Option to reveal an R&D Investment

by

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Bibliographical Statement

Francisco José da Silva Gonçalves is 25 years old and was born in Barcelos, a small town in the north of Portugal. Francisco completed a bachelor in Economics at the School of Economics and Management of the University of Porto (FEP), before joining the Master in Finance at the same school. Nowadays, Francisco is having his first professional experience, working as an actuary, in the Retirement Service Center at Mercer, a subsidiary of Marsh & McLennan Companies, in Lisbon. During the Master in Finance, he developed a special interest in the real options field and really enjoyed the process of academic investigation. This sentiment makes him believe that the Master in Finance will not be the last academic experience of his life.

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Abstract

Research & Development (R&D) projects comprise several risk factors. In particular, they carry two types of uncertainty. Stochastic uncertainty related to the expected cash flow of the project and probabilistic uncertainty that captures the likelihood of innovation happen. Furthermore, R&D investments are likely to be hidden from the market. Sometimes companies choose to disclose the investment at the moment they make it, sometimes choose to wait for a while after investing, in some cases they never reveal it in case of failure of the research and in other cases they choose to signal the will to investing to the market before the investment itself. The decision to reveal an investment in R&D is a powerful tool that managers hold to maximize the value of their companies and they have flexibility about the timing of doing so. Therefore, the decision to do reveal an investment in R&D is an option for the company that should be exercised in the optimal timing.

We developed a real options model, with three different settings, which aims to demonstrate that the optimal decision for the moment of revelation varies according to the parameters of the model. The three settings are: the benchmark setting; the compound option setting (monopoly and exogenous competition); and the independent options setting. In the first setting, it is assumed that both options are a unique one and therefore always exercised at the same time. In the second, it is considered that the option to reveal the investment is received when the firm invests, assumption inspired in Delaney and Thijssen (2015). In this setting, we take two different approaches. In the first one, the firm does not face any competition at all, so we consider that the firm is enrolled in a monopoly framework. In the second approach, we assume that there is exogenous competition over the option to reveal the investment. In the last setting, we abandon the assumption of the compound option and allow the firm to disclose information before investing if this is the optimal behavior. We show that, depending on the parameters, other strategies can be better than the benchmark strategy. In addition, we also found theoretical evidence demonstrating that every time the firm must choose to reveal before investing, the optimal timing to exercise the option to invest will be anticipated relative to the case where it would be better to invest and reveal later, due to reputational cost savings.

Keywords: Voluntary Disclosures, R&D Investment, Real Options, Announcement Options
JEL codes: D82; G31; O32

Resumo

Projetos de Investigação & Desenvolvimento (I&D) comportam vários fatores de risco. Nomeadamente, estão associados a dois tipos de incerteza. Incerteza estocástica, relacionada com o *cash flow* esperado do projeto e incerteza probabilística, que capta a probabilidade da inovação acontecer. Além disso, investimentos em I&D são passíveis de ser escondidos do mercado. Por vezes as empresas optam por revelar o investimento no momento em que o fazem, outras vezes optam por esperar algum tempo, nalguns casos nunca chegam a revelar que o fizeram em caso de fracasso da investigação e noutros até optam por sinalizar ao mercado a intenção de investir antes de o fazer. A decisão de revelar um investimento em I&D é uma ferramenta poderosa que os gestores detêm para maximizar o valor das suas empresas e sobre a qual detêm flexibilidade. Por isso, esta é uma opção para a empresa que deve ser exercida no momento ótimo.

Desenvolvemos, então, um modelo de opções reais com três fases, onde procuramos demonstrar que a decisão ótima para o momento de revelação pode variar de acordo com os parâmetros do modelo. As três fases são: fase de *benchmark*; fase da opção composta (monopólio e competição exógena); e a fase das opções independentes. Na primeira fase, é assumido que as duas opções são apenas uma e portanto sempre exercidas ao mesmo tempo. Na segunda, considera-se que a opção de revelar o investimento é recebida no momento em que se investe, pressuposto inspirado em Delaney and Thijssen (2015). Dentro desta fase da opção composta, temos duas diferentes abordagens. Na primeira, a empresa não enfrenta qualquer concorrência e portanto estabelecemos que a empresa está inserida num contexto monopolístico. Na segunda abordagem, assumimos que existe competição exógena sobre a opção de revelar o investimento. Na última fase, abandonamos o pressuposto da opção composta e permitimos que a empresa possa revelar informação antes de investir caso esse seja o comportamento ótimo. Provamos que, dependendo dos parâmetros, outras estratégias podem ser melhores que a de *benchmark*. Além disso, também encontramos evidência teórica que demonstra que sempre que uma empresa deva optar por revelar informação antes de investir, o momento ótimo para exercer a opção de investir será antecipado em relação ao caso em que é ótimo investir e só depois revelar, devido à poupança de custos reputacionais.

