Patent Races and R&D Disclosures under U.S. GAAP and International Financial Reporting Standards*

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Abstract

We investigate the economic effects of accounting disclosures under USGAAP and IFRS regarding research and development expenditures in a two-stage patent race between two firms. We study the effects of accounting disclosures on the firms' investment decisions and social welfare. The two accounting regimes that we examine differ in the treatment of development costs, which are expensed under USGAAP but capitalized under IFRS. Capitalization of a firm's development costs provides information to its rival in the patent race, allowing the rival to make a more informed decision regarding whether to proceed with development in case the competitor is ahead in the race. As this is valuable to each firm, entry in the patent race may increase. Therefore, capitalization of development costs decreases investment in development by competitors, but increases investments in research. We find that the disclosure has ambiguous effects on social welfare, with USGAAP tending to reduce redundant research investments and IFRS tending to reduce redundant development investments.

1 INTRODUCTION

We investigate the economic effects of how firms account for research and development (R&D) expenditures in the context of a two-stage patent race between two firms. Under U.S. Generally Accepted Accounting Principles (USGAAP), R&D investments are expensed. Under International Financial Reporting Standards (IFRS), investments in research are expensed, whereas development costs are capitalized. The competitor's capitalization of its development costs provides a signal that can affect a firm's decision whether to drop out of the patent race at the start of the second stage. This in turn can affect a firm's decision to enter race in the first stage.

Statement of Financial Accounting Standards No. 2*, Accounting for Research and Development Costs*, (recently codified as Topic 730-10-25-1) requires that all R&D be expensed under USGAAP. International Accounting Standard 38, *Intangible Assets* (IAS 38), requires that research costs be expensed, but that development costs be capitalized under IFRS. The development stage begins when six criteria are satisfied. These criteria include that the firm can demonstrate that completing the project is technically feasible and that it will generate probable future economic benefits.

We consider a patent race with two stages. In the research stage, two firms each have the opportunity to make a discovery by investing in research. Depending on the cost of research, either no firm, one firm, or both firms make the initial investment. When a firm makes the discovery, that firm has the opportunity to invest in developing the project. The first firm to complete both the research and development stages wins the patent race; the loser of the race receives nothing. Under USGAAP, a firm that completes the research stage does not know whether its rival is in the development stage or the research stage. Under IFRS, the firm can observe whether its rival has capitalized development costs, which provides a signal regarding whether it is ahead in the race. The disclosure of the development costs by the firm that finishes its research stage first reveals information that allows the competitor to make a more informed decision regarding whether to stay in the race. In particular, capitalizing the development costs induces the rival to drop out of the race in our model when the disclosure suggests that the expected benefits from staying in the race, given that the competitor is ahead, are lower than the costs. Therefore, each firm has an incentive to to claim that it has finished its research stage, and thus the claim as such is not credible. However, capitalization of development costs under IFRS makes this claim credible as the external auditor has confirmed that the six criteria for capitalization are met, revealing that the development phase has indeed started.

If the signal induces the second firm to finish the research stage to drop out of the race, both firms benefit. The first firm to make the discovery is better off because its rival drops out of the race, which ensures that the first firm will eventually win the patent race. The second firm to discover is also better off, because it avoids incurring development costs when it knows its rival is already in the development stage. This in turn increases the range of research costs for which both firms invest in research in the first stage.

We find that the disclosure of development costs under IFRS has ambiguous effects on social welfare. When research costs are low, both firms enter the patent race under both USGAAP and IFRS. IFRS eliminates redundant development investments, but also increases the expected length of the development stage. The importance of this second effect depends in part on the level of consumer surplus associated with the project. For intermediate research costs, two firms invest in research under IFRS, but only one firm invests under USGAAP. In this case, USGAAP eliminates redundant research investments, but also increases the expected length of the research stage. The social cost of this delay depends again in part on the consumer surplus associated with the project.

Our study relates to several earlier studies of R&D investments and accounting disclosures. Our model of the patent race is similar in spirit to that of Dasgupta and Stiglitz [1980]. A key difference between our model and theirs, however, is that the patent race in our case has two stages, research and development. Winning the patent race in our model requires finishing both stages before the rival finishes both stages.

Although there is a vast literature on the strategic interactions among firms making R&D investments, only Reinganum [1984] distinguishes between the research stage and the development stage of an R&D project. In her model, the first firm to make a discovery in the research stage becomes a Stackelberg leader in the development stage. A key difference between her model and ours is that her model features information spillover; whenever any firm makes a discovery in the research stage, all of its rivals immediately learn what the discovering firm learned. All that discovery yields is the ability to be the first-mover in the development stage of the patent race. In contrast, in our model each firm in the patent race must make the discovery in the research stage before it can proceed to the development stage. The accounting disclosure of capitalized development costs only reveals that a firm has made a discovery that ends its research stage, or gives credibility to a firm's claim that it started the development stage; the disclosure does not reveal the (e.g., technical) details of the discovery.[1]

Our study provides a new justification for capitalizing certain investments in internally developed intangible assets and extends the theory on the economic consequences of doing so. Lev [2001, 95] argues that the inability of investors to distinguish operating expenses from investments in intangible assets creates an information asymmetry that raises the cost of capital from such investments, thereby deterring them. Kanodia and Mukherji [1996] and Kanodia et al. [2004] develop this idea in formal models of firm investment decisions. These papers find that when capital market participants cannot distinguish operating expenses from investments in internally developed intangible assets, a firm has an incentive to reduce these investments relative to a world in which investors could disentangle investments in intangible assets from operating expenses.[2] Consistent with this, Mohd [2005] shows that capitalization of R&D, which is allowed for software development costs, decreases

[1] An incentive to disclose technical details may be that it expands prior knowledge. It therefore may make it more difficult for the rival to obtain a patent, because obtaining a patent requires a substantial increase in knowledge compared to what is publicly known. This issue is considered in Baker and Mezzetti [2005].

[2] A second reason for lower investments under an expensing regime could be that expensing lowers current earnings which could deter investments if bonuses depend on earnings, as argued in Dukes et al. [1980].

information asymmetry between the firm and investors. Whereas these studies focused on capitalization as a means of credibly distinguishing investments in intangibles from operating expenses to the capital market, capitalization in our model credibly signals to a rival that the firm has successfully finished the research stage and has entered the development stage in a patent race. Because this signal induces the rival to drop out of the race, the consequence of capitalization in our model is that it may *lower* investments in R&D due to less firms engaging in development. Therefore, whereas prior literature suggests that capitalization would increase R&D investments, we find the opposite effect. This could partly explain the rather weak empirical evidence on the effect of prohibiting capitalization (the October 1974 SFAS 2 guideline) on investment in R&D (see, e.g., Dukes et al., 1980, Horwitz and Kolodny, 1980, Elliott et al., 1984, Wasley and Linsmeier, 1992).

Furthermore, our study provides insights in the effects of capitalization on firm value. As argued above, once the firms have entered the patent race, capitalization increases the value of both firms because it provides the firm that finishes research second with an option to drop out of the race if investing in development yields negative NPV. The effect of capitalization on firm value at the start of the race, however, is ambiguous. The reason is that the possibility to credibly signal progress to the rival at the end of the research stage may induce both firms to enter the race, whereas absent the credible signal only one firm would enter.

A premise of our study is that external users regard the disclosure of capitalized development costs as a credible signal regarding the progress that a firm has made in the patent race. Consistent with this premise, Tsoligkas and Tsalavoutas [2010] find that capitalized development expenditures are more highly valued than expensed research expenditures for a sample of UK firms between 2006 and 2008, following the adoption of IFRS in 2005.

