hörner (2011) study moral hazard among collaborators. They find that free riding generates procrastination—each contributor postpones his effort in the hope that others' efforts would suffice. Imposing a deadline is thus beneficial because it accelerates effort from the whole group.[6] Our paper focuses on a different mechanism underlying procrastination. We assume that the product development agent has no psychological bias or free-riding tendency. He shirks effort today to earn a lucrative reward for success tomorrow.

This paper also contributes to the literature on project termination decisions. Previous research has explored why some projects seem to stop too late. Reasons include project managers' excessive optimism (March and Shapira 1987), escalating commitment to chosen paths (Boulding et al. 1997), and ignorance of negative information (Biyalagorsky et al. 2006). Simester and Zhang (2010) find that bad products are hard to kill because managers have better knowledge about project quality. Rewarding managers for killing bad products weakens their incentive to work—they can always shirk effort, claim that the project is bad, and be rewarded. We share Simester and Zhang (2010)'s view that firms' trade-off between project returns and payroll costs affects their project termination decisions. Our paper complements this literature by asking when firms would find it optimal to terminate a project that is still worth continuing.[7]

Finally, this paper is related to the literature on dynamic moral hazard. Bergemann and Hege (2005) study the financing of innovative ventures and find that equilibrium funding stops too early compared with the first-best case in which the investor and entrepreneur are integrated. However, the authors do not focus on an investor's ex ante commitment to early withdrawal of funding. Funding stops too early because, compared with the first-best case, both the investor and entrepreneur incur opportunity costs of fund use, which raises the bar as to what is worth funding above the first-best level. The problem persists even if the investor observes the entrepreneur's fund use. By contrast, our model allows the firm to commit to early termination of product development with a hard deadline. The firm may endogenously choose to end the project prematurely after trading off the continuation value of the project and the excessive compensation to the agent. The commitment to premature termination becomes unnecessary once the firm observes the agent's effort choice. Moreover, as we will discuss later, in Bergemann and Hege (2005) the entrepreneur's need to attract future funding motivates appropriate use of current funding, whereas the agent's dynamic incentive generates the opposite effect in our paper—it exacerbates the agent's current moral hazard problem.[8]

3. Model Setup and Preliminary Analysis

3.1. Model Setup

We consider a firm who pays an agent to lead a product development project over a maximum of two

[6] Also in a team setting, Campbell et al. (2014) find that deadlines help motivate effort and reduce delays. In their paper, delays happen because of free riding and the lack of communication, as agents conceal their progress to maintain their partners' incentives to work hard.

[7] There is a large literature on product development. Previous research has investigated how firms' new product strategies interact with, for example, buyer self-selection (Moorthy 1984), product obsolescence (Levinthal and Purohit 1989), R&D and engineering metrics (Hauser 1998), distribution channel relationship (Villas-Boas 1998), demand uncertainty (Desai 2000), dynamic competition (Ofek and Sarvary 2003), network effects (Sun et al. 2004), firm alliances (Amaldoss and Rapoport 2005), idea generation (Toubia 2006), channel acceptance (Luo et al. 2007), subjective characteristics (Luo et al. 2008), sequential entry (Ofek and Turut 2008), reference group effects (Amaldoss and Jain 2010), innovation incentives (Manso 2011), and consumer deliberation (Guo and Zhang 2012). The incentive design aspect of this paper is also related to the literature on salesforce compensation (e.g., Basu et al. 1985, Lal and Staelin 1986, Rao 1990, Coughlan and Narasimhan 1992, Raju and Srinivasan 1996, Kalra et al. 2003, Lim et al. 2009, Simester and Zhang 2014).

[8] In a recent paper, Hörner and Samuelson (2013) explore the optimal funding of experiments when the experimenter can divert funds for his private use (similar to Bergemann and Hege 2005). The principal cannot commit to a deadline; it manages the dynamic agency cost by delaying the pace of experimentation.

periods.[9] The project must terminate by the end of the second period for exogenous reasons. For example, if the goal is to develop a new product that meets seasonal demand, development work must finish by the end of the season. A two-period model suffices to illustrate the mechanism of interest, although the same intuition applies to a model of longer horizons.[10]

In period t, where $t \in \{1, 2\}$, the outcome of the project is either success ($d_t = 1$) or the lack thereof ($d_t = 0$), which is observed by both the firm and the agent. Once success is achieved, the firm receives a lump-sum yield $Y > 0$ and closes the project. A *hard deadline* (hereafter referred to as *deadline* for brevity) in this context is defined as the commitment to terminating the project at the end of period one regardless of its development outcome. We will focus on the nontrivial case in which the deadline is premature; we will make parameter assumptions to ensure that the project is worth continuing into period 2 even if it has not succeeded in period 1. The firm makes the deadline decision at the beginning of the game. The agent observes this decision.

We assume that the firm is able to credibly commit to a hard deadline (see also Bonatti and Hörner 2011, Campbell et al. 2014). Without such commitment power, the firm will want to extend the project past the deadline given the aforementioned assumption about positive project continuation value, which renders the deadline a soft one that is never strictly enforced. Commitment can happen through various channels in practice. For example, the majority of today's companies use the Stage-Gate® system to organize the new product development process (Schmidt et al. 2009). Stages comprise development activities. Gates are checkpoints where the company evaluates projects and cancels those that fail to meet expectations. Each gate, often predetermined, serves as the deadline of the preceding stage.[11] For instance, the LEGO Group schedules specific calendar dates for its development gates (Robertson and Crawford 2008). These dates are published in company guidelines and are laborious to revise. In addition, product releases require complex coordination within a company and beyond. Postponing a project's deadline often causes tension with collaborators and customers. For instance, during Adobe's release of Creative Suite 3, the developer of Device Central was warned that this component was behind schedule and would be pulled from the launch (Thomas and Barley 2008). To the extent that it is sufficiently costly to miss a deadline, the deadline is credible.

The chance of success depends on two factors: the effort from the agent and the nature of the project. To simplify, we assume that the agent can choose to either work ($e_t = 1$) or shirk ($e_t = 0$) in each period, and the project can be either viable or unviable. If the agent shirks or if the project is unviable, the probability of success in that period is 0; if the agent works and if the project is viable, the probability of success is $a \in (0, 1)$. A larger a represents higher productivity of effort. For the main model we assume that the agent's product development effort is noncumulative across periods. We will extend the analysis to allow for cumulative effort in §5.2.

If the agent works, he incurs a per-period cost of $C > 0$. Whether the agent works is unobserved by the firm, which creates the standard moral hazard problem. To motivate the agent to work, the firm must pay the agent a reward if success is achieved. The main model focuses on short-term contracting, whereby in period t the firm pays the agent a reward R_t if success is achieved in this period. The focus on short-term contracts accommodates the possibility that the firm and the agent can renegotiate the wage contract during the product development process. (Section 5.1 shows that the firm cannot improve profits by committing to a long-term contract.) The agent enjoys an outside utility of zero and holds limited liability to the firm (Simester and Zhang 2010). Therefore, in period t the firm will optimally pay the agent a wage normalized to zero if success is not achieved.

The firm and the agent share the common prior belief that the project is viable with probability $\mu_0 \in (0, 1)$. In practical terms, this assumption suits the development of new products about which neither the firm nor the agent has superior prior knowledge. In theoretical terms, it is a conservative assumption for this model because any (off-equilibrium)

[9] The main model does not differentiate between internal and external agents. We also assume that workforce turnover is sufficiently costly, so that the firm retains the same agent throughout the project. We will discuss these issues in §4.4.

[10] We could, in theory, consider an infinite-horizon model. However, as we will discuss, beliefs about project viability decline over time as the agent works without achieving success. For any positive cost of effort, there exists an efficient project termination period t^*, beyond which the cost of effort outweighs the expected yield from the project and the beliefs about project viability can never improve. Therefore, we are essentially studying a finite-horizon problem, where the question becomes whether the firm will want to impose a deadline that occurs before time t^*.

[11] In other words, we can think of project development described in this model as corresponding to a stage and think of each period of the model as corresponding to a "sub-stage" (e.g., Ajam 2014). Typical stages include opportunity identification, preliminary marketing and technical assessment, development and testing, and commercialization (e.g., Schmidt et al. 2009). The development and testing stage best describes the product development activities studied in this paper, although the same idea applies to other stages. Also, the model can be extended to capture the entire Stage-Gate process, in which prior beliefs of product viability and the productivity of effort can vary across stages.

Table 1 Summary of Notations

Notation	Definition
Parameters	
a	Probability of success if the project is viable and if the agent works, $a \in (0, 1)$
C	Agent's cost of effort, $C > 0$
δ_A	Agent's discount factor, $\delta_A \in (0, 1)$
δ_F	Firm's discount factor, $\delta_F \in (0, 1)$
μ_0	Prior belief (i.e., perceived probability) that the project is viable, $\mu_0 \in (0, 1)$
Y	Firm's yield from success, $Y > 0$
Variables	
d_t	Indicator of whether success arrives in period t
e_t	Indicator of whether the agent incurs effort in period t
μ_t	Belief (i.e., perceived probability) at the end of period t that the project is viable
p	Firm's belief (i.e., perceived probability) that the agent has worked in period 1 if project has failed in period 1
Π	Firm's expected discounted profit
R_t	Agent's reward in period t if success is achieved in this period
U	Agent's expected discounted utility
V_A	Net present value of successive projects to the agent (§5.3)
V_F	Net present value of successive projects to the firm (§5.3)

divergence of beliefs between the firm and the agent can only arise endogenously.[12]

As the project progresses, beliefs about project viability evolve. In particular, at the end of each period, the firm and the agent commonly observe whether success has been achieved. The agent privately observes his effort and is able to form the correct belief about project viability. The firm does not observe the agent's effort and must form its belief about project viability based on its belief about the agent's effort decision (to be developed in §4.2).