Palavras-chave: Revelações voluntárias, Investimentos em I&D, Opções Reais, Opções de revelação
Classficações JEL: D82; G31; O32

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Chapter 1

Introduction

An investment in an R&D project differs from a standard investment in what concerns to its uncertainty. R&D investments have two sources of uncertainty: the technological success of the R&D process; and the stochastic path of the potential profit flow as time goes by. In our model, the technological uncertainty is captured by an hazard rate similar to the one presented by Weeds (2002), the first model in real options literature combining both kinds of uncertainties.

R&D investments also have the particularity of being easily hidden from the market. Sometimes managers, because they do not want to reveal information that could be an advantage to peer companies or just because they do not believe that the optimal timing to reveal has already come, hide investments in R&D projects, keeping this information private. Actually, sometimes managers hide investments from the market until the new product is ready to be commercialized. But other times, managers follow other strategies, like revealing the investment during the R&D process or even before investing. Some examples of these different strategies are the following:

- Google X, the department of Google responsible for R&D projects, has announced the development of the self-driving car, during the R&D process and in presence of technological uncertainty. On May 2016, Google announced a partnership with Chrysler and the likelihood of innovation happen has clearly increased in the recent past.

- Steve Jobs announced in 2010 that the iPad was developed before the iPhone. Nevertheless, the announcement of the development of the iPad was postponed until almost three years after the iPhone being launched. Steve Jobs realized that the moment the iPad was ready to be commercialized was not even the optimal timing to announce it.[1]

- Jean-Philippe Courtois, Microsoft International President, announced on April 7th 2011 that the company would invest around 8.64 billion USD in R&D in the cloud strategy. This is a good example of an announcement about an investment that would be done afterwards.

As one should realize, there are several strategies about the timing of revealing an R&D investment and they should not be randomly decided, since they have impact on the market value of the firm (Ba et al. (2013); Kelm et al. (1995); Woolridge and Snow (1990)). This decision about the timing of revealing information is an option for the manager of the firm. Once the information is revealed, the consequences can be irreversible, with impact on a profit flow that is also uncertain and clearly the manager has flexibility to choose the timing for revealing the information. For that reason, it is also surprising why real options literature is scant on this topic.

Our model contemplates three steps. The first one will be the most intuitive strategy. The firm invests and reveals the investment at the same time. We state this as the benchmark strategy and it is in accordance with a full disclosure equilibrium presented in seminal papers by Grossman (1981) and Milgrom (1981). The second step is the compound option setting, inspired in the assumption of Delaney and

[1] This story also inspired Delaney and Thijssen (2015).

Thijssen (2015), where we consider that the firm will only reveal information about the R&D project after investing. This happens because the option to reveal is received when the option to invest is exercised. Within this setting, we consider two different approaches. The first one is the monopoly setting, where the firm does not face any competition. The other one is the exogenous competition setting, where the firm faces competition over the option to reveal the investment. Thus we expect that in this setting the firm will tend to reveal sooner than in the monopoly setting, as the likelihood of competition increases. Finally, in the last setting of the model we abandon the assumption of Delaney and Thijssen (2015), to allow the firm, if perceiving it as optimal, to reveal information about the investment opportunity, even before investing. To the best of our knowledge, this is the first academic work to cover an announcement option about an R&D investment under Real Options approach.

The dissertation is structured as follows. Chapter 2 presents a literature review of the main topics of the dissertation, including R&D literature (real options and voluntary disclosures), disclosure literature and announcement optionality literature. Chapter 3 presents the model and its implications. Chapter 4 concludes the dissertation, presenting some discussion about the model, main conclusions and future research.