We present our model in Section 2. In Section 3, we characterize the equilibrium investment behavior of the firms under the different accounting regimes. We determine social welfare under each accounting regime in Section 4, and the effect of capitalizing development costs on firm value in Section 5. Section 6 concludes.

2 MODEL

We consider a patent race involving two firms, x and y. Firm x is the Incumbent and y is a potential entrant. On date zero, each firm $i \in \{x, y\}$ has the opportunity to invest R dollars in research, which allows the firm to make a discovery at a future date $T_{i,R}$. Following Dasgupta and Stiglitz [1980], we assume that the time to discovery follows an exponential distribution, i.e.,

$$T_{i,R} \backsim Exp(\lambda), \text{ for } i \in \{x, y\}. \tag{1}$$

The dates at which the firms make their discoveries are independent.

Next, when the discovery takes place, i.e., at date $T_{i,R}$, the firm making the discovery has the opportunity to invest D dollars in development. The investment allows the firm to implement a project at date $T_{i,R} + T_{i,D}$, i.e., $T_{i,D}$ denotes the time it takes firm i to finish the development stage, which is a random variable satisfying

$$T_{i,D} \backsim Exp(\theta), \text{ for } i \in \{x, y\}, \tag{2}$$

with $\lambda < \theta$. This assumption implies that the expected length of the research stage exceeds the expected length of the development stage.[3] The development costs are the same for each firm.

On the date that firm i finishes the development stage, i.e., on date $T_{i,R} + T_{i,D}$, the firm can invest K dollars in a project that will produce future cash flows with a present value that depends on how many firms produce. With only one of the two firms producing, the present value of the cash flows is larger than K, so that the net present value from producing is strictly positive. If two firms would implement the project, then the net present value to each firm would be negative. Therefore, a firm that finishes the development stage will invest in the project if and only if its rival did not yet implement the project. We will denote V for the net present value of the project for the firm that finishes the development stage first. Figure 1 displays the timeline.

[INSERT FIGURE 1 ABOUT HERE]

To make the decision whether to invest in development, the firm determines the expected value of remaining in the race. There are two possibilities. If the firm observes that its rival has already invested K and thus started producing, then it knows that the race is over and thus that investing D is futile. If its rival has not

[3] This is in line with the requirements for capitalizing R&D expenses under IFRS, as the requirements make it clear that the main risks are in the research phase of the project.

invested K, it infers that the rival is either still in the research stage or that the rival has entered the development stage but not yet finished it. Depending on the financial accounting regime, the firm may or may not be able to update its beliefs regarding at which stage the rival is depending on information disclosed in financial statements.

We consider two accounting disclosure regimes, USGAAP and IFRS. Under USGAAP, both the research costs R and the development costs D are expensed. Under IFRS, research costs are expensed but development costs are capitalized. The tangible investment K is capitalized under both regimes.

We assume that capitalization of D under IFRS provides a credible signal to the other firm that its rival has made the discovery, but that the expensing of D under USGAAP prevents the firm from knowing whether its rival is in the research stage or the development stage of the project when it makes its discovery.[4]

We assume that $R < \frac{V\lambda\theta}{(\lambda+r)(\theta+r)}$, which ensures that if $D = 0$, at least one firm will enter the patent race on date zero. We also assume that $D < \frac{V\theta}{\lambda+\theta+r}$, which ensures that a firm will enter the development stage if it is possible that the rival is still in the research stage.

[4]More generally, the level of the firm's R&D expenses under USGAAP provides a noisy signal regarding whether the firm has reached the development stage. If the prior belief regarding the firm's total research investments is sufficiently diffuse, however, the ability to infer whether a firm has incurred development costs from observing total R&D expenses is negligible.

3 INVESTMENT DECISIONS

In this section, we analyze the investment decisions under the two different accounting regimes (USGAAP and IFRS). The firms face two strategic decisions. First, the firms must choose whether to enter the patent race at date zero. Second, a firm that enters the patent race, finishes the research stage, and observes that the rival has not yet implemented the project must decide whether to enter the development stage at cost D. To make this decision, the firm determines the present value of the expected benefits of remaining in the race. When both firms potentially enter the patent race on date zero, the accounting regime may affect the decision whether to invest in development at the end of the research stage, because the capitalization of development costs under IFRS provides a credible signal regarding the rival's progress in the patent race. Capitalization of development costs increases the value of entering the patent race on date zero if a firm's decision whether to invest D is affected by whether the rival is in the development stage; this in turn affects the decision whether to enter the patent race on date zero.

In the following two subsections, we analyze the investment decisions under USGAAP and under IFRS, respectively. We assume that if only one firm enters the race, it is the Incumbent that enters and the Entrant that stays out of the race. We provide formal derivations of the present values used in this section in the Appendix.

R&D investments under USGAAP

In this subsection, we analyze R&D investment decisions under USGAAP. We first determine the conditions under which a firm will invest in development once it finishes its research stage if only one firm enters the patent race, and the conditions under which a firm invests in development if two firms enter the patent race. We then use these results to determine the conditions under which the Incumbent and the Entrant will enter the patent race.

The development decision under USGAAP

We first determine the condition under which the Incumbent will invest in development once it finishes its research stage if the Entrant did not enter the patent race. Let T denote the time at which the Incumbent finishes its research stage, i.e., $T = T_{x,R}$. At the end of the development stage, i.e., on date $T + T_{x,D}$, the project is worth V. Therefore, the expected present value to the Incumbent from investing D on date T is

$$\Pi^{\text{single}|\text{USGAAP}}(T) = V \cdot \mathbb{E}\left[e^{-rT_{x,D}}\right] = V \int_0^\infty \theta e^{-\theta t} e^{-rt} dt = V \frac{\theta}{\theta + r}, \tag{3}$$

where r denotes the discount rate. The assumption $D < \frac{V\theta}{\lambda+\theta+r}$ implies that investing D at time T has strictly positive NPV because $\Pi^{\text{single}|\text{USGAAP}}(T) > D$. Therefore, if the Entrant did not enter the patent race, it is optimal for the Incumbent to enter the development stage once it finishes its research stage.

Next, we analyze the development investment decision in case both firms enter the patent race on date zero. When both firms are in the patent race, they are in strategically symmetric positions. Therefore, without loss of generality we focus on the present value for firm x; the expressions for firm y are the same. We again denote T for the time at which the firm finishes its research stage, i.e., $T = T_{x,R}$. Under USGAAP, the firm cannot infer from the rival's financial statements whether the rival has finished its research stage; the firm only knows that the rival has not yet implemented the project. Clearly, it is not optimal to invest D if the rival has already implemented the project. We now show that if the rival has not yet implemented the project at time T, it is optimal for the firm to stay in the race and invest in development. It is sufficient to show that the firm will stay in the race if the rival stays in the race until the first one implements the project.[5] If both firms stay in the race until the first one implements the project, firm x will implement the project if it finishes its development stage before the rival does. Given this, the expected present value at date T of the benefits from investing D, given that the rival has not finished the development stage, is given by

$$\Pi^{\text{both}|\ \text{USGAAP}}(T) = \frac{V\theta}{(\theta e^{\theta T} - \lambda e^{\lambda T})} \left[\frac{\theta e^{\theta T}}{\lambda + \theta + r} - \frac{\lambda e^{\lambda T}}{2\theta + r} \right]. \tag{4}$$

The derivation is in the appendix. Differentiation shows that this expression is decreasing in T. Using the assumption that $\lambda < \theta$ yields

$$\lim_{t \to \infty} \Pi^{\text{both}|\ \text{USGAAP}}(t) = \frac{V\theta}{\lambda + \theta + r}. \tag{5}$$

[5]The present value of the expected benefits from investing D in development depends on whether the rival will invest (or has invested) in development when it finishes its research stage, because the rival's decision affects the probability that the firm will win the race. Because the firms are *ex ante* identical, they will in equilibrium follow the same strategy.