Both the firm and the agent are risk neutral. Let Π denote the firm's expected discounted profit at the beginning of period 1, and similarly let U denote the agent's expected discounted utility. The firm and the agent's discount factors are δ_F and δ_A, respectively, where $0 < \delta_F, \delta_A < 1$. We allow these two discount factors to differ in order to identify their separate effects on the equilibrium. Table 1 summarizes the key notations of this paper. All parameter values are commonly observed by the firm and the agent.

The full sequence of moves unfolds as follows.

1. At the beginning of period 1, the firm decides whether to impose a deadline. The agent observes this decision.

2. The firm sets the reward R_1.

3. Observing the firm's reward offer R_1, the agent determines his effort level e_1.

4. If success is achieved in period 1, the game ends. The firm receives its return Y and the agent receives reward R_1. If success is not achieved and the firm has imposed a deadline, the game ends. The firm and the agent both receive zero payoff. If success is not achieved and the firm has not imposed a deadline, the game continues into period 2, which involves steps 5–7.

5. The firm sets the reward R_2.

6. Observing the firm's reward offer R_2, the agent determines his effort level e_2.

7. If success is achieved in period 2, the firm receives its return Y, and the agent receives his reward R_2. If success is not achieved, the firm and the agent both receive zero payoff. The game ends.

3.2. Equilibrium Concept

We derive the perfect Bayesian equilibrium of this dynamic game of imperfect information (Fudenberg and Tirole 1991). A perfect Bayesian equilibrium contains each player's strategy and each player's belief at each information set where the player has the move. Each strategy must be optimal given the player's belief at that information set and the other players' subsequent strategies. Beliefs on the equilibrium path are determined by Bayes' rule and equilibrium strategies. Moreover, beliefs off the equilibrium path are also determined by Bayes' rule and equilibrium strategies whenever applicable. The last requirement ensures that strictly dominated strategies off the equilibrium path are not credible threats.

The firm's strategy profile contains its deadline decision and the reward offer for each period. The agent's strategy profile contains his effort decision in each period. The only nonsingleton information set is the firm's information set when it gets to choose the reward R_2; the firm believes that the agent has worked in period 1 with probability $p \in [0, 1]$ and has shirked with probability $1 - p$. Therefore, for the subgame where the firm imposes a deadline, the perfect Bayesian equilibrium simply coincides with the subgame-perfect Nash equilibrium. For the subgame where the firm does not impose a deadline, however, the perfect Bayesian equilibrium depends on the firm's off-equilibrium belief of the agent's effort in period 1, which we will analyze in §4.2.

3.3. Evolution of Beliefs About Project Viability

We begin the analysis by describing the firm and the agent's posterior beliefs about project viability. If success is achieved in period $t \in \{1, 2\}$, the project is trivially proven to be viable; hence, $\mu_t = 1$. If success is not achieved, the posterior belief about the project's viability is updated following Bayes' rule, depending on whether the agent is believed to have worked during period t. For example, if the agent is believed to have worked in period t, then

$$\begin{aligned}\mu_t(d_t = 0, e_t = 1) &= \Pr(\text{viable} \mid d_t = 0, e_t = 1)\\ &= \big(\Pr(d_t = 0 \mid \text{viable}, e_t = 1)\Pr(\text{viable})\big)\end{aligned}$$

[12] See Desai and Srinivasan (1995) and Simester and Zhang (2010) for analyses of situations where moral hazard interacts with exogenous information asymmetry.

$$\cdot \big(\Pr(d_t = 0 \mid \text{viable}, e_t = 1)\Pr(\text{viable}) + \Pr(d_t = 0 \mid \text{unviable}, e_t = 1)\Pr(\text{unviable})\big)^{-1}$$
$$= \frac{(1-a)\mu_{t-1}}{(1-a)\mu_{t-1} + (1-\mu_{t-1})}$$
$$= \frac{(1-a)\mu_{t-1}}{1-\mu_{t-1}a}.$$

The posterior belief if the agent is believed to have shirked can be similarly derived. In particular, the updating of beliefs at the end of the first period is as follows:

$$\mu_1(d_1, e_1) = \begin{cases} 1 & \text{if } d_1 = 1, \\ \mu_0 & \text{if } d_1 = 0 \text{ and } e_1 = 0, \\ \dfrac{(1-a)\mu_0}{1-\mu_0 a} & \text{if } d_1 = 0 \text{ and } e_1 = 1. \end{cases} \tag{1}$$

Intuitively, failure conveys no information about the project's viability if the agent has shirked, because shirking alone renders success impossible. By contrast, failure in spite of effort raises doubt about the project's viability.

It is important to note that posterior beliefs about project viability, as specified above, depend on the *perceived* effort input. The agent privately observes his effort decision and is thus able to formulate the correct beliefs about project viability. On the other hand, the firm's beliefs about project viability depend on its beliefs about the agent's effort decision. In particular, when there is no deadline and the project has yielded no success by the end of period 1, the firm's belief about project viability depends on whether the lack of success is due to the agent's lack of effort or simply bad luck. If the firm believes that the agent has shirked, its belief about project viability remains as μ_0. If the firm believes that the agent has worked without success, its belief about project viability deteriorates to $\mu_1(d_1 = 0, e_1 = 1)$. For notational simplicity, we write this belief as μ_1^w (where w stands for for "work"):

$$\mu_1^w = \frac{(1-a)\mu_0}{1-\mu_0 a} < \mu_0. \tag{2}$$

3.4. First-Best Project Termination Decision

Before we derive the firm's optimal deadline decision, it is useful to establish the first-best project termination decision as a benchmark. We assume that the agent works for his own product development project, which eliminates the agency problem. The agent observes his own effort input and forms the correct beliefs about project viability. Since beliefs weakly deteriorate over time with the lack of success, if the prior belief μ_0 is already too pessimistic, the project is not worth starting in the first place. Specifically, if $\mu_0 aY \le C$, then the agent will trivially make no profit from the project. We define the following threshold of beliefs:

$$\hat{\mu} = \frac{C}{aY}. \tag{3}$$

We will focus on the nondegenerate parameter space in which $\mu_0 > \hat{\mu}$, such that it is efficient for the project to last for at least one period.

Note that the agent will want to work in the first period. He gains no payoff from the project and learns no information about the project's viability by shirking. If success has not arrived at the end of the first period, the agent updates his belief about project viability to μ_1^w, knowing that effort has been incurred in vain. If $\mu_1^w \le \hat{\mu}$, then the updated belief is so pessimistic that the project is not worth continuing into period 2. The more interesting case is the decision to impose a deadline at the end of period 1 even if the project has positive continuation value for period 2. Hence, for the rest of the analysis, we will restrict attention to the parameter space satisfying the following assumption.

Assumption. *It is efficient for the project to continue into period* 2 *even if the agent has worked without success in period* 1:

$$\mu_1^w > \hat{\mu}. \tag{4}$$

In other words, the project is sufficiently promising that it is not only worth pursuing but also worth two periods of effort in the first-best scenario. The question is why firms, back in the principle–agent framework, would commit to an inefficient, premature deadline at the end of period 1. We turn to this question next.

4. Firm's Deadline Decision

The firm's optimal deadline decision depends on its expected profit with versus without a deadline. We analyze these two subgames in order. This analysis yields conditions under which the firm should impose a deadline. We will discuss these findings in light of product development practice at the end of this section.

4.1. With a Deadline

Imposing a deadline reduces the interactions between the firm and agent to a simple one-period game. The firm offers reward R_1 and the agent in turn chooses whether to work. If the agent shirks, he derives no utility, and the firm earns no profit in this period. If the agent works, he earns an expected utility of $\mu_0 aR_1 - C$, and the firm earns an expected profit of $\mu_0 a(Y - R_1)$. Therefore, when there is a deadline, the optimal reward to induce the agent to work is[13]

$$R_1^d = \frac{C}{\mu_0 a}. \tag{5}$$

[13] In practice, the firm can offer a reward infinitesimally higher than R_1^d to ensure that the agent strictly prefers to work. The same is true for all reward offers in the rest of the paper.

We use the superscript d to denote optimal values in the subgame with a deadline. Similarly, we will use nd to denote optimal values in the subgame without a deadline.

With reward offer R_1^d, the firm earns an expected profit of $\mu_0 aY - C$ by inducing the agent to work. This profit is positive by assumption. As a result, when there is a deadline, the firm will indeed choose to motivate effort. In doing so, the firm earns an expected discounted profit of

$$\Pi^d = \mu_0 aY - C. \tag{6}$$

The firm allows the project only one period of effort and extracts the entire expected surplus associated with this effort without overcompensating the agent. However, by imposing a deadline, the firm also forfeits a positive continuation value left in the project. By condition (4), the deadline is premature because the project is still worth continuing at the end of the first period. Why, then, would the firm impose a deadline? We explore this issue next by examining the distortions that arise in the absence of a deadline.

4.2. Without a Deadline

Without a deadline, the interactions between the firm and the agent are more complex. What drives the complexity is the fact that the firm cannot observe the agent's effort in a dynamic setting. When the project reaches the end of the first period without success, the firm does not observe whether this is because the agent has worked without luck or has simply shirked. The firm forms its belief about the agent's effort decision in period 1. This belief determines the firm's reward offer—and the agent's payoff—in period 2. The anticipation of his period 2 payoff affects the agent's effort decision in period 1. The agent's effort decision in period 1, in turn, needs to be Bayesian-consistent with the firm's belief about this effort in equilibrium. In addition, a perfect Bayesian equilibrium requires that the agent's effort decision in period 1 also be Bayesian-consistent with the firm's belief off equilibrium, whenever applicable. This is a useful refinement. Specifically, it permits a credible portrait of the possible outcomes following any period 1 reward offer. After all, to establish the optimal period 1 reward (the firm gains nothing from randomizing this reward), we need to know what might happen following other possible rewards (i.e., the off-equilibrium path). We derive all perfect Bayesian equilibria of the subgame without a deadline and establish the following result (see the appendix for proof).