Chapter 2

Literature Review

Typically, an R&D investment is a risky one, since the firm undertakes a project without knowing if it will get profit flow afterwards because the innovation may never happen. Therefore, this kind of investment has clearly two sources of uncertainty. On the one hand, there is uncertainty about the potential profit flow that evolves stochastically as any other standard investment opportunity. On the other hand, there is uncertainty regarding the technological success of the project, i.e. the likelihood of innovation actually happen. This latter uncertainty has been modeled in the literature as a Poisson arrival rate (see e.g.: Loury (1979), Dasgupta and Stiglitz (1980), Lee and Wilde (1980), Reinganum (1983), Dixit (1988)). However, the first paper combining both kinds of uncertainties, economical and technological, in a single model was Weeds (2002). The author assumed the existence of a parameter that captured the likelihood of a breakthrough taking place and called it hazard rate.

Taking into consideration the features of an R&D project and also that this kind of project might be hidden from the market or sometimes never be revealed, for instance when discovery never happens, it is intuitive that revealing an investment in R&D is a powerful tool for any firm and it should not be randomly managed.

The objective now is to understand what, according to the literature, drives the information release by the firms, especially about R&D investments.

One could wonder which impact regulatory requirements have on corporate disclosures. Beyer et al. (2010) argue that there is a lot of empirical evidence suggesting a substantial part of information available to the market comes from voluntary disclosures. James (2011) defines voluntary R&D disclosure as "*information about the nature of R&D activities such as the initiation of a research project, direction of a research stream, intermediate R&D success, or strategic significance of R&D efforts. Such disclosures occur in the pre-commercialization stage of the innovation process and often prior to the filing of a patent application. Disclosure is voluntary because it provides information that exceeds mandatory disclosure requirements by regulators such as the FDA, the SEC, and the USPTO disclosure requirements. Moreover, because managers control the content of these disclosures, they reflect managerial choice, and are arguably more strategic.*"

In the presence of R&D projects, voluntary disclosures clearly assume an important role. Woolridge and Snow (1990) analyzed the way in which a strategic investment publicly announced, such as an R&D project disclosure, *inter alia*, has impact in the stock prices. They found empirical evidence, analyzing 767 strategic investment decisions announced by 248 companies in 102 industries, showing that there is a positive reaction. The authors justify this result arguing, "*stock market rewards managers for developing strategies that increase shareholder wealth*". Kelm et al. (1995) also analyzed the impact of R&D announcements in the US capital markets and among other things, concluded that markets positively reacted to announcements like new information about both project continuations and new product introductions in the case of well established industries, and also to project initiation and project continuation announcements in the case of the biotechnology industry. Ba et al. (2013) examined whether the stock market positively reacted to automaker's announcements of global green vehicle innovations over the period 1996-2009. The authors found a positive reaction of stock markets to those announcements, even after controlling for firm size, leverage, profitability, R&D intensity and oil price changes. Nekhili et al. (2012) also found empirical evidence showing that voluntary R&D disclosure improves equity market value of the disclosing firm.

Since R&D investments are considered a huge source of agency problems, due to the asymmetric information between managers and stakeholders and the great uncertainty of the projects, R&D discretionary disclosure is a powerful tool that can help managers maximize their firm's value. Healy and Palepu (1993) showed that more R&D disclosures reduce asymmetric information. Nagar et al. (2003) claim that asymmetric information between managers and stakeholders can lead to a non-reflection of R&D investments into stock prices. Therefore, R&D credible disclosures are a powerful tool for managers.

All these findings inspired our model, as it will accommodate a positive reaction to an R&D investment announcement made by the firm. An implicit assumption of our model is that markets are efficient in the semi-strong form as it was early stated by Malkiel and Fama (1970). So the market cannot observe any private investment made by the firm until the information is publicly disclosed. In that moment, the market will react and update its beliefs about the firm and its market value.

Although revealing an R&D investment will have a positive impact in the market valuation of the firm, one could argue against that fact advocating that by revealing the investment in R&D, the firm clearly faces the risk of imitation and might jeopardize the success of the project. James (2011) argued that, without need of financing and in the absence of legal requirement, revealing an investment in R&D might be a puzzle.