The assumption that $D < \frac{V\theta}{\lambda+\theta+r}$ combined with (5) implies that $\Pi^{\text{both}|\text{ USGAAP}}(T) \geq D$, so that it is optimal for the firm to stay in the race and invest in development unless the rival has completed its development stage. We summarize the development investment decisions under USGAAP in Proposition 1.

Proposition 1 *Under USGAAP, the development decision is as follows:*

- *if only one firm enters the patent race, it will invest D in development once it finishes its research stage;*
- *if both firms enter the patent race, each firm will invest D in development when its research stage ends, unless the rival completed its development stage.*

The entry decision under USGAAP

We now turn to the decision whether to invest R at date zero. We proceed as follows. We first determine the condition under which neither firm will enter the race. Next, we determine the condition under which both firms will enter the race.

Neither firm will enter the race if it is not optimal for the Incumbent to enter, given that the Entrant stays out. If the Entrant does not enter, it follows from (3) that the expected present value to the Incumbent from investing R on date zero (i.e., at the start of the research stage) is

$$\begin{aligned}\Pi^{\text{single}|\text{USGAAP}}(0) &= \mathbb{E}\left[e^{-rT_{x,R}} \cdot \left(V \cdot e^{-rT_{x,D}} - D\right)\right] = \int_0^\infty \lambda \left(V\frac{\theta}{\theta+r} - D\right) e^{-\lambda t} e^{-rt} dt \\ &= \frac{\lambda}{\lambda+r}\left[V\frac{\theta}{\theta+r} - D\right]. \qquad (6)\end{aligned}$$

Therefore, neither firm will enter the patent race if

$$R \geq \widehat{R}_h = \frac{\lambda}{\lambda + r}\left[V\frac{\theta}{\theta + r} - D\right]. \tag{7}$$

We now investigate the conditions under which both the Incumbent and the Entrant enter the race. To do so, we determine the net present value of investing R on date zero under the assumption that both firms enter the race, and then determine the conditions under which this is positive. Firm value also depends on the development decisions of the two firms once they finish their research stage. We know from Proposition 1 that when both firms enter the race on date zero, a firm that finishes its research stage invests D when the research stage ends, unless the race is over. Using this, we find that the combined expected value of the project to both firms as of the date that the first firm completes the research phase is

$$\frac{1}{\lambda + \theta + r}\left[\frac{V\theta(2\lambda + 2\theta + r)}{2\theta + r} - D(2\lambda + \theta + r)\right]. \tag{8}$$

The derivation is in the appendix.

When both firms enter the race, the time until the first one finishes research, $\min\{T_{x,R}, T_{y,R}\}$, is exponentially distributed with mean $\frac{1}{2\lambda}$. Therefore, the expected discount factor associated with the length of time it takes for the first firm to finish the research stage is

$$\int_0^\infty 2\lambda e^{-2\lambda t}e^{-rt}dt = \frac{2\lambda}{2\lambda + r}. \tag{9}$$

Moreover, if both firms enter the race on date zero, they are equally likely to be the first firm to finish the research stage as they are to be the second. Therefore, for each firm, the expected present value of investing R at the start of the research phase is

$$\Pi^{\text{both}|\text{USGAAP}}(0) = \frac{\lambda}{2\lambda + r}\left[\frac{V\theta(2\lambda + 2\theta + r)}{(\lambda + \theta + r)(2\theta + r)} - \frac{D(2\lambda + \theta + r)}{\lambda + \theta + r}\right]. \tag{10}$$

It therefore follows that under USGAAP, both firms enter the patent race and invest R on date zero if and only if

$$R < \widehat{R}_l = \frac{\lambda}{2\lambda + r}\left[\frac{V\theta(2\lambda + 2\theta + r)}{(\lambda + \theta + r)(2\theta + r)} - \frac{D(2\lambda + \theta + r)}{\lambda + \theta + r}\right]. \tag{11}$$

When $R \geq \widehat{R}_l$, it is not optimal for the firms to both enter the race, and so the Entrant will not enter the race. This in turn implies that when $\widehat{R}_l \leq R < \widehat{R}_h$, it is optimal for the Incumbent to enter the patent race; the Entrant does not enter the race, and it then follows from (6) that entering the race has positive NPV to the Incumbent, because $\Pi^{\text{single}|\text{USGAAP}}(0) = \widehat{R}_h \geq R$.

We summarize the research investment decisions under USGAAP in Proposition 2.

Proposition 2 *The entry decisions under USGAAP are as follows:*

- *when $R < \widehat{R}_l$, both firms invest R on date zero;*
- *when $\widehat{R}_l \leq R < \widehat{R}_h$, the Incumbent invests R on date zero, and the the Entrant does not invest;*
- *when $\widehat{R}_h \leq R$, neither firm invests.*

R&D under IFRS

In this section, we consider the firms' R&D investment decisions under IFRS. We again first analyze the development decision in case only the Incumbent enters the patent race and in case both firms enter the patent race, and then use these results to determine the conditions under which firms will enter the race.

The development decision under IFRS

First, when only the Incumbent enters the patent race, it again follows from (3) that the Incumbent will invest D in development once it finishes the research stage, because

$$\Pi^{\text{single}|\text{ IFRS}}(T) = \int_0^\infty \theta V e^{-\theta t} e^{-rt} dt = \frac{\theta V}{\theta + r} \geq D.$$

Now consider the case where both firms enter the patent race. As in the case of USGAAP, the firm can condition its decision whether to invest in development on whether its rival has finished its development stage. In addition, the firm can now also infer from the financial statements whether the rival has started its development stage by observing whether the amount D has been capitalized. Stated differently, once the firm finishes its research stage, it knows whether it is first or second. It can use this information to update its expectation regarding the benefits from investing in development. First, we determine whether the first firm to finish research will invest in development. The present value of the expected benefits from investing D in development depends on whether the rival will invest in development when it finishes its research stage, because the rival's decision affects the probability that the firm will win the race. If the rival would quit, the expected present value on date T equals

$$\Pi^{\text{IFRS}|\text{ rival quits}}(T) = V \cdot \mathbb{E}\left[e^{-rT_{x,D}}\right] = \int_0^\infty \theta V e^{-\theta t} e^{-rt} dt = \frac{\theta V}{\theta + r}. \tag{12}$$

If the disclosure of the firm would not deter the rival from investing in development, then the expected present value at date T from investing D, given that the rival did not yet finish its research stage, is given by

$$\Pi^{\text{IFRS}|\text{ rival second}}(T) = \frac{V\theta(\lambda + 2\theta + r)}{(\lambda + \theta + r)(2\theta + r)}. \tag{13}$$

The derivation is in the appendix. Clearly, the expected present value to the firm that is first to finish research is higher if the rival quits than if the rival decides to stay in the race, i.e., $\Pi^{\text{IFRS}|\text{ rival quits}}(T) \geq \Pi^{\text{IFRS}|\text{ rival second}}(T)$. Moreover, it follows from (13) that the first firm to finish research will invest in development once it finishes its research stage, because the assumption that $D < \frac{V\theta}{\lambda+\theta+r}$ implies that the investment has positive NPV even if the rival will stay in the race, because $D < \Pi^{\text{IFRS}|\text{ rival second}}$.