Lemma 1. *Without a deadline, to ensure that the agent works in period* 1, *the firm must offer a reward that overcompensates the agent for his cost of effort*:

$$R_1^{nd} = \frac{C}{\mu_0 a}\left[1 + \delta_A\left(\frac{\mu_0}{\mu_1^w} - 1\right)\right] > R_1^d. \tag{7}$$

The intuition is as follows. Since the agent can choose either to work or to shirk in period 1, observing the lack of success the agent's correct belief about project viability at the end of period 1 is either μ_1^w or μ_0, respectively. When period 2 begins, the firm thus chooses between offering a big reward $C/(\mu_1^w a)$ to motivate a more pessimistic agent with belief μ_1^w to work and offering a small reward $C/(\mu_0 a)$ to motivate a less pessimistic agent of belief μ_0. The firm will choose the big reward if it believes that the agent is more likely to have worked in period 1 ($p > \hat{p}$, where $\hat{p}$ is derived in the appendix) and a small reward if it believes the agent is more likely to have shirked ($p < \hat{p}$). The firm's period 2 reward offer, denoted by $R_2(p)$, is thus an increasing step function of its belief about the agent's period 1 effort.

The agent understands the firm's thinking when he chooses whether to work in period 1. If he chooses to work, he will earn a utility of zero in period 2 regardless of the firm's belief; the best he can receive is the big reward, which is just enough to make him want to work in period 2. Therefore, for any firm belief p, the agent's expected discounted utility from working in period 1 is

$$U(e_1 = 1; R_1, p) = \mu_0 a R_1 - C.$$

On the other hand, if the agent shirks in period 1, he will be willing to work in period 2 at either reward offer. Importantly, his expected discounted utility will depend on the firm's belief p:

$$U(e_1 = 0; R_1, p) = \delta_A[\mu_0 a R_2(p) - C],$$

where $R_2(p)$ captures the aforementioned effect of the firm's belief p on its period 2 reward offer.

The firm, in turn, understands the agent's thinking. By offering a sufficiently large reward of R_1^{nd}, the firm ensures that the agent will work in period 1 for all possible beliefs the firm might hold, including the equilibrium belief that the agent will indeed work in period 1 ($p = 1$). This reward overcompensates the agent for his cost of effort in the first period:

$$U(e_1 = 1; R_1^{nd}, p) = \delta_A\left(\frac{\mu_0}{\mu_1^w} - 1\right)C > 0. \tag{8}$$

We refer to the term $\delta_A(\mu_0/\mu_1^w - 1)C$ as a *dynamic rent* enjoyed by the agent. This dynamic rent reflects a combination of moral hazard and asymmetric information; by privately shirking in period 1, the agent gains an information rent in period 2 from his more accurate inference of project viability. As long as the firm believes that the agent is sufficiently likely to have worked in period 1, it will offer a generous reward in period 2 to motivate this likely pessimistic agent. However, the agent knows that the lack of success is attributed to his lack of effort, and therefore he maintains the private, more optimistic belief about the project. The combination of a generous reward and a disproportionately optimistic chance to earn this reward leads to a dynamic rent in period 2. This dynamic effect accentuates the moral hazard problem in period 1 as the firm must pay more than the cost of effort to induce the agent to work.[14]

Bergemann and Hege (2005) also study the issue of dynamic moral hazard but derive an opposite result. In their case, an entrepreneur (the agent) makes a take-it-or-leave-it offer to attract funding from an investor (the principal). If the entrepreneur deviates and diverts funding to his personal use, the unsuspecting investor will think that success has not been achieved in spite of proper use of funding. This pessimistic investor will thus demand a greater share in the project to be willing to continue funding, which makes deviation less attractive to the entrepreneur. In other words, the entrepreneur's dynamic incentives help discipline his fund usage in Bergemann and Hege (2005), whereas the agent's dynamic incentives exacerbate his moral hazard problem in our paper.

Since the firm incurs a dynamic rent, the question is whether the firm can do better by offering a smaller reward in period 1. An obvious option is to offer a sufficiently low reward $R_1 < C/(\mu_0 a)$. In this case, if the agent works in period 1, he will incur a net loss in this period because the reward is not even sufficient to cover his cost of effort. Moreover, he will earn a utility of zero in period 2 because the best he can receive is the big reward, which is just enough to cover his cost of effort in period 2. Therefore, the agent will shirk in period 1 for all possible beliefs the firm might hold, including the belief that the agent indeed shirks in period 1 ($p = 0$). The firm essentially postpones development for one period and gives the project only one shot of effort. This option is strictly dominated by the firm imposing a deadline, which generates the same expected profit, only sooner.

It remains to examine the "intermediate" range of first-period rewards $R_1 \in [C/(\mu_0 a), R_1^{nd})$. There are no pure-strategy perfect Bayesian equilibria in this case (see the appendix). Intuitively, if the firm is sufficiently confident that the agent has worked in period 1 ($p > \hat{p}$), it will offer a big reward in period 2. Compared with postponing effort to earn a big reward in period 2, the intermediate reward in period 1 is insufficient to motivate effort. The agent will then choose to shirk in period 1, which is inconsistent with the firm's belief $p > \hat{p}$. Similarly, if the firm is sufficiently doubtful that the agent has worked in period 1, it will offer a small reward in period 2, and the agent will then prefer to work in period 1, contrary to the firm's belief. Finally, when $p = \hat{p}$, there is a mixed-strategy equilibrium: the firm offers $R_1 = R_2 = C/(\mu_0 a)$, the agent randomizes between working and shirking in period 1, and the agent will work in period 2 if and only if he shirks in period 1. However, this is equivalent to exerting only one shot of effort at the project, with probabilistic delay into period 2. The firm can again do better by imposing a deadline.

These results suggest that any firm strategy that does not impose a deadline but offers a period 1 reward other than R_1^{nd} is off the equilibrium path. We state this finding below (see the appendix for proof).

Lemma 2. *Whenever the firm prefers not to impose a deadline, it will offer R_1^{nd} to ensure effort in period* 1.

It follows from Lemma 2 that, whenever the firm prefers not to impose a deadline, it will offer a period 2 reward big enough to motivate a pessimistic agent who worked in period 1 without success:

$$R_2^{nd} = \frac{C}{\mu_1^w a}. \tag{9}$$

The agent will work in both periods, and the firm will earn an expected discounted profit of

$$\Pi^{nd} = \underbrace{\mu_0 a Y - C}_{\Pi^d} - \underbrace{\delta_A \left(\frac{\mu_0}{\mu_1^w} - 1\right) C}_{\text{Dynamic rent}} + (1 - \mu_0 a)\delta_F \underbrace{(\mu_1^w a Y - C)}_{\text{Continuation value}}. \tag{10}$$

Comparing Π^{nd} with Π^d, we can see the costs and benefits of deadlines. By imposing a deadline, the firm loses the chance to earn a positive project continuation value in period 2 but avoids paying the agent a dynamic rent in period 1. Trading off these two factors determines whether the firm should impose a deadline. We turn to this comparison next.

[14] The mere fact that large rewards are required to motivate a pessimistic agent is insufficient to generate the dynamic rent. For the dynamic rent to arise, the agent also needs to have better information about how pessimistic he is. This happens as the firm and the agent attribute the lack of success to project viability versus effort in different ways. The agent's private knowledge of his effort allows him to make more accurate attribution. In a related paper, Miklós-Thal and Zhang (2013) study the implications of attribution in firm–consumer interactions. To the extent that consumers attribute product sales to marketing push versus product quality firms may benefit from conspicuously toning down their marketing intensity. The idea of attribution extends to signal jamming models in which hidden actions are taken to influence observable outcomes. For example, firms can make hidden investment in enhancing buyers' shopping experience (Iyer and Kuksov 2010) or offer unexpected frills in exchange for favorable customer ratings (Kuksov and Xie 2010). In equilibrium, however, consumers may still draw rational attribution of their quality perception to true product quality versus firms' hidden efforts.

4.3. When Should a Firm Impose a Deadline

In deciding whether to impose a deadline, the firm only needs to compare Π^d and Π^{nd}. Comparative statics of the relative value of the deadline $(\Pi^d - \Pi^{nd})$ reveal the following results.

If success is more valuable to the firm (higher Y), deadlines will be more wasteful. If effort is more costly to the agent (higher C), deadlines will help the firm save on a greater amount of reward payment. If the firm is more patient (higher δ_F), the continuation value of the project will loom more important than the payroll savings in period 1, making deadlines less attractive. If the agent is more patient (higher δ_A), he will demand a higher dynamic rent, which makes deadlines a better choice for the firm. These results are intuitive.