A lot of academic studies addressed this question and the results show that depending on some features, like the business or the type of firm (see e.g.: Healy and Palepu (1993); Ahmed and Shehata (2015)), it might be beneficial to reveal an investment. Ghnaya (2015) found empirical evidence proving that R&D strategy disclosures are different depending on internationality degree, industry type, firm size and R&D intensity. De Fraja (1993) showed that technological leaders, firms with technological advance, tend to disclose more R&D processes, because the benefits of deterring R&D competition outweigh the costs of being imitated. However, for firms that are technological followers, the costs are more likely to cancel out the benefits. Bag and Dasgupta (1995) argued that the type of firm influences the speed of success of the R&D process, because some firms are more likely to make innovation happen once they have higher hazard rates and found that if the success occurs in the beginning of the process, the firm is more likely to be one of those with higher hazard rates and reveal the success. In this case, by revealing the success, the firm will drop out the peers in the R&D race.

Considering now the way how firms disclose R&D information, Li et al. (2014) found empirical evidence from China showing that the firm's value vary depending on the methods chosen to reveal R&D investments. Specifically, the firms that chose to capitalize their R&D investments have higher stock price and return. On the contrary, the companies that would rather expense their R&D expenditures have lower stock price and return. James (2011) argues that the way in which disclosure is done impacts market reaction. The author showed that strategic disclosures create value for the company, creating a sustainable advantage and discouraging the imitators and peer's patenting applications.

Literature is extensive explaining why R&D disclosures happen. Jones (2007) points out three important reasons: information asymmetry, proprietary costs and firm characteristics. A literature review made by Beyer et al. (2010) also pointed out proprietary costs, liquidity and cost of capital, as reasons for information disclosures. Information asymmetry happens when the manager has access to firm-specific information before the market. This information will become public most of the times either as time goes by or through an information disclosure (Dierkens et al. 1991). Regarding the liquidity, Beyer et al. (2010) found a lot of evidence in literature showing that information disclosures decrease information asymmetries and consequently the firm's stock liquidity is increased. Leuz and Verrecchia (2000) show that firms that have adopted a high quality reporting regime exhibited lower information asymmetry reflected by lower bid-ask spreads and higher trading volumes. Tang (2014) argues providing theoretical evidence that as the uncertainty about the project is reduced by the disclosure of information, consequently the cost of capital should be reduced. Coller and Yohn (1997) found evidence showing that voluntary disclosures are higher when a firm's bid-ask spread is larger than the rival in the previous period relative to the disclosure.

Suijs (2005) defines proprietary costs as the ones that a firm incurs as the opponents react to information disclosure. For instance, if after an earnings announcement, a new firm enters in the market, the market share that goes to that firm is a proprietary cost. Seminal works of Grossman (1981) and Milgrom (1981) in disclosure literature assumed that managers follow a full disclosure policy, because if they did not, the market would discount the value of the firm, once it would expect the worst about the hidden information. But this is not a realistic conclusion. For instance, several authors argued that a manager would only disclose proprietary information when the increase in the firm's value exceeded those proprietary costs ((Dye 1985); (Jovanovic 1982); (Verrecchia 1983)). Therefore sometimes it might be optimal for a manager to reveal information if by doing so, proprietary costs can be avoided. James and Shaver (2008) stated that firms with technological advantages have incentives to reveal R&D investments in order to deter competition and avoid proprietary costs. Moreover, Jones (2007) found that higher proprietary costs are associated with lower levels of information revealed about R&D investments in a study with a sample of 119 R&D-intensive firms. On the other hand, Choi (1991) argued that success in an R&D project can be seen as good news to the peers, since it will encourage the firm to continue the process, in the sense of "*if you can do that, why not me?*"'. This argument clearly supports the idea that more disclosures would increase the proprietary costs. Suijs (2005) presented the existence of two costs, this proprietary cost and also a disclosure cost that has been earlier presented by Verrecchia (1983). The disclosure cost is the fixed cost of releasing information. Its existence is indispensable for the equilibrium we find in Suijs (2005) and without it, the equilibrium on this model would be just the same as in Wagenhofer (1990).

A complementary study was presented by Coff et al. (2007) in which they found other strategic reasons for voluntary R&D disclosures. The reasons are the need for complementary resources, exploitation of some advantages such as, for instance, marketing or secure licensing agreements and managerial opportunism, whereby timing of releasing information is considered crucial for the manager's wealth.