Next, we consider whether the second firm to finish research will invest in development. Given that the rival has already invested D, the expected value of investing D at time T to the second firm to finish research is given by

$$\Pi^{\text{IFRS}|\text{ rival first}}(T) = \frac{\theta V}{2\theta + r}. \tag{14}$$

The derivation is in the Appendix. It follows from (14) that whether the second firm to finish research will invest in development depends on the development costs. If $D \leq \frac{V\theta}{2\theta+r}$, then $\Pi^{\text{IFRS}|\text{ rival first}} > D$, and so the investment has positive NPV. Even though the firm is behind in the race, it still has a positive probability of winning the race. Because the development costs are sufficiently low, the second firm to finish the research stage enters the development stage unless the rival has completed its development stage. In contrast, if $D > \frac{V\theta}{2\theta+r}$, development costs are so high that even though the firm still has a possibility of winning the race, the investment has negative NPV ($\Pi^{\text{IFRS}|\text{ rival first}} < D$). Therefore, in this case it is optimal for the second firm to finish the research stage to quit the race. We summarize the development investment decisions under IFRS in Proposition 3.

Proposition 3 *Under IFRS, the development investment decision is as follows:*

- *if only one firm enters the patent race, it will invest D in development when the research stage ends;*
- *if both firms enter the patent race, it holds that:*
  - *if $D \leq \frac{V\theta}{2\theta+r}$, each firm will enter the development stage when the research stage ends, unless the rival completed its development stage;*
  - *if $D > \frac{V\theta}{2\theta+r}$, each firm will enter the development stage when the research stage ends, unless the rival has started its development stage.*

The above proposition implies that if $D > \frac{V\theta}{2\theta+r}$, a firm always has an incentive to claim that it has reached the development phase. If the claim is credible, it deters the rival from entering the development stage. However, the claim as such is not credible, but capitalization makes this claim credible as the external auditor has confirmed that the six criteria for capitalization are met, revealing that the development phase has indeed started.

The entry decision under IFRS

We now analyze the firm's decision to enter the patent race. When $D \leq \frac{V\theta}{2\theta+r}$, it follows from Propositions 1 and 3 that the decision to invest in development when the research stage ends is the same as under USGAAP. Stated differently, even though the firm is able to observe whether the rival has already started the development stage, that information does not affect the firm's decision to invest in development. As a consequence, the decision to enter the patent race is the same as under USGAAP.

When $D > \frac{V\theta}{2\theta+r}$, we know from Proposition 3 that it is optimal for the firm to invest in development only if absence of capitalization of the rival reveals that the rival is not yet in the development stage. In contrast, under USGAAP the firm will invest unless the rival has finished its development stage (Proposition 1). Therefore, under IFRS the development decision are different than under USGAAP, and, as a consequence, the entry decision can also differ.

As under USGAAP, neither firm enters the patent race if $R > \widehat{R}_h$, because the expected present value to the Incumbent from investing R on date zero when the Entrant does not enter the race is

$$\Pi^{\text{single}|\text{IFRS}}(0) = \frac{\lambda}{\lambda + r}\left[V\frac{\theta}{\theta + r} - D\right] = \widehat{R}_h < R. \tag{15}$$

We now determine the condition under which both firms will enter the patent race. When $D > \frac{V\theta}{2\theta+r}$, we know from Proposition 3 that only the firm that finishes research first will invest in development. Therefore, the date T value of the project to the firm that is the first to end its research stage is $\Pi^{\text{IFRS}|\text{ rival quits}}(T) = \frac{V\theta}{\theta+r} - D$. Each firm has probability $\frac{1}{2}$ of being the first to finish research, and the discount factor associated with time until the first firm to finish its research stage is $\frac{2\lambda}{2\lambda+r}$. Therefore, when both firms enter the patent race on date zero, the date zero present value of investing R to each firm is

$$\Pi^{\text{IFRS}|\text{ both}}(0) = \frac{\lambda}{2\lambda + r}\left[\frac{V\theta}{\theta + r} - D\right]. \tag{16}$$

Thus, both firms will invest R on date zero if and only if

$$R < \widehat{R}_m = \frac{\lambda}{2\lambda + r}\left[\frac{V\theta}{\theta + r} - D\right]. \tag{17}$$

Combined with (7) it follows that if $\widehat{R}_m \leq R < \widehat{R}_h$, the Incumbent enters the patent race and the Entrant stays out.

We summarize the results of this section in Proposition 4.

Proposition 4 *The entry decisions under IFRS are as follows:*

- *if* $D \leq \frac{V\theta}{2\theta+r}$, *the entry decision is the same as under USGAAP;*
- *if* $D > \frac{V\theta}{2\theta+r}$ *the entry decision is as follows:*
  - *if* $R < \widehat{R}_m$, *both firms invest* R *on date zero;*
  - *if* $\widehat{R}_m \leq R < \widehat{R}_h$, *the Incumbent invests* R *on date zero, and the the Entrant does not invest;*
  - *if* $R \geq \widehat{R}_h$, *neither firm enters the race.*

Comparing R&D investments under USGAAP and IFRS

In this subsection, we use the results from Propositions 1-4 to compare research and development investments under the two accounting regimes. We distinguish the case in which development costs are low ($D \leq \frac{V\theta}{2\theta+r}$) and the case in which development costs are high ($D > \frac{V\theta}{2\theta+r}$).

Low development costs

When development costs are low, i.e., $D \leq \frac{V\theta}{2\theta+r}$, the R&D investment decisions of the firms are the same under USGAAP and IFRS. The incumbent invests in research on date zero if $R < \widehat{R}_h$, the entrant invests in research on date zero if $R < \widehat{R}_l$, and both firms invest in development as long as the rival has not finished its development stage.

High development costs

When development costs are high, $D > \frac{V\theta}{2\theta+r}$, comparing Propositions 1 and 3 shows that when two firms enter the race, their investment decisions once they reach the development stage are different under USGAAP and IFRS. This implies that investment decisions differ between the two accounting regimes if either the entry decision is different, or if both firms enter the race in under both regimes, in which case the development decisions differ.

To see when entry decisions are different under the two regimes, first note that the critical values in Propositions 2 and 4 can be ranked as follows:

$$\widehat{R}_l \leq \widehat{R}_m \leq \widehat{R}_h. \tag{18}$$

The derivation is in the appendix.

We distinguish three cases. First, when research costs are low, $R < \widehat{R}_l$, both firms will enter the patent race on date zero under both accounting regimes, but the decision to invest in development once the research stage ends is different. Under USGAAP, each firm will invest in development unless the rival has finished its development stage. Under IFRS, the second firm to finish the research stage drops out of the patent race at that point. The reason is that when $D > \frac{V\theta}{2\theta+r}$, investing D is a negative NPV proposition if the rival has entered the development stage. Because the capitalization of D provides a signal that the rival is in the development stage, the second firm to finish the research stage drops out of the patent race at that point under IFRS. The capitalization provides the firm with a real option to drop out of the race (avoid a negative NPV investment) when the firm learns it is behind in the race.

Second, consider the case in which $\widehat{R}_l < R \leq \widehat{R}_m$. Then only the Incumbent enters the patent race under USGAAP, but both firms enter the patent race under IFRS. The reason is that the signal whether the rival has entered the development stage under IFRS makes both firms better off at the time the first firm finishes research. The second firm to finish the research stage benefits because the signal allows it to avoid making a negative NPV investment in development; the first firm benefits because the signal induces the rival to drop out of the patent race, which ensures that the first firm ultimately wins the race. This in turn increases the range of R values for which both firms are willing to enter the patent race under IFRS, relative to USGAAP.