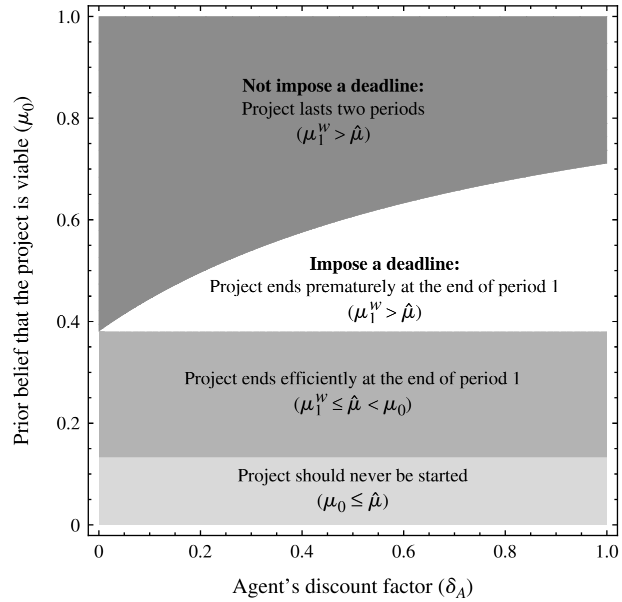
The effect of the prior belief (μ_0) is more subtle. A more pessimistic prior belief directly lowers the continuation value of the project. In addition, it also increases the dynamic rent paid to the agent if the firm does not impose a deadline. This is because, when the prior belief is already pessimistic, the lack of success is an especially bleak sign of project viability, and the firm will have to pay a steep reward to motivate effort in period 2, which in turn means the firm must pay a prohibitive dynamic rent in period 1 to prevent the agent from procrastinating. It is in the firm's best interest to impose a deadline in this case.

Last, when effort is productive (large a), it might appear that the project is worth continuing. However, the more productive the effort, the stronger the lack of success as a sign of low product viability (lower μ_1^w). This pessimistic belief again implies expensive reward offers in both periods, unless the firm imposes a deadline. Therefore, counterintuitive as it sounds, the firm may find deadlines more profitable when effort is more productive. The following proposition summarizes the comparative statics results (see the appendix for proof).

Proposition 1. *The relative value of deadlines decreases with the firm's yield from success (Y) and degree of patience (δ_F), increases with the agent's cost of effort (C) and degree of patience (δ_A), decreases with the prior belief that the project is viable (μ_0), and increases with the productivity of effort (a) when effort is sufficiently productive.*

Finally, we prove the existence of the equilibrium in which the firm chooses to impose a deadline. One example suffices, and we present such an example in Figure 1. Since the relative value of deadlines decreases with firm patience, the figure conservatively sets $\delta_F \to 1$. For completeness, the figure includes the degenerate area in which the prior belief about project viability is so poor that the project is never worth starting ($\mu_0 \le \hat{\mu}$), and the area in which the prior belief is better but not great so that it is efficient to terminate the product at the end of the first period ($\mu_1^w \le \hat{\mu} < \mu_0$). These are the areas ruled out by condition (4).

Figure 1 **A Patient Firm's Equilibrium Deadline Decision**



Note. This figure sets parameter values to $\delta_F \to 1$, $Y/C = 10$, $a = 0.75$.

With better prior beliefs, the project has positive continuation value for the second period ($\mu_1^w > \hat{\mu}$). However, there exists a parameter range in which imposing a deadline turns out to be the optimal firm strategy. This parameter range grows with the agent's discount factor, consistent with Proposition 1. Note that the firm may adopt a deadline even though its own discount factor approaches 1. In other words, a firm's seemingly impatient use of deadlines is not a mere reflection of time discounting but a result of trading off product development returns with payroll costs. The following proposition states this result formally (proof holds by construction).

Proposition 2. *There exist parameter values under which it is more profitable for a firm to impose a deadline, even though the project is worth continuing past the deadline.*

4.4. Discussion

So far we have presented an agency-theoretic model of deadlines in product development. The analysis yields conditions under which deadlines benefit firms and explains why deadlines can be beneficial. Understanding the mechanism of deadlines also sheds light on alternative ways to manage product development efforts in place of deadlines. We discuss these findings in this section.

4.4.1. Internal vs. External Agents. More and more companies have been outsourcing new product development responsibilities to external agents

(Raassens et al. 2012). This is not surprising, as outsourcing brings in additional labor, fresh ideas, and new expertise (Kahn 2012). Some companies also believe that outsourcing saves on labor costs (Marion and Friar 2012), which in our model would mean less need for deadlines. But there is a countervailing effect. Physical separation makes it difficult for companies to witness external developers' daily activities and prevent potential "opportunist behaviors" (Williamson 2008). In the context of our model, the inability to observe the agent's effort is the source of inefficiency—it allows the agent to form better inference about project viability and extract an information rent. If effort is observable, the firm will be able to restore the first-best project termination decision. For internal employees, monitoring technologies can, in fact, serve as a substitute for deadlines (see also Holmström 1979). The same level of monitoring is hardly applicable to external agents, which escalates payroll costs unless the firm imposes deadlines. Indeed, a survey by Deloitte Consulting (2005) indicates that 44% of participating companies "did not see cost savings materializing" from outsourcing and that 62% found that outsourcing required more management efforts than expected. This finding highlights the importance of using deadlines to manage external development efforts, although outsourcing is traditionally associated with relinquishing control.

4.4.2. Core vs. Ancillary Products. Imposing deadlines would be too wasteful if the firm has a lot to gain from successful product development, which may come from the high commercial value of an invention, first-mover advantage in a new product category, or the image of an innovative and dependable brand. To the point that core products are more likely to serve these central values than ancillary products, we would expect firms to impose deadlines less often for core products or set nominal soft deadlines such that core product development continues after its due date. One example is Boeing's 787 Dreamliner (Healy 2009). Development underwent numerous delays. When the first Dreamliner was delivered to All Nippon Airways in 2011, it was more than three years behind schedule. The core significance of this new aircraft to Boeing makes it unrealistic to implement a hard deadline.

4.4.3. Hire Short-Term Developers. Besides monitoring, another alternative to deadlines is to hire product development personnel on a short-term basis. Even if the agent recruited for the late stage of development observes the unsuccessful past of the project and requires a large reward, this reward does not undermine the work incentive of the agent hired for the early stage. In other words, the value of restaffing is not to conceal pessimism but to prevent the agent from gaming this pessimism to obtain a dynamic rent. Indeed, Marion and Friar (2012) find that hiring contract employees on a short-term basis reduces monthly cash drain compared with hiring full-time employees. The downside is that labor turnover is often costly (e.g., Bentolila and Bertola 1990). Companies should then weigh the savings in payroll costs against the restaffing cost. Recall that the dynamic rent increases with the productivity of the agent; failure in spite of productive effort is a particularly alarming signal about project viability, which means the firm must provide a significant reward to motivate continued effort. The prospect of earning this dynamic rent weakens effort incentives during early development, especially when the agent is forward-looking. As a result, counterintuitive as it sounds, companies may want to accelerate workforce turnover if the workforce is more productive and more long-term oriented—characteristics that are conventionally associated with employees who are worth retaining.

5. Extensions

We have presented the key mechanism underlying the effect of deadlines in the main model. In this section, we will relax a set of assumptions made in the main analysis. In doing so, we ask whether alternative market features present the firm with new challenges and new opportunities in managing product development efforts.

5.1. Long-Term Contracts

The main model assumes that the firm offers short-term contracts. These contracts are time-consistent and renegotiation-proof (see also Bergemann and Hege 2005). It remains to explore whether the firm could do better by committing to a long-term contract at the onset of product development. In the context of the two-period model, this long-term contract consists of a reward pair (R_1^L, R_2^L) if success is achieved in period 1 or 2, respectively (L for "long term"). If success is not achieved, the optimal reward continues to be zero. The perfect Bayesian equilibrium in this case coincides with the subgame-perfect equilibrium.[15]

If the firm intends to induce only one shot of effort, it would prefer effort to occur in period 1; otherwise, it gains no return from the project in period 1 and learns nothing new about it. It follows that the optimal long-term contract is $(R_1^L = C/(\mu_0 a), R_2^L < C/(\mu_0 a))$, which achieves equivalent outcomes as short-term contracting with a deadline.

[15] Since the firm commits to the long-term contract, a flexible reward pair weakly dominates a constant reward that is paid upon success. Meanwhile, imposing a deadline can be seen as a long-term contract where the firm commits to paying $R_2^L = 0$.

It remains to examine the scenario in which the firm intends to motivate effort over both periods. If the agent has worked in period 1 without achieving success, to motivate effort in period 2, the firm must ensure that $R_2^L \geq C/(\mu_1^w a) = R_2^{nd}$. But R_2^{nd} is the optimal short-term reward that induces the agent to work in period 2 after failing in period 1; regardless of the contract horizon, the firm must offer a large reward to motivate a genuinely pessimistic agent to exert effort in period 2. Now consider the agent's decision in period 1. He earns a discounted expected utility of $\mu_0 a R_1^L - C + \delta_A(1-\mu_0 a)(\mu_1^w a R_2^L - C)$ if he works and $\delta_A(\mu_0 a R_2^L - C)$ if he shirks. A higher R_2^L increases the relative utility of shirking and makes effort more expensive to induce in period 1. It follows that the firm will minimize R_2^L as long as it is sufficient to induce effort in period 2. The optimal long-term contract is thus derived as

$$(R_1^L = R_1^{nd},\ R_2^L = R_2^{nd}). \tag{11}$$

The optimal long-term contract to induce two periods of effort coincides with the optimal short-term contract in the absence of a deadline. The intuition is as follows. A long-term contract benefits the firm if it makes effort less expensive to induce by reallocating the agent's rents over time. In the case of short-term contracts without a deadline, the agent earns no rents in period 2 but a positive dynamic rent in period 1. The only reallocation a long-term contract could achieve in this case—while maintaining effort incentive in period 2—is to allocate more rent for period 2, but that only serves to exacerbate the agent's procrastination tendency. Therefore, the firm cannot improve profits through long-term contracts in this setting. We summarize this result with the following proposition (proof holds by construction).