Since disclosing an R&D investment is part of a huge field in the literature about corporate disclosures, we find it interesting to analyze the most important determinants of corporate disclosures. Beyer et al. (2010) present some of the reasons for voluntary disclosures discussed in the literature.

The first one is related to the capital market transactions. After earnings announcements, i.e. in the presence of good information, which increases the firm's value, firms are most likely to issue equity, because managers believe firms in those cases might be overpriced (Korajczyk et al. 1991). The same happens when companies use equity to finance their acquisition (Ge and Lennox 2011).

Another reason is the stock-based compensation and corporate control contests. Sometimes managers disclose or hide information in order to avoid shareholder's reaction. Of course, at the limit, if the manager is the owner of the company, this problem does not exist but the disclosure discussion still remains. Noe (1999) presented empirical evidence showing that after good news announcements managers tend to sell more shares than after bad news announcements and buy more after bad news announcements than good news releases. Moreover, managers also benefit from having options over the firm's stocks and tend to time information disclosure according to their own benefit (Aboody and Kasznik 2000). Kothari et al. (2009) found empirical evidence showing that managers tend to delay the release of bad news in comparison to good news. The paper argues that good information is quickly disclosed, whereas bad information is usually withheld. The authors argued that the agency conflict given by the misalignment between managerial and shareholders' disclosure preferences might be one of the most important reasons for this phenomenon.

The relation between agency costs and information disclosure has been deeply discussed on literature. Lo et al. (2010) found empirical evidence showing that an advanced quality corporate governance, given by the percentage of independent directors, percentage of parent directors and having financial experts on audit committees, reduces the manipulation on earnings announcements. Chung et al. (2015) also found that firms making more comprehensive information disclosures, in the presence of high quality corporate governance, alleviate agency conflicts. Since we are now able to recognize the importance of agency costs when dealing with the question of information disclosure, we also want to point out an important paper that presents a model under the real options methodology. Grenadier and Wang (2005) present a model on whether managers, taking into account the existence of agency conflicts and information asymmetries, time investment or not. The model finds theoretical evidence for greater inertia regarding investment timing since the manager's option to wait is more valuable than the owner's. Moreover, in order to show the pertinence of a real options model to the disclosure topic, we present you the evidence found by Graham et al. (2005). This paper shows that managers hide information because they believe that something better can happen in the future. Intuitively, managers wait to disclose bad information, expecting that uncertain future bring better news.

When a manager faces information disclosures, he has to be aware of the impact in terms of reputation. Every time managers hide information, they might face litigation risk. Skinner (1994) points out litigation risk as a motivation for managers to quickly reveal bad information, in order to avoid lawsuits. However, Nagar et al. (2003) defend that career concerns might motivate managers to hide bad information and gamble that subsequent corporate events will allow them to hide the information forever. Once again, managers expecting better news coming from the uncertain future. Somehow, managers face a trade-off between reputation cost and litigation risk.

The decision to voluntarily reveal an investment in R&D or any other information has a flavor of optionality. Real options literature has made a scarce approach to this issue. The first paper to recognize the announcement option was Dempster (2006). The author addressed the problem with a practical case and considered that the announcement would increase the volatility of the underlying profit flow. Therefore, the additional value created by the announcement would come from the increase of volatility. It is surprising that this option was only addressed in real options literature so recently. As Delaney and Thijssen (2015) argued, the announcement option has three important characteristics: it is irreversible, the payoff is uncertain and in the case of an R&D investment has two sources on uncertainty, and finally the manager has clear flexibility upon the timing to disclose the information. Related to our work, the model by Delaney and Thijssen (2015) considered the option to disclose as a compound option, acquired after exercising the investment. The manager would only reveal the investment after receiving a certain number of net positive signals coming from the market. To the best of our knowledge, there is no academic work addressing the option to disclose an R&D investment using real options methodology and this is the gap we want to cover in the literature.

Chapter 3

The Model

The decision-taker, the firm, has two related options, to invest and to reveal the investment. The firm needs to decide when it is optimal to exercise each of them. The most intuitive and obvious strategy regarding the revelation of the investment is to communicate it to the market immediately after investing. Thus, we would say that a natural strategy is to have both options exercised at the same time. As long as the firm invests, it will reveal the action to the market. We expose this strategy in the benchmark setting. We will show that other strategies might be optimal relative to the benchmark strategy depending on the relevant parameters of the model and the optimal stopping regions.