Finally, when $R \geq \widehat{R}_m$, the investment decisions are the same under the two accounting regimes; only the Incumbent enters the patent race on date zero under both regimes when $\widehat{R}_m < R \leq \widehat{R}_h$; neither firm invests under both regimes when $R \geq \widehat{R}_h$.

We summarize the differences between the firms' investment decisions under

USGAAP and under IFRS.when development costs are high in Proposition 5.

Proposition 5 *If $D > \frac{V\theta}{2\theta+r}$, differences in investment decisions under USGAAP and IFRS arise in the following two situations:*

- *if $R < \widehat{R}_l$, both firms enter the race, but the second firm to finish its research stage drops out of the patent race under IFRS;*
- *if $\widehat{R}_l < R < \widehat{R}_m$, only the Incumbent enters under IFRS; both firms enter under USGAAP.*

In the following two sections, we investigate the consequences of differences in investment decisions on social welfare and on firm value.

4 SOCIAL WELFARE

In this section, we determine social welfare under the two accounting disclosure regimes, focusing on the two cases in which USGAAP and IFRS induce different investment decisions.

We define social welfare as the difference between the present value of the project less the research and development costs of the two competing firms, plus the present value of any consumer surplus, S, associated with the project. We compute social welfare under each regime as of date zero.

Low research costs

The first difference in welfare arises when $0 < R < \widehat{R}_l$ and $D > \frac{V\theta}{2\theta+r}$. In this case, both firms enter the research stage, but the second firm to finish its research stage drops out of the patent race under IFRS.

First, we characterize social welfare under USGAAP when both firms enter the race. We know from (10) the value to each firm of investing R in research on date zero. Social welfare is equal to the value of the project to both firms, plus the present value of consumer surplus, reduced by the research costs. Therefore, social welfare is derived by doubling the private present value from (10), then adding consumer surplus S to V, and subtracting $2R$ to get

$$W^{\mathrm{USGAAP}} = \frac{2\lambda}{2\lambda + r}\left\{\frac{1}{\lambda+\theta+r}\left[\frac{(V+S)\theta(2\lambda+2\theta+r)}{2\theta+r} - D(2\lambda+\theta+r)\right]\right\} - 2R.$$

Next, we characterize social welfare under IFRS when both firms enter the race and the second firm to finish its research stage drops out of the race. Doubling the present value to each firm from investing R on date zero from (16), replacing the private value V with the social value $V+S$, and subtracting the research costs $2R$ yields the social value of the project on date zero

$$W^{\mathrm{IFRS}} = \frac{2\lambda}{2\lambda+r}\left[\frac{(V+S)\theta}{\theta+r} - D\right] - 2R. \tag{19}$$

We first separately consider the excess benefits and the excess costs from the USGAAP regime relative to IFRS, i.e.,

$$E\left[\mathrm{Benefit}^{\mathrm{USGAAP}}\right] - E\left[\mathrm{Benefit}^{\mathrm{IFRS}}\right] = \frac{(V+S)\lambda\theta r}{(\lambda+\theta+r)(2\theta+r)(\theta+r)} > 0, \tag{20}$$

and

$$E\left[\text{Cost}^{\text{USGAAP}}\right] - E\left[\text{Cost}^{\text{IFRS}}\right] = \frac{\lambda D}{\lambda + \theta + r} > 0. \tag{21}$$

USGAAP has a higher present value of future benefits, but also has a higher present value of costs. The reason is that the investment decision of the firm that finishes research second differs under the two regimes. Under IFRS, the firm will not invest; under USGAAP, it will invest as long as it finishes its research stage before the first firm can implement the project. Therefore, USGAAP has a higher present value of future benefits because there is a higher probability that two firms compete in the development stage, which implies that the project is implemented sooner in expectation. USGAAP has a higher present value of costs because under IFRS, the development expense is never made twice. Because only one firm will ultimately implement the project, the development cost of the firm that loses the race is, under USGAAP, a deadweight loss to society.

We now consider the aggregate effect. Combining (20) and (21) shows that USGAAP yields higher welfare than IFRS when the following condition holds:

$$W^{\text{USGAAP}} > W^{\text{IFRS}} \text{ iff } D < (S+V)\frac{\theta r}{(2\theta + r)(\theta + r)}. \tag{22}$$

The intuition for this condition is as follows. First, suppose $S = 0$, which implies that all of the social costs and benefits of the accounting regimes are reflected in firm profits. Expected firm profits are higher under IFRS than under USGAAP. The first firm to finish the research stage has higher expected profits because its costs are the same, but is certain to win the patent race under IFRS. The second firm to finish the research stage is also better off, because it avoids a negative NPV investment under IFRS that it makes under USGAAP. We note that because $D \geq V\frac{\theta}{2\theta+r}$, condition (22) cannot be satisfied if S is sufficiently close to zero, so IFRS is better from a social welfare perspective than is USGAAP. For $S > 0$, there is a component of social welfare that is not reflected in firm profits. The greater is S, the greater is the benefit of USGAAP. The reason for this is that the expected length of time between the start of the research stage and the date on which the first firm finishes its development stage is shorter under USGAAP, because sometimes both firms are in the patent race during the development stage. It is possible that the second firm to finish research is the first to finish development. When only one firm is in the patent race, the discount factor as of the start of the development stage is $\frac{\theta}{\theta+r}$; when two firms are in the patent race, the discount factor when the second firm start developing is $\frac{2\theta}{2\theta+r}$. The difference between the two discount factors is $\frac{\theta r}{(2\theta+r)(\theta+r)}$.

It is clear from (22) that neither system dominates the other. USGAAP is better when the consumer surplus term S or the value of the project V is high. IFRS is better when the development costs D are high or when r is low. Finally, we note that $\frac{\theta r}{(2\theta+r)(\theta+r)}$ is not monotone in θ, but rather is maximized at

$$\theta = \frac{r\sqrt{2}}{2}.$$

This implies that IFRS is better for very high or very low values of θ, but USGAAP is better for intermediate values of θ. When θ is very large, the expected length of the development stage is very short even when only one firm is in the development stage. If the second firm also incurs development costs, the expected time until one of the two firms develops the technology decreases only slightly, whereas the development costs incurred doubles. When θ is very small, the expected length of the development stage is very large and so the present value of future benefits is quite small. If the second firm also incurs development costs, the present value of the social benefits increases only slightly (as it is still subject to high discounting), whereas the development costs incurred doubles. In either case, IFRS increases social welfare by inducing the second firm to finish the research stage to not incur socially inefficient development costs. For intermediate values, welfare is higher under USGAAP because the increase in the present value of the social benefits more than offsets the doubled development costs for intermediate values of θ.

Intermediate research costs

In this subsection, we consider the case in which $\widehat{R}_l < R < \widehat{R}_m$ and $D > \frac{V\theta}{2\theta+r}$. We first characterize welfare under USGAAP. Then, the Incumbent enters the patent race and the Entrant stays out. Therefore, social welfare on date zero is equal to the date zero value of the project to the Incumbent, plus the present value of consumer surplus, reduced by the Incumbent's research costs. We know from (6) the value to the Incumbent of investing R in research on date zero. Adding consumer surplus S and subtracting research costs R yields

$$W^{\text{USGAAP}} = \frac{\lambda}{\lambda + r}\left[\frac{\theta(V+S)}{\theta + r} - D\right] - R. \tag{23}$$

Under IFRS, both firms enter the race on date zero, but the second firm to finish the research stage drops out of the patent race. Therefore, welfare under IFRS is given by (19).