Proposition 3. *Optimal short-term and long-term contracts generate identical outcomes for the product development setting analyzed in this paper.*

Comparing R_1^L and R_2^L suggests that the agent receives a larger bonus if he achieves success later. This finding is counterintuitive because companies would normally want to reward early success and penalize late completion.[16] The reason is that the agent, having worked in period 1 to no avail, feels more pessimistic about the project in period 2 and needs greater incentives to be willing to work. This result echoes real-world observations where companies have to increase budgets to maintain development efforts on (nearly) failing projects. RCA kept escalating investment into SelectaVision over a prolonged development of 14 years. When the product was finally terminated, it had cost the company \$580 million (Royer 2003). Ford's Edsel, having posted a loss of \$250 million, continued for another two and half years, at an additional cost of \$200 million (Whyte 1991). A strict deadline might have alleviated these costs.

[16] The firm can commit to a reward for early completion. Given the limited liability constraint, the firm can also commit to a "penalty" for late completion in the form of a small, nonnegative payment. By definition, these arrangements are weakly dominated by the optimal long-term contract.

5.2. Cumulative Effort

In some product categories, the agent's effort becomes more productive as product development progresses. To capture this effect, we extend the main model by assuming that, if the project is viable, the chance of success is a on the agent's first trial and is $a' > a$ on his second. That is, the agent will enjoy a higher productivity of a' in period 2 if and only if he has worked in period 1. The value of a' is common knowledge.

The cumulative nature of effort makes deadlines less valuable to the firm. With a deadline, the firm earns Π^d, the same expected total profit as in the main model; without a deadline, it earns a higher expected total profit than Π^{nd} for two reasons. First, the continuation value for the second period, $\mu_1^w a' Y - C$, is higher than if effort were noncumulative. Second, the dynamic rent is lower. To see the latter effect, note that the optimal reward to induce a second period of effort is $C/(\mu_1^w a')$. This reward is lower than R_2^{nd} of the main model because the agent is now more productive. The reduction in period 2 reward dampens the agent's shirking incentive in period 1. Moreover, shirking in period 1 prevents the agent from growing his productivity, which limits his chance of earning the reward in period 2. Indeed, following the logic of the main model, we can derive the agent's dynamic rent as

$$\delta_A \max\left[0, \left(\frac{\mu_0 a}{\mu_1^w a'} - 1\right) C\right]. \tag{12}$$

This dynamic rent is lower than its counterpart in the main model since $a' > a$. As a result, the firm earns a higher expected total profit by abandoning the deadline. The following proposition states the result (proof holds by construction).

Proposition 4. *The value of deadlines decreases if product development effort is cumulative.*

This result expands the paper's managerial recommendations regarding the applicability of deadlines. Product development effort can carry over to the future for various reasons. First, product development may involve learning-by-doing in some industries, such as software development. Also, when the product is new to the market or the development staff new to the product, development proficiency grows through experience. Second, when there are a relatively small number of product development options, identifying the poor options increases the chance of finding the right solution (if there is one). For example, the Stage-Gate model of product development screens ideas successively down the development funnel, such that there are fewer development options in later stages than in earlier stages. Proposition 4 implies that, other things being equal, companies may want to enforce hard deadlines in earlier stages of development and allow for a more lenient schedule in later stages. Along the same line of reasoning, in product categories where development has to navigate a large set of possible options—the pharmaceutical industry being a good example—eliminating poor options does not significantly improve the odds of success. Deadlines will be worth considering in these categories. Indeed, pharmaceutical companies face the decision to kill drugs with further investigative potential almost on a daily basis, even going as far as developing the Quick-Kill model to ensure that projects are being frequently eliminated.

5.3. Successive Products

In the main model, the game ends once product development yields success. In practice, however, the firm may be able to start another product upon finishing. This creates an opportunity cost of time for both the firm and the agent. The firm may have the extra incentive to impose a deadline and move fast. At the same time, the opportunity to work on future products induces the agent to finish the current project earlier, an extra motivation that makes deadlines less necessary.

To examine these effects, we extend the main model into an infinite horizon. Each product development project can again last at most two periods for exogenous reasons such as seasonality of demand. However, the firm can assign the agent to a new project once the current project succeeds, hits the deadline, or exhausts its two-period development window. By the same argument of the main model, the firm will prefer the agent to embark on the new project without further delay.[17] We focus on the steady state in which the stream of projects are ex ante identical and the firm maintains the same deadline policy among these projects.

Let V_A and V_F be the steady-state net present value of the stream of successive projects to the agent and the firm, respectively. The availability of future projects does not change the agent's work incentives if the firm imposes a deadline. If he works, he earns an expected utility of $\mu_0 a\bar{R}_1 - C + \delta_A V_A^d$, where we use the upper bar to denote reward offers in this extension. If he shirks, he earns $\delta_A V_A^d$. In both cases, the agent knows that regardless of development outcome he will start on a new project in the following period and earn a discounted net present value of $\delta_A V_A^d$, where d again denotes optimal values if the firm imposes a deadline. The firm's optimal reward offer is thus $\bar{R}_1^d = C/(\mu_0 a)$, which is the same as in the main model. The agent earns an expected surplus of zero from each project, which leads to a net present value of $V_A^d = 0$. This is consistent with the result of the main model that deadlines help the firm eliminate the agent's dynamic rent. The firm, as a result, captures a net present value of $V_F^d = (\mu_0 aY - C)/(1-\delta_F)$.

If the firm does not impose a deadline, how does the availability of future projects change the agent's work incentives? The dynamic rent again arises, because the agent's private information about his effort input leads to better inference about project viability. However, the prospect of earning a dynamic rent on future projects motivates the agent to finish sooner, which serves to mitigate the dynamic rent on the current project.

Following the logic of the main model, we can show that the firm will offer a big reward $C/(\mu_1^w a)$ in period 2 of each project if it is sufficiently confident that the agent has worked in period 1; it will offer a small reward $C/(\mu_0 a)$ if it is sufficiently doubtful. The agent's expected discounted utility from working in period 1 is

$$U(e_1=1;\bar{R}_1,p)=\mu_0 a(\bar{R}_1+\delta_A V_A^{nd})-C+(1-\mu_0 a)\delta_A^2 V_A^{nd}.$$

He knows that, if he works in period 1, he will succeed and start on a new project in period 2 with probability $\mu_0 a$; he will continue working on the same project in period 2 and begin a new one in period 3 with probability $1-\mu_0 a$. The discounted net present values of future projects are $\delta_A V_A^{nd}$ and $\delta_A^2 V_A^{nd}$ for these two scenarios, respectively, where nd denotes optimal values without deadlines. Similarly, the agent's expected discounted utility from shirking in period 1 is

$$U(e_1=0;\bar{R}_1,p)=\delta_A[\mu_0 a\bar{R}_2(p)-C+\delta_A V_A^{nd}].$$

Again, whenever the firm prefers not to impose a deadline, it should offer a sufficiently generous reward $\bar{R}_1^{nd}$ in period 1 to ensure effort. The agent's expected discounted utility given this reward in turn equals his steady-state net present value of incoming projects, such that $U(e_1=1;\bar{R}_1^{nd},p) = U(e_1=0;\bar{R}_1^{nd},p=1)=V_A^{nd}$. From this system of equations, we derive the agent's net present value of successive projects as

$$V_A^{nd}=\frac{\delta_A}{1-\delta_A^2}\left(\frac{\mu_0}{\mu_1^w}-1\right)C>0. \tag{13}$$

[17] The firm could motivate effort by, for example, threatening to delay the new project if the current project finishes in failure. However, such arrangements are not time-consistent.

This net present value is positive because of the dynamic rent. However, the prospect of accelerating future projects motivates the agent to work in period one of each project at a lower reward than in the main model:

$$\bar{R}_1^{nd} = R_1^{nd} - \frac{\delta_A^2}{1+\delta_A}\left(\frac{\mu_0}{\mu_1^w} - 1\right)C < R_1^{nd}. \tag{14}$$

The firm will motivate effort in period 2 of each project by offering $\bar{R}_2^{nd} = C/(\mu_1^w a) = R_2^{nd}$. These reward choices affect the firm's net present value from a stream of successive products in the absence of a deadline: V_F^{nd}. Weighing V_F^{nd} and V_F^d, the firm determines whether to impose a deadline. We analyze this decision and compare it with the firm's deadline choice in the main model. We establish the following result (see the appendix for proof).

Proposition 5. *When there is a stream of successive product development projects, the relative value of deadlines compared with that in the case of a stand-alone project (e.g., the main model) decreases with the agent's degree of patience* (δ_A).

Recall that Proposition 1 states that the value of deadlines for stand-alone projects *increases* with the agent's degree of patience. This is because, in the absence of a deadline, a patient agent needs to be offered a greater dynamic rent to be willing to work. The seemingly opposite result obtained in Proposition 5 actually captures the same underlying impact of the dynamic rent on the firm's deadline decisions. When there is a stream of product development opportunities, a patient agent values the option of working on future projects, which motivates him to work harder today in the hopes of early completion. This extra motivation to work allows the firm to pay the agent a smaller dynamic rent (we have shown that $\bar{R}_1^{nd} < R_1^{nd}$), an effect that mitigate the firm's reliance on deadlines to reduce its payroll costs.[18]

6. Concluding Remarks

Deadlines are commonly used in the product development process, although many projects are still worth continuing when the deadline hits. This paper offers an agency-theoretic account of harsh deadlines. The explanation centers on firms' trade-off between the return from a project and the labor cost of this project. As the project proceeds without success, the firm and the agent become more pessimistic about the project's inherent viability. The firm must sufficiently reward late success to motivate continued development effort. However, rewarding late success in turn undermines the agent's effort incentive during the early stage of development. A deadline benefits the firm by eliminating the agent's dynamic incentives to procrastinate. Table 2 summarizes the managerial recommendations of the paper.