Comparing social welfare under IFRS and USGAAP in this case yields

$$W^{\text{USGAAP}} > W^{\text{IFRS}} \quad \text{iff} \quad R > \left[\frac{(S+V)\theta}{\theta + r} - D \right] \frac{\lambda r}{(\lambda + r)(2\lambda + r)}. \tag{24}$$

The welfare effects of IFRS and USGAAP are quite different when research costs are intermediate than they were when research costs are low. In this case, there are no wasted development costs, as only one firm invests in development in each case. However, research costs are twice as high under IFRS because both firms enter the patent race, as opposed to only one firm entering the race under USGAAP. The benefit of of IFRS is that the expected length of the research stage is shorter because two firms are trying to make the initial research discovery instead of just one. The social value of the project on the date at which the first firm to make the discovery is $\frac{(S+V)\theta}{\theta+r} - D$, which is increasing in S, V, and θ, and decreasing in D. The present value of this project as of date zero is discounted by $\frac{\lambda}{\lambda+r}$ under USGAAP, but by $\frac{2\lambda}{2\lambda+r}$ under IFRS. The difference between these two discount factors is $\frac{\lambda r}{(\lambda+r)(2\lambda+r)}$. Therefore, IFRS is preferable when the difference between the present values of the project, $\left[\frac{(S+V)\theta}{\theta+r} - D\right] \frac{\lambda r}{(\lambda+r)(2\lambda+r)}$, is greater than the difference in date zero research costs, R. Finally, we note that the term $\frac{\lambda r}{(\lambda+r)(2\lambda+r)}$ is not monotone in λ; instead, it attains a maximum at

$$\lambda = \frac{r\sqrt{2}}{2}.$$

When λ is very large, the expected length of the research stage is very short, and so the social value created by having a second firm in the patent race is very small and so

USGAAP is better than IFRS. When λ is very small, the expected length of the research stage is very long, and so the present value of the project is also very small. In this case, the social value created by having a second firm in the patent race is again very small and so USGAAP is better than IFRS. But for intermediate values of λ, the increase in social value exceeds the social cost of having two firms incur the research costs, and so IFRS is better than USGAAP in that case.

5 DISCLOSURES AND FIRM VALUE

In this section, we examine the consequences of capitalizing development costs on the value of the project for the two firms. Capitalization affects firm behavior in two cases. First, when development costs are high and research costs are low, capitalization induces the second firm to finish the research stage to drop out of the patent race, whereas both firms may invest development costs under USGAAP. Second, when when development costs are high and research costs are intermediate, capitalization induces both firms to enter the patent race, whereas only the incumbent enters the patent race under USGAAP.

Low research costs, high development costs

When research costs are low, $R < \hat{R}_l$, and development costs are high, $D > \frac{V\theta}{2\theta+r}$, both firms enter the patent race. It follows from (10) that the date zero value of the project to each firm under USGAAP is

$$\Pi^{\text{both}|\text{USGAAP}}(0) - R = \frac{\lambda}{2\lambda + r}\left[\frac{V\theta(2\lambda + 2\theta + r)}{(\lambda + \theta + r)(2\theta + r)} - \frac{D(2\lambda + \theta + r)}{\lambda + \theta + r}\right] - R. \quad (25)$$

It follows from (16) that the date zero value of the project to each firm under IFRS is

$$\Pi^{\text{both}|\text{IFRS}}(0) - R = \frac{\lambda}{2\lambda + r}\left[\frac{V\theta}{\theta + r} - D\right] - R. \tag{26}$$

Taking the difference between these two expressions shows that firm value is higher under IFRS if

$$D > \frac{V\theta}{2\theta + r}\frac{r}{r + \theta}, \tag{27}$$

which is always satisfied when development costs are high. Therefore, firm value is higher under IFRS than under USGAAP when development costs are high and research costs are low. Because the value of the project is the same to both firms, the value of the industry is also higher under IFRS than under USGAAP.

The intuition is that both firms benefit from the disclosure. The second firm to finish the research stage avoids a negative NPV investment by dropping out. This in turn increases the value of the project to the first firm to end the research stage, by ensuring its victory in the patent race.

Intermediate research costs, high development costs

When research costs are intermediate, i.e. $\hat{R}_l < R < \hat{R}_m$, and development cost are high, capitalization of development costs under IFRS induces both the Incumbent and the Entrant to enter the patent race; under USGAAP, only the Incumbent enters the race. Because the expected value of the project must be positive to the Entrant (otherwise it would not enter), IFRS increases the value of the Entrant.

To determine the effect of IFRS on the Incumbent, we note that the value of the project to the Incumbent when it is the only firm in the race, from (15), is

$$\Pi^{\text{single|IFRS}}(0) - R = \frac{\lambda}{\lambda + r}\left[\frac{V\theta}{\theta + r} - D\right] - R. \tag{28}$$

We compare this value to the value of the project under IFRS when both firms enter from (26). Taking the difference shows that

$$\left\{\frac{\lambda}{2\lambda + r}\left[\frac{V\theta}{\theta + r} - D\right] - R\right\} - \left\{\frac{\lambda}{\lambda + r}\left[\frac{V\theta}{\theta + r} - D\right] - R\right\} = \frac{\lambda^2}{(\lambda + r)(2\lambda + r)}\left[D - \frac{V\theta}{\theta + r}\right] < 0.$$

Therefore, IFRS increases the value of the Entrant but decreases the value of the Incumbent, compared to firm value under USGAAP.

The effect of IFRS on the value of the industry is ambiguous. To see this, note that the difference between the value of the project to the Incumbent under USGAAP to the value of the project to both firms under IFRS is

$$\left\{\frac{\lambda}{\lambda + r}\left[\frac{V\theta}{\theta + r} - D\right] - R\right\} - \left\{\frac{2\lambda}{2\lambda + r}\left[\frac{V\theta}{\theta + r} - D\right] - 2R\right\}.$$

Evaluating this difference at $R = \hat{R}_l$ and $D = \frac{V\theta}{\lambda + \theta + r}$ shows that the difference has the same sign as

$$\lambda[2\lambda(\theta + r)z + r(\theta + 2r)] - 2\theta r(\theta + r),$$

which is negative for λ sufficiently small and positive for λ sufficiently large, $0 < \lambda < \theta$. Therefore, increased competition due to capitalization can either increase or decrease the value of the industry.

6 CONCLUSIONS

Our study of the effect of accounting disclosures on R&D investments has focused on how the capitalization of development costs under IAS 38 affects investments in a two-stage patent race between two firms. Capitalization of development costs yields a credible signal to the rival, which in turn has the potential to change the rival's investment behavior. If development costs are expensed, as they are under USGAAP, a firm does not know whether it is ahead or behind its rival in the patent race when it completes the research stage. Under IAS 38, a firm knows whether its rival has reached the development stage or is still in the research stage.

When development costs are high and research costs are sufficiently low, both firms enter the patent race. In this case, the capitalization of development costs increases the expected profits of both firms because the second firm to finish its research stage drops out of the patent race. However, the social welfare implications are ambiguous, as the present value of future consumer surplus decreases because the expected length of time until the development stage ends increases.

When development costs are high and research costs are intermediate, both firms enter the patent race if development costs are capitalized, but only one firm enters the race if development costs are expensed. Capitalization increases the value of the incumbent and decreases the value of the entrant in this case; the effect on the value of the industry is ambiguous. The effects on social welfare are also ambiguous. Capitalization doubles the amount invested in research, even though one only of the firms will benefit from the investment. However, the higher investment in research shortens the expected length of the research stage, which increases the present value of consumer surplus from the project.

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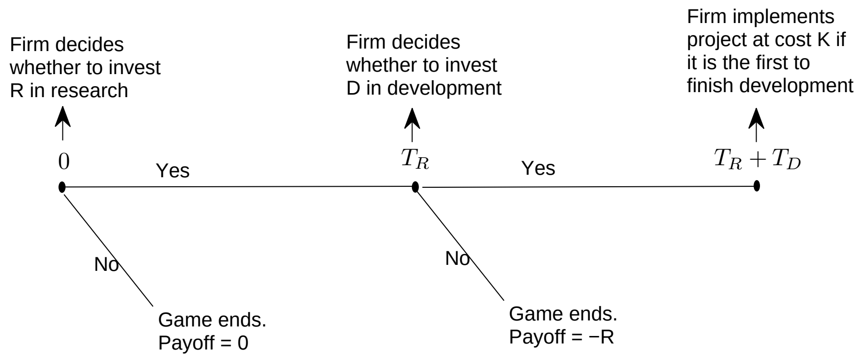

Figure 1: Timeline

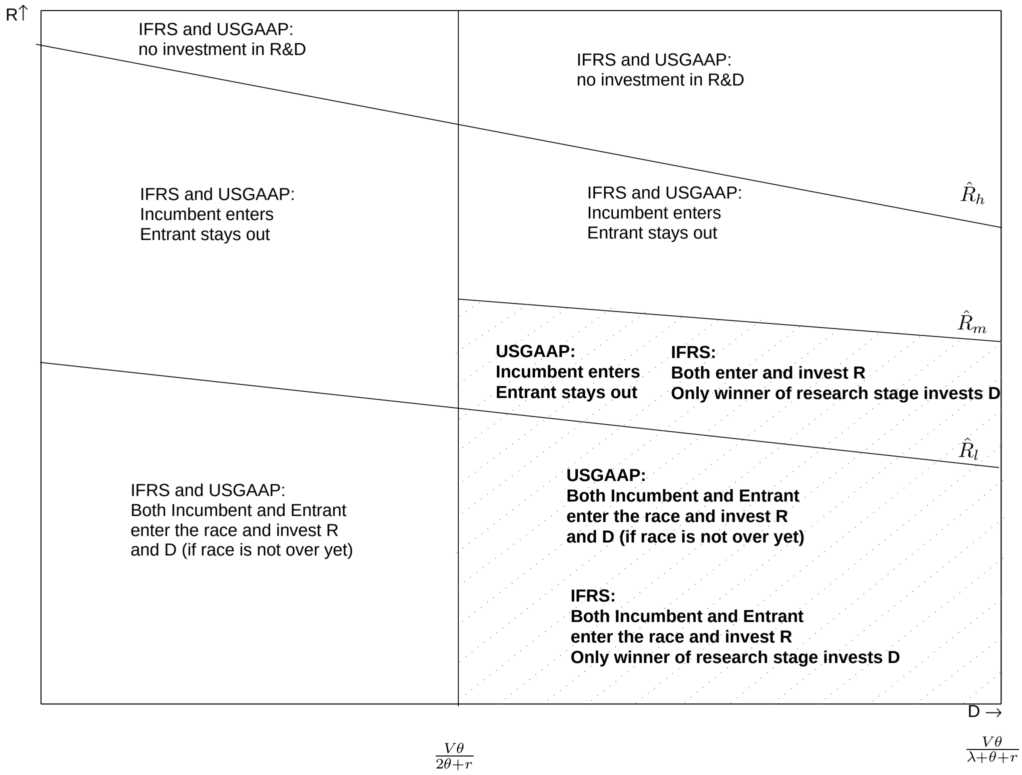

Figure 2: Optimal R&D investment decisions under U.S. GAAP and IFRS dependent on research costs R and development costs D.

Appendix

In this appendix, we derive the expected present value of the benefits from investing in development on the date the research stage ends, under different information sets. We first present two lemmas that will be used in deriving these results.

Lemma 6 *For both firms $i \in \{x, y\}$, it holds that the cdf of $T_{i,R} + T_{i,D}$ is given by*

$$P(T_{i,R} + T_{i,D} \leq t) = 1 - \frac{\theta e^{-\lambda t} - \lambda e^{-\theta t}}{\theta - \lambda}. \tag{29}$$

The pdf of $T_{i,R} + T_{i,D}$ is given by

$$\frac{\theta\lambda\left(e^{-\lambda t} - e^{-\theta t}\right)}{\theta - \lambda}. \tag{30}$$

Proof. Using (1) and (2) and the fact that $T_{y,D}$ and $T_{y,R}$ are independent yields

$$P(T_{i,R} + T_{i,D} \leq t) = \int_0^t \int_s^t \theta e^{-\theta(v-s)} \lambda e^{-\lambda s} dv ds = 1 - \frac{\theta e^{-\lambda t} - \lambda e^{-\theta t}}{\theta - \lambda}. \tag{31}$$

Taking the derivative of (29) with respect to t yields (30). ■

Lemma 7 *Let $T > 0$ be given. Then it holds that:*

(i) conditional on $T_{i,R} \geq T$, the remaining research time after time T, i.e., $T_{i,R} - T$, is exponentially distributed with parameter λ;

(ii) conditional on $T_{i,R} \leq T \leq T_{i,R} + T_{i,D}$, the remaining development time after time T, i.e., $T_{i,D} - (T - T_{i,R}) = T_{i,R} + T_{i,D} - T$, is exponentially distributed with parameter θ.

Proof. (i) Follows from the memoryless property of the exponential distribution.

(ii) Follows from the memoryless property of the exponential distribution, which implies that conditional on $T_{i,D} \geq T - T_{i,R}, T_{i,R} \leq T$, it holds true that $T_{i,D} - (T - T_{i,R}) \backsim T_{i,D}$. ■

Derivation of equation (4)

We first determine the expected present value from investing in development under USGAAP. Because no information is available regarding whether the rival finished the research stage, firm x will implement the project if it finishes its development stage before the rival does, i.e., if $T + T_{x,D} \leq T_{y,R} + T_{y,D}$. Therefore, the present value of investing in development on date T is given by:

$$PV(T) = \begin{cases} V \cdot e^{-rT_{x,D}}, & \text{if } T + T_{x,D} \leq T_{y,R} + T_{y,D}, \\ 0, & \text{otherwise.} \end{cases} \quad (32)$$

The expected present value at date T from investing D, given that if the rival did not finish the development stage, , i.e., if $T + T_{x,D} \leq T_{y,R} + T_{y,D}$ is given by:Because no information is available regarding whether the rival finished the research stage, the expected present value at date T from investing D, given that if the rival did not finish the development stage, is given by:

$$\begin{aligned} \Pi^{\text{both}|\text{ USGAAP}}(T) &= E\left[PV(T)\,|T_{y,R} + T_{y,D} \geq T\right] \\ &= E\left[e^{-rT_{x,D}} \cdot V \cdot I_{(T_{x,D}+T \leq T_{y,R}+T_{y,D})}\right]/P(T_{y,R} + T_{y,D} \geq T), \end{aligned}$$

where $I_{(T_{x,D}+T \leq T_{y,R}+T_{y,D})}$ is a random variable that equals 1 if $T_{x,D} + T \leq T_{y,R} + T_{y,D}$, and zero otherwise.