This paper serves to highlight the impact of agency problems on product development. There are a number of ways to extend this line of research. One direction is to explore the optimal division of effort among a portfolio of product development projects, as well as its interaction with the design of deadlines. Another important extension is to consider a stream of heterogeneous development projects. It is nontrivial to decide how to schedule these projects and how much development time to assign to each project. Last but not least, agents may privately observe the productivity of their efforts. The firm's screening incentive and the agent's reputation concerns can both generate interesting dynamics.

Table 2 **Summary of Managerial Recommendations**

- Main takeaway: Deadlines can improve firm profit from product development
- Deadlines are worth considering when
  - agent's cost of effort is high
  - firm's yield from success is low
  - agent is patient
  - firm is impatient
  - prior belief of the project is pessimistic
  - agent is productive
  - effort is noncumulative
- Other strategies to consider
  - monitor effort
  - hire agents on a short-term basis
  - use future projects to motivate current effort

Acknowledgments

The author has received helpful comments from Alessandro Bonatti, Ganesh Iyer, Dmitri Kuksov, Lan Luo, Jeanine Miklós-Thal, Harikesh Nair, Elie Ofek, Ram Rao, Mengze Shi, Matthew Shum, Raphael Thomadsen, J. Miguel Villas-Boas, and Hema Yoganarasimhan and from attendees of the 2012 Frank M. Bass UT Dallas FORMS Conference, the 2012 INFORMS Marketing Science Conference, and the 2012 Summer Institute in Competitive Strategy. The author thanks the department editor, associate editor, and two anonymous reviewers for their support of this study and their constructive feedback.

Appendix

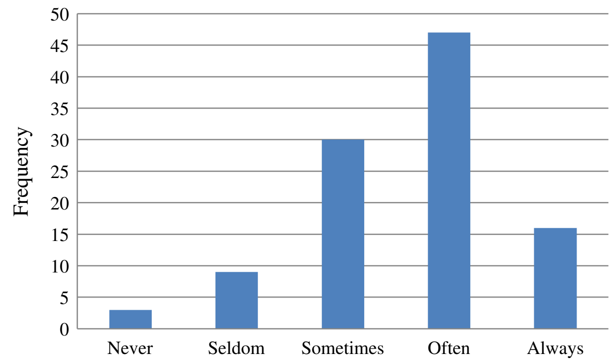
A.1. Proof of Lemma 1

Consider the only nonsingleton information set, the one at which the firm gets to set period 2 reward R_2. The project

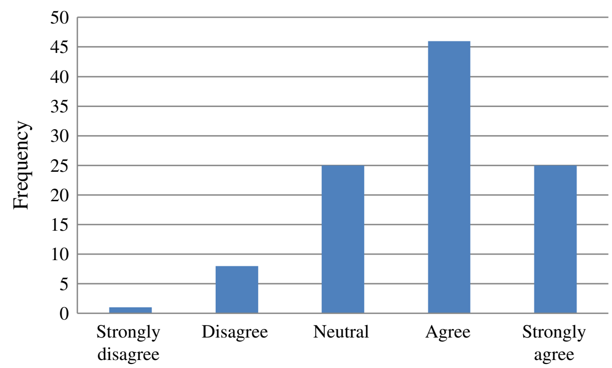
[18] The effect of firm patience on the relative value of deadlines is ambiguous. The more forward-looking a firm is, the more it values its future projects. Imposing deadlines allows the firm to expedite development. However, if the availability of future projects saves the firm enough payoff costs, deadlines become less useful compared with the main model. In this case, the more forward-looking a firm is, the more it has to gain from future projects without deadlines (see the appendix for details).

Figure A.1 (Color online) Deadlines in Product Development—A Survey

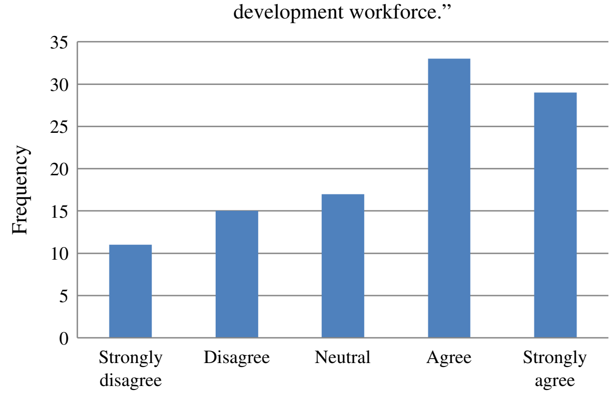
(a) "The company I work(ed) with enforces hard deadlines in the product development process."



(b) "Some of the products are still worth continuing at the time of the deadline."



(c) "The less likely the product is going to succeed, the greater incentives the company has to offer to motivate its product development workforce."



has just failed in period 1. The firm must assign a probability distribution over this information set: it believes that the agent has worked in period 1 ($e_1 = 1$) with probability $p \in [0, 1]$ and shirked ($e_1 = 0$) with probability $1 - p$. This, in turn, determines the firm's belief about the agent's private, correct belief about project viability at the end of the unsuccessful period 1: the firm believes that it is μ_1^w with probability p and μ_0 with probability $1 - p$.

By working in period 2, the agent earns an expected utility of $\mu_1^w a R_2 - C$ if he worked in period 1 without success and $\mu_0 a R_2 - C$ if he shirked. By shirking in period 2, the agent earns a utility of zero. It follows that in period 2 the firm can choose between offering a "high reward" R_2^h that is just sufficient to motivate an agent with belief μ_1^w to work and offering a "low reward" R_2^l that is just sufficient to motivate a more optimistic agent with belief μ_0 to work:

$$R_2^h = \frac{C}{\mu_1^w a}, \tag{15}$$

$$R_2^l = \frac{C}{\mu_0 a}. \tag{16}$$

Any other reward levels in period 2 are suboptimal.

Which reward the firm will offer in period 2 depends on p, its belief about the agent's effort in period 1. If the firm offers the high reward, the agent will be willing to work in period 2 regardless of his belief about project viability, and the firm will earn an expected period 2 profit (denoted as Π_2) of

$$\Pi_2(R_2^h; p) = p\mu_1^w a(Y - R_2^h) + (1-p)\mu_0 a(Y - R_2^h).$$

If the firm offers the low reward in period 2, the agent will only be willing to work if he shirked in period 1, and the firm will earn an expected period 2 profit of

$$\Pi_2(R_2^l; p) = (1-p)\mu_0 a(Y - R_2^l).$$

Equating $\Pi_2(R_2^h; p)$ with $\Pi_2(R_2^l; p)$ yields

$$\hat{p} = \frac{\mu_0(R_2^h - R_2^l)}{\mu_1^w(Y - R_2^h) + \mu_0(R_2^h - R_2^l)} \in (0, 1). \tag{17}$$

Comparing $\Pi_2(R_2^h; p)$ and $\Pi_2(R_2^l; p)$, the firm's optimal period 2 reward offer is

$$R_2(p) = \begin{cases} R_2^h & \text{if } p > \hat{p}, \\ R_2^l & \text{if } p < \hat{p}, \\ R_2^h \text{ with prob } q, R_2^l \text{ with prob } 1-q & \text{if } p = \hat{p}, \end{cases} \tag{18}$$

where $q \in [0, 1]$ captures the firm's indifference between R_2^h and R_2^l when $p = \hat{p}$.

Now consider the first period of the game. The firm offers R_1 and the agents chooses e_1. By working in period 1, the agent earns an expected discounted utility of

$$U(e_1 = 1; R_1, p) = \mu_0 a R_1 - C + (1 - \mu_0 a)\delta_A \max[0, \mu_1^w a R_2(p) - C].$$

The term $\max[0, \mu_1^w a R_2(p) - C]$ captures the agent's option to not work in period 2. However, this term equals 0. If the agent works in period 1, then in period 2 he either faces the low reward and chooses to shirk or faces the high reward and is just willing to work. In both cases, the agent expects zero utility in period 2. Therefore, the agent's expected discounted utility from working in period 1 does not depend on the firm's belief p:

$$U(e_1 = 1; R_1, p) = \mu_0 a R_1 - C. \tag{19}$$

On the other hand, the agent's expected discounted utility from shirking in period 1 is

$$U(e_1 = 0; R_1, p) = \delta_A \max[0, \mu_0 a R_2(p) - C].$$

The term $\max[0, \mu_0 a R_2(p) - C]$ equals $\mu_0 a R_2(p) - C$ because, if the agent shirks in period 1, he is always willing to work in period 2 even at the low reward. His period 2 utility depends on $R_2(p)$, which is given in Equation (18). Therefore, the agent's expected discounted utility from shirking in period 1 does depend on the firm's belief p:

$$U(e_1 = 0; R_1, p) = \delta_A[\mu_0 a R_2(p) - C]. \tag{20}$$

Now consider the firm's first-period reward offer R_1. There are three possible cases.

I. $R_1 \geq [C/(\mu_0 a)][1 + \delta_A(\mu_0/\mu_1^w - 1)]$.

In this case, $U(e_1 = 1; R_1, p) \geq U(e_1 = 0; R_1, p)$ for any p. The agent will work in period 1 for certain, and the only consistent belief is $p = 1$. It follows that the firm will offer $R_2 = R_2^h$ in period 2. By choosing R_1 in this range, the firm earns an expected discounted profit of $\Pi^{\mathrm{I}}(R_1) = \mu_0 a \cdot (Y - R_1) + (1 - \mu_0 a)\delta_F \mu_1^w a(Y - R_2^h)$. Therefore, the firm's dominant choice of period 1 reward in this case, denoted as R_1^{I}, is

$$R_1^{\mathrm{I}} = \frac{C}{\mu_0 a}\left[1 + \delta_A\left(\frac{\mu_0}{\mu_1^w} - 1\right)\right]. \tag{21}$$

This establishes a perfect Bayesian equilibrium for the subgame without a deadline:

$$\{R_1 = R_1^{\mathrm{I}}, e_1 = 1, R_2 = R_2^h, e_2 = 1, p = 1\}. \tag{22}$$

II. $R_1 < C/(\mu_0 a)$.

In this case, $U(e_1 = 1; R_1, p) < U(e_1 = 0; R_1, p)$ for any p. The agent will shirk in period 1 for certain, and the only consistent belief is $p = 0$. It follows that the firm will offer $R_2 = R_2^l$ in period 2. This establishes a set of perfect Bayesian equilibria for the subgame without a deadline:

$$\left\{R_1 < \frac{C}{\mu_0 a}, e_1 = 0, R_2 = R_2^l, e_2 = 1, p = 0\right\}. \tag{23}$$

III. $C/(\mu_0 a) \leq R_1 < [C/(\mu_0 a)][1 + \delta_A(\mu_0/\mu_1^w - 1)]$.

We will show that no pure-strategy equilibrium exists in this case. There are three subscenarios:

- If $p > \hat{p}$, the firm will offer $R_2 = R_2^h$. It follows that $U(e_1 = 1; R_1, p > \hat{p}) < U(e_1 = 0; R_1, p > \hat{p})$ because $R_1 < [C/(\mu_0 a)][1 + \delta_A(\mu_0/\mu_1^w - 1)]$. Therefore, the agent will shirk in period 1 for certain, which is inconsistent with the belief $p > \hat{p}$.
- If $p < \hat{p}$, the firm will offer $R_2 = R_2^l$. It follows that $U(e_1 = 1; R_1, p < \hat{p}) \geq U(e_1 = 0; R_1, p < \hat{p})$ because $R_1 \geq C/(\mu_0 a)$. Therefore, the agent will work in period 1 for certain, which is inconsistent with the belief $p < \hat{p}$.
- If $p = \hat{p}$, the firm will offer $R_2 = R_2^h$ with probability q and offer $R_2 = R_2^l$ with probability $1 - q$. It follows that $U(e_1 = 0; R_1, p = \hat{p}) = \delta_A q(\mu_0 a R_2^h - C)$. The agent's indifference between working and shirking in period 1 requires $U(e_1 = 1; R_1, p = \hat{p}) = U(e_1 = 0; R_1, p = \hat{p})$, which yields

$$q^*(R_1) = \frac{\mu_0 a R_1 - C}{\delta_A(\mu_0 a R_2^h - C)}.$$

By offering R_1, the firm earns an expected discounted profit of

$$\Pi^{\mathrm{III}}(R_1) = \hat{p}\big[\mu_0 a(Y - R_1) + (1 - \mu_0 a)\delta_F q^*(R_1)\mu_1^w a(Y - R_2^h)\big] + (1 - \hat{p})\delta_F \mu_0 a\big[Y - q^*(R_1)R_2^h - (1 - q^*(R_1))R_2^l\big].$$

Rearranging terms shows that $d\Pi^{\mathrm{III}}(R_1)/dR_1 < 0$. Therefore, the firm's dominant choice of period 1 reward is $R_1 = C/(\mu_0 a)$. It follows that $q^* = 0$ so that $R_2 = R_2^l$. This establishes a perfect Bayesian equilibrium for the subgame without a deadline:

$$\left\{\begin{array}{ll} R_1 = \dfrac{C}{\mu_0 a}, & e_1 = \begin{cases} 1 & \text{with prob } \hat{p}, \\ 0 & \text{with prob } 1 - \hat{p}, \end{cases} \\ R_2 = R_2^l, & e_2 = \begin{cases} 1 & \text{if } e_1 = 0, \\ 0 & \text{if } e_1 = 1, \end{cases} \quad p = \hat{p} \end{array}\right\}. \tag{24}$$

In summary, (22)–(24) are all perfect Bayesian equilibria of the subgame without a deadline, among which (22) is the unique perfect Bayesian equilibrium that ensures first-period effort (that is, $e_1 = 1$ with probability 1) in the subgame without a deadline. □

A.2. Proof of Lemma 2

The proof of Lemma 1 identifies all perfect Bayesian equilibria of the subgame without a deadline, given by (22)–(24). The firm's corresponding expected discounted profits are

$$\Pi^{\mathrm{I}} = \mu_0 a(Y - R_1^{\mathrm{I}}) + (1 - \mu_0 a)\delta_F \mu_1^w a(Y - R_2^h), \tag{25}$$

$$\Pi^{\mathrm{II}} = \delta_F \mu_0 a(Y - R_2^l), \tag{26}$$

$$\Pi^{\mathrm{III}} = [\hat{p} + (1 - \hat{p})\delta_F]\mu_0 a(Y - R_2^l). \tag{27}$$

The firm's expected discounted profit from imposing a deadline is Π^d, as given in Equation (6). It is easy to see that $\Pi^d > \max(\Pi^{\mathrm{II}}, \Pi^{\mathrm{III}})$. If $\Pi^d > \max(\Pi^{\mathrm{I}}, \Pi^{\mathrm{II}}, \Pi^{\mathrm{III}})$, the firm will impose a deadline. If $\Pi^d \leq \max(\Pi^{\mathrm{I}}, \Pi^{\mathrm{II}}, \Pi^{\mathrm{III}})$, it must be that $\Pi^{\mathrm{I}} > \max(\Pi^{\mathrm{II}}, \Pi^{\mathrm{III}})$ so that the firm will not impose a deadline but will choose $R_1 = R_1^{\mathrm{I}}$. □

A.3. Proof of Proposition 1

The firm prefers to impose a deadline if and only if $\Delta = \Pi^d - \Pi^{nd} > 0$. It follows from Equations (6) and (10) that

$$\begin{aligned}\Delta &= \delta_A\left(\frac{\mu_0}{\mu_1^w} - 1\right)C - (1 - \mu_0 a)\delta_F(\mu_1^w a Y - C) \\ &= \delta_A \frac{a}{1 - a}(1 - \mu_0)C - \delta_F[a(1 - a)\mu_0 Y - (1 - \mu_0 a)C]. \end{aligned} \tag{28}$$

It is straightforward to verify that

$$\frac{\partial\Delta}{\partial Y} < 0, \quad \frac{\partial\Delta}{\partial\delta_F} < 0, \quad \frac{\partial\Delta}{\partial C} > 0, \quad \frac{\partial\Delta}{\partial\delta_A} > 0, \quad \frac{\partial\Delta}{\partial\mu_0} < 0.$$

In addition,

$$\frac{\partial\Delta}{\partial a} = \delta_A \frac{1}{(1 - a)^2}(1 - \mu_0)C + \delta_F \mu_0[(2a - 1)Y - C].$$

The sign of $\lim_{a\to 0} \partial\Delta/\partial a$ is ambiguous, but $\lim_{a\to 1} \partial\Delta/\partial a = +\infty$. Meanwhile, $\partial^2\Delta/\partial a^2 > 0$. Therefore, by continuity, there must exist $\hat{a} \in (0, 1)$ such that

$$\frac{\partial\Delta}{\partial a} > 0, \quad \forall a > \hat{a}. \quad □$$

A.4. Proof of Proposition 5

Without deadlines, the firm's net present value from a stream of successive products is determined from the following equation:

$$V_F^{nd} = \mu_0 a(Y - \bar{R}_1^{nd} + \delta_F V_F^{nd}) + (1-\mu_0 a) \cdot \delta_F[\mu_1^w a(Y - \bar{R}_2^{nd}) + \delta_F V_F^{nd}].$$

Rearranging terms yields

$$V_F^{nd} = \frac{\Pi^{nd} + \mu_0 a(R_1^{nd} - \bar{R}_1^{nd})}{1 - \mu_0 a\delta_F - (1-\mu_0 a)\delta_F^2}, \tag{29}$$

where Π^{nd} is given by Equation (10) and $R_1^{nd} - \bar{R}_1^{nd}$ is given by Equation (14) .

Recall that $V_F^d = 1/(1-\delta_F)(\mu_0 aY - C) = 1/(1-\delta_F)\Pi^d$. In the main model, the firm will prefer to impose a deadline if and only if $\Pi^d > \Pi^{nd}$. In this extension, the firm will prefer to impose deadlines if and only if $V_F^d > V_F^{nd}$. Therefore, we define

$$\phi = \frac{1}{1-\delta_F}\Pi^{nd} - V_F^{nd}, \tag{30}$$

where ϕ represents the relative value of deadlines in the extension compared with that in the main model. If $\phi > 0$, deadlines are more valuable in the extension than in the main model, other things being equal; mathematically, the condition for the firm to prefer imposing deadlines is less stringent in the extension than in the main model. The reverse is true if $\phi < 0$. Collecting terms, we rewrite ϕ as

$$\phi = \frac{(1-\mu_0 a)\delta_F \Pi^{nd} - \mu_0 a(R_1^{nd} - \bar{R}_1^{nd})}{1 - \mu_0 a\delta_F - (1-\mu_0 a)\delta_F^2}.$$