Using (29) and (30) yields

$$
\begin{aligned}
\Pi^{\text{both}|\text{ USGAAP}}(T) &= \left[\int_T^\infty \int_0^{s-T} Ve^{-rt}\theta e^{-\theta t}\frac{\theta\lambda\left(e^{-\lambda s}-e^{-\theta s}\right)}{\theta-\lambda}dtds\right] / \left[\frac{\theta e^{-\lambda T}-\lambda e^{-\theta T}}{\theta-\lambda}\right] \\
&= \int_T^\infty \int_0^{s-T} Ve^{-rt}\theta e^{-\theta t}\frac{\theta\lambda\left(e^{-\lambda s}-e^{-\theta s}\right)}{\left(\theta e^{-\lambda T}-\lambda e^{-\theta T}\right)}dtds \\
&= \frac{V\theta}{\left(\theta e^{\theta T}-\lambda e^{\lambda T}\right)}\left[\frac{\theta e^{\theta T}}{\lambda+\theta+r}-\frac{\lambda e^{\lambda T}}{2\theta+r}\right].
\end{aligned}
$$

Derivation of equation (8)

Without loss of generality, we assume that firm x is the first to finish research. Given that firm x finishes research first, i.e., $T_{x,R} \leq T_{y,R}$, and given that $T_{x,R} = T$, the expected present value of the benefits to both firms on date T is given by

$$
V \cdot E\left[e^{-r\cdot\min\left\{T_{x,D},\widetilde{T}_{y,R}+T_{y,D}\right\}}\right],
$$

where $\widetilde{T}_{y,R}$ again denotes the remaining research time of firm y. Note that

$$
\begin{aligned}
E\left[e^{-r\cdot\min\left\{T_{x,D},\widetilde{T}_{y,R}+T_{y,D}\right\}}\right] &= E\left[e^{-r\cdot\left(\widetilde{T}_{y,R}+T_{y,D}\right)}\cdot I_{\left(\widetilde{T}_{y,R}+T_{y,D}\leq T_{x,D}\right)}\right] \\
&\quad +E\left[e^{-r\cdot T_{x,D}}\cdot I_{\left(\widetilde{T}_{y,R}+T_{y,D}>T_{x,D}\right)}\right].
\end{aligned}
$$

The first term on the right-hand-side represents the case where the firm that finishes research second is the first to finish development, i.e., $\widetilde{T}_{y,R}+T_{y,D} \leq T_{x,D}$. The second term on the right-hand-side represents the case where the firm that finishes research second is the second to finish development, i.e., $\widetilde{T}_{y,R}+T_{y,D} > T_{x,D}$. We will consider each term separately, and will denote s for a realization of $\widetilde{T}_{y,R}+T_{y,D}$, and t for a realization of $T_{x,D}$.

Using Lemma 6 and Lemma 7 yields

$$\begin{aligned} E\left[e^{-r\cdot\left(\widetilde{T}_{y,R}+T_{y,D}\right)}\cdot I_{\left(\widetilde{T}_{y,R}+T_{y,D}\leq T_{x,D}\right)}\right] &= \int_0^\infty\int_0^t e^{-rs}\theta e^{-\theta t}\frac{\theta\lambda\left(e^{-\lambda s}-e^{-\theta s}\right)}{\theta-\lambda}dsdt \\ &= \frac{\theta\lambda}{(2\theta+r)(\theta+\lambda+r)}, \end{aligned} \tag{33}$$

and

$$\begin{aligned} E\left[e^{-r\cdot T_{x,D}}\cdot I_{\left(\widetilde{T}_{y,R}+T_{y,D}>T_{x,D}\right)}\right] &= \int_0^\infty\int_0^s e^{-rt}\theta e^{-\theta t}\frac{\theta\lambda\left(e^{-\lambda s}-e^{-\theta s}\right)}{\theta-\lambda}dtds \\ &= \frac{\theta(\lambda+2\theta+r)}{(\lambda+\theta+r)(2\theta+r)}. \end{aligned} \tag{34}$$

Adding the values of (33) and (34) yields the appropriate discount factor, which multiplied with V equals:

$$\frac{V\theta(2\lambda+2\theta+r)}{(2\theta+r)(\theta+\lambda+r)}. \tag{35}$$

Next, we consider the expected present value on date T of the development investment costs of the two firms. Because firm x invests D on date T, and firm y invests D on date $T_{y,R}$ if and only if firm x is not producing at that time, i.e., if $\widetilde{T}_{y,R}\leq T_{x,D}$, the expected present value of investment costs equals:

$$\begin{aligned} & D+E\left[e^{-rT_{y,R}}\cdot I_{\left(\widetilde{T}_{y,R}\leq T_{x,D}\right)}\right]\cdot D \\ = \; & D\cdot\left(1+\int_0^\infty\int_0^x \lambda e^{-\lambda z}\theta e^{-\theta x}e^{-rz}dzdx\right) \\ = \; & \frac{(\theta+2\lambda+r)\,D}{\theta+\lambda+r}. \end{aligned} \tag{36}$$

Using (35) and (36), the combined value of the project to the two firms on date T under USGAAP is:

$$\frac{1}{\lambda+\theta+r}\left[\frac{V\theta(2\lambda+2\theta+r)}{2\theta+r}-D(2\lambda+\theta+r)\right].$$

Derivation of equation (13)

When it is known that the rival did not finish the research stage, we know from Lemma 7 that the remaining research time of firm y, $\widetilde{T}_{y,R} = T_{y,R} - T$ is exponentially distributed with parameter λ. Therefore, the expected present value at date T from investing D is given by

$$\begin{aligned}
\Pi^{\text{IFRS}|\text{rival second}} &= E\left[PV|T_{y,R} \geq T\right] \\
&= V \cdot E\left[e^{-rT_{x,D}} \cdot I_{(T_{x,D} \leq \widetilde{T}_{y,R} + T_{y,D})}\right] \\
&= V \cdot \int_0^\infty \int_0^s e^{-rt}\theta e^{-\theta t} \frac{\theta\lambda\left(e^{-\lambda s} - e^{-\theta s}\right)}{\theta - \lambda} dtds \\
&= \frac{V\theta(\lambda + 2\theta + r)}{(\lambda + \theta + r)(2\theta + r)}.
\end{aligned}$$

Derivation of equation (14)

When it is known that the rival did finish the research stage, the remaining development time of the rival $\widetilde{T}_{y,D} = T_{y,R} + T_{y,D} - T$ is exponentially distributed with parameter θ. The expected present value at date T from investing $\widetilde{D}$ is given by

$$\begin{aligned}
\Pi^{\text{IFRS}|\text{rival first}} &= E\left[PV\,|T_{y,R} \leq T \leq T_{y,R} + T_{y,D}\right] \\
&= V \cdot E\left[e^{-rT_{x,D}} \cdot I_{(T_{x,D} \leq \widetilde{T}_{y,D})}\right] \\
&= V \cdot \int_0^\infty \int_0^s e^{-rt}\theta e^{-\theta t}\theta e^{-\theta s} dtds \\
&= \frac{\theta V}{2\theta + r}
\end{aligned}$$

Derivation of (18)

First compare $\hat{R}_m$ to $\hat{R}_l$. Taking the difference and multiplying by a positive constant yields:

$$(\hat{R}_m - \hat{R}_l)\frac{2\lambda + r}{\lambda} = \frac{\lambda(D(r+\theta)(r+2\theta) - r\theta V)}{(r+\theta)(r+2\theta)(r+\lambda+\theta)},$$

which is increasing in D. The denominator is clearly positive. Evaluating the numerator at the lower bound $D = \frac{V\theta}{2\theta+r}$ yields a value of the numerator equal to $\lambda\theta^2 V$. Therefore $\hat{R}_m > \hat{R}_l$ for all $D > \frac{V\theta}{2\theta+r}$.

The difference $\hat{R}_h - \hat{R}_m$ is equal to

$$\frac{\lambda^2(\theta V - D(r+\theta))}{(r+\theta)(r+2\lambda)(r+\lambda)},$$

which is positive because $D < \frac{\theta V}{r+\theta}$.