The sign of $\partial\phi/\partial\delta_F$ is ambiguous. It depends on the magnitude of $\mu_0 a(R_1^{nd} - \bar{R}_1^{nd})$, the payroll costs the firm is expected to save as a result of the presence of future projects. However, it is easy to verify that

$$\frac{\partial\phi}{\partial\delta_A} < 0. \quad \square$$

References

Ajam MA (2014) *Redefining the Basics of Project Management: Filling the Practice Gaps by Integrating PMBOK Guide with a Project Life Span Approach!* (AuthorHouse, Bloomington, IN).
Amaldoss W, Jain S (2010) Reference groups and product line decisions: An experimental investigation of limited editions and product proliferation. *Management Sci.* 56(4):621–644.
Amaldoss W, Rapoport A (2005) Collaborative product and market development: Theoretical implications and experimental evidence. *Marketing Sci.* 24(3):396–414.
Ariely D, Wertenbroch K (2002) Procrastination, deadlines, and performance: Self-control by precommitment. *Psych. Sci.* 13(3):219–224.
Barczak G, Griffin A, Kahn KB (2009) Trends and drivers of success in NPD practices: Results of the 2003 PDMA Best Practices Study. *J. Product Innovation Management* 26(1):3–23.
Basu AK, Lal R, Srinivasan V, Staelin R (1985) Salesforce compensation plans: An agency theoretic perspective. *Marketing Sci.* 4(4):267–291.
Bentolila S, Bertola G (1990) Firing costs and labour demand: How bad is Eurosclerosis? *Rev. Econom. Stud.* 57(3):381–402.
Bergemann D, Hege U (2005) The financing of innovation: Learning and stopping. *RAND J. Econom.* 36(4):719–752.
Biyalagorsky E, Boulding W, Staelin R (2006) Stuck in the past: Why managers persist with new product failures. *J. Marketing* 70(2):108–121.
Bonatti A, Hörner J (2011) Collaborating. *Amer. Econom. Rev.* 101(2):632–663.
Boulding W, Morgan R, Staelin R (1997) Pulling the plug to stop the new product drain. *J. Marketing Res.* 34(1):164–176.
Burroughs JE, Dahl DW, Moreau CP, Chattopadhyay A, Gorn GJ (2011) Facilitating and rewarding creativity during new product development. *J. Marketing* 75(4):53–67.
Campbell A, Ederer F, Spinnewijn J (2014) Delay and deadlines: Freeriding and information revelation in partnerships. *Amer. Econom. J.: Microeconom.* 6(2):163–204.
Chung DJ, Steenburgh T, Sudhir K (2014) Do bonuses enhance sales productivity? A dynamic structural analysis of bonus-based compensation plans. *Marketing Sci.* 33(2):165–187.
Cohen MA, Eliashberg J, Ho T-H (1996) New product development: The performance and time-to-market tradeoff. *Management Sci.* 42(2):173–186.
Coughlan A, Narasimhan C (1992) An empirical analysis of salesforce compensation plans. *J. Bus.* 65(1):93–121.
Deloitte Consulting (2005) *Calling a Change in the Outsourcing Market: The Realities for the World's Largest Organizations* (Deloitte Consulting, New York).
Desai PS (2000) Multiple messages to retain retailers: Signaling new product demand. *Marketing Sci.* 19(4):381–389.
Desai PS, Srinivasan K (1995) Demand signalling under unobservable effort in franchising: Linear and nonlinear price contracts. *Management Sci.* 41(10):1608–1623.
Eisenhardt KM, Tabrizi BN (1995) Accelerating adaptive processes: Product innovation in the global computer industry. *Admin. Sci. Quart.* 40(1):84–110.
Fudenberg D, Tirole J (1991) Perfect Bayesian equilibrium and sequential equilibrium. *J. Econom. Theory* 53(2):236–260.
Gersick CJG (1988) Time and transition in work teams: Toward a new model of group development. *Acad. Management J.* 31(1):9–41.
Gersick CJG (1989) Making time: Predictable transitions in work groups. *Acad. Management J.* 31(2):274–309.
Guo L, Zhang J (2012) Consumer deliberation and product line design. *Marketing Sci.* 31(6):995–1007.
Hauser JR (1998) Research, development, and engineering metrics. *Management Sci.* 44(12):1670–1689.
Healy J (2009) Boeing, behind schedule, plans Dreamliner flight. *New York Times* (August 27), http://www.nytimes.com/2009/08/28/business/28boeing.html.
Himmelfarb PA (2008) Being first to market isn't enough. *Quality Digest* (February), http://www.qualitydigest.com/feb/product.html.
Holmström B (1979) Moral hazard and observability. *Bell J. Econom.* 10(1):74–91.
Hörner J, Samuelson L (2013) Incentives for experimenting agents. *RAND J. Econom.* 44(4):632–663.
Iyer G, Kuksov D (2010) Consumer feelings and equilibrium product quality. *J. Econom. Management Strategy* 19(1):137–168.
Joglekar NR, Yassine AA, Eppinger SD, Whitney DE (2001) Performance of coupled product development activities with a deadline. *Management Sci.* 47(12):1605–1620.
Kahn KB (2012) *The PDMA Handbook of New Product Development*, 3rd ed. (John Wiley & Sons, Hoboken, NJ).
Kalra A, Shi M, Srinivasan K (2003) Salesforce compensation scheme and consumer inferences. *Management Sci.* 49(5):655–672.
Kerzner HR (2013) *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*, 11th ed. (John Wiley & Sons, Hoboken, NJ).
Kuksov D, Xie Y (2010) Pricing, frills, and customer ratings. *Marketing Sci.* 29(5):925–943.
Lal R, Staelin R (1986) Salesforce compensation plans in environments with asymmetric information. *Marketing Sci.* 5(3):179–198.
Levinthal DA, Purohit D (1989) Durable goods and product obsolescence. *Marketing Sci.* 8(1):35–56.

Lim N, Ahearne MJ, Ham SH (2009) Designing sales contests: Does the prize structure matter? *J. Marketing Res.* 46(3):356–371.

Lindkvist L, Söderlund J, Tell F (1998) Managing product development projects: On the significance of fountains and deadlines. *Organ. Stud.* 19(6):931–951.

Luo L, Kannan PK, Ratchford BT (2007) New product development under channel acceptance. *Marketing Sci.* 26(2):149–163.

Luo L, Kannan PK, Ratchford BT (2008) Incorporating subjective characteristics in product design and evaluations. *J. Marketing Res.* 45(2):182–194.

Manso G (2011) Motivating innovation. *J. Finance* 66(5):1823–1860.

March JG, Shapira Z (1987) Managerial perspectives on risk and risk taking. *Management Sci.* 33(11):1404–1418.

Marion TJ, Friar JH (2012) Managing global outsourcing to enhance lean innovation. *Res.-Tech. Management* 55(5):44–50.

Markham SK, Lee H (2013) Product development and management association's 2012 comparative performance assessment study. *J. Product Innovation Management* 30(3):408–429.

Miklós-Thal J, Zhang J (2013) (De)marketing to manage consumer quality inferences. *J. Marketing Res.* 50(1):55–69.

Misra S, Nair H (2011) A structural model of sales-force compensation dynamics: Estimation and field implementation. *Quant. Marketing Econom.* 9(3):211–257.

Moorthy KS (1984) Market segmentation, self-selection, and product line design. *Marketing Sci.* 3(4):288–307.

Nivi B (2009) How to bring a product to market: A very rare interview with Sean Ellis. *Venture Hacks* (December 14), http://venturehacks.com/articles/sean-ellis-interview.

O'Donoghue T, Rabin M (1999) Incentives for procrastinators. *Quart. J. Econom.* 114(3):769–816.

Ofek E, Sarvary M (2003) R&D, marketing, and the success of next-generation products. *Marketing Sci.* 22(3):355–370.

Ofek E, Turut O (2008) To innovate or imitate? Entry strategy and the role of market research. *J. Marketing Res.* 45(5):575–592.

Pragmatic Marketing (2013) 2013 State of product management and marketing. Report, Pragmatic Marketing, Scottsdale, AZ. https://pragmatic-marketing-469ad240.s3.amazonaws.com/PDF/AnnualSurvey2013Final.pdf.

Raassens N, Wuyts S, Geyskens I (2012) The market valuation of outsourcing new product development. *J. Marketing Res.* 49(5):682–695.

Raju JS, Srinivasan V (1996) Quota-based compensation plans for multiterritory heterogeneous salesforces. *Management Sci.* 42(10):1454–1462.

Rao RC (1990) Compensating heterogeneous salesforces: Some explicit solutions. *Marketing Sci.* 9(4):319–341.

Robertson D, Crawford RJ (2008) Innovation at the LEGO Group (B). Case IMD-3-1979, International Institute for Management Development, Lausanne, Switzerland.

Royer I (2003) Why bad projects are so hard to kill. *Harvard Bus. Rev.* 81(2):48–56.

Schmidt JB, Sarangee KR, Montoya MM (2009) Exploring new product development project review practices. *J. Product Innovation Management* 26(5):520–535.

Simester D, Zhang J (2010) Why are bad products so hard to kill? *Management Sci.* 56(7):1161–1179.

Simester D, Zhang J (2014) Why do sales people spend so much time lobbying for low prices? *Marketing Sci.* 33(6):796–808.

Sun B, Xie J, Cao H (2004) Product strategy for innovators in markets with network effects. *Marketing Sci.* 23(2):243–254.

Thomas DA, Barley L (2008) Adobe Systems: Working towards a "suite" release (A). HBS Case 9-409-014, Harvard Business School, Boston.

Toubia O (2006) Idea generation, creativity, and incentives. *Marketing Sci.* 25(5):411–425.

Urban GL, Hauser JR (1993) *Design and Marketing of New Products* (Prentice-Hall, Englewood Cliffs, NJ).

Villas-Boas JM (1998) Product line design for a distribution channel. *Management Sci.* 17(2):156–169.

Whyte G (1991) Decision failures: Why they occur and how to prevent them. *Executive* 5(3):23-31.

Williamson OE (2008) Outsourcing: Transaction cost economics and supply chain management. *J. Supply Chain Management* 44(2):5–16.

Wu Y, Balasubramanian S, Mahajan V (2004) When is a preannounced new product likely to be delayed? *J. Marketing* 68(2):101–113.

Zenger TR, Lazzarini SG (2004) Compensating for innovation: Do small firms offer high-powered incentives that lure talent and motivate effort? *Managerial Decision Econom.* 25(6–7):329–345.