Inspired in Delaney and Thijssen (2015) we will consider the option to invest and to reveal the investment in a compound option setting: the option to reveal an investment is received when the firm invests.[1] Consequently, the alternative strategy is to consider the existence of two different optimal timings to invest and to reveal the investment. The intuition is straightforward. The firm invests and hides the

[1] A nice argument to support this compound option approach is related to the internal policy of releasing information of a firm. According to James (2011), some managers assume that only release information about R&D projects, when the product is ready to be launched. So it is not totally unrealistic assume that a firm will only reveal information about a project after investing, although sometimes it can be optimal to do it before.

action from the market, until the moment that it is optimal to reveal it.

Then, we extend the model considering the existence of exogenous competition over the option to reveal the investment. In other words, the model accommodates a new parameter that captures the likelihood of a peer company publicly announcing to the market an investment in a project on the same business opportunity before the firm. If a peer does so, the option to reveal the investment in that specific project becomes worthless, since the impact of being an innovator from the viewpoint of the market disappears, even if the firm announces the investment after the peer. The market will not react to a second announcer, since this latter is perceived as an imitator with lower probability of success on the R&D process.

Finally, we extend the model abandoning the assumption of the compound option. Assuming that sometimes it might be optimal to release information about an investment opportunity before investing, we will present the independent options setting. This turn, we no longer consider that the option to reveal is received after the option to invest being exercised, but both options are just related.

3.1 The benchmark setting

The model will be developed through a contingent claim analysis, early presented by Dixit and Pindyck (1994) and the profit flow X is assumed to follow a geometric Brownian motion (gBm):

$$dX = \alpha X dt + \sigma X dz \tag{3.1}$$

where α is the growth rate of profit flow, σ represents its standard deviation and dz is the increment of Wiener process.

In order to solve our conundrum, we need to start by computing the value of the active project. In other words, the value of the project after investing and revealing the investment might be found solving the following ordinary differential equation (ODE):

$$\frac{1}{2}\sigma^2 X^2 V''(X) + \alpha X V'(X) - rV(X) - c - k + h\left(\frac{X}{r-\alpha} - V(X)\right) = 0 \quad (3.2)$$

where c is an R&D continuous cost, that starts at the moment the firm invests and lasts until the innovation happens,[2] k is a reputational cost that starts at the moment the firm reveals the investment to the market and will cease to exist when the innovation happens,[3] r is the risk-free rate of return and $V(X)$ is the value of the active R&D project. The last term of the left-hand side of the equation (3.2) captures the probabilistic uncertainty about this option, where h is the parameter that captures the likelihood of the innovation happening. If the breakthrough happens, the firm will start receiving cash flows from the new product by the amount of $\frac{X}{r-\alpha}$. The parameter h follows a Poisson distribution. This parameter is similar to the hazard rate presented by Weeds (2002). The solution that satisfies the equation (3.2) and gives us the value of the active R&D project is

$$V(X) = C_1 X^{\beta_1} + C_2 X^{\beta_2} + \frac{h}{h+r-\alpha}\frac{X}{r-\alpha} - \frac{c+k}{r+h} \quad (3.3)$$

We assume that once the option is exercised, the process will only end up when the innovation happens, therefore there is no additional flexibility.[4] Thus, the constants C_1 and C_2 are set equal to zero, and the value of the active project is:

$$V(X) = \frac{h}{h+r-\alpha}\frac{X}{r-\alpha} - \frac{c+k}{r+h} \quad (3.4)$$

[2] These R&D costs are the ones that the firm has to pay to keep the R&D process alive, such as maintenance of the investigation laboratory, scientific costs, among others.

[3] The intuition behind this reputational cost is straightforward. If the manager of the firm reveals something that afterwards will not happen, firm's value might be decreased. Nagar et al. (2003) provides good insights on this issue.

[4] Weeds (2002) presented the same assumption.

At this time, it would be interesting to highlight that the value of the active project after investing and without revealing it to the market is the same but not considering the reputational cost, given by the parameter k. Please notice that the expected value of the continuous costs, both R&D and reputational, are decreasing as the probability of innovating increases.

After computing the value of the active R&D project, $V(X)$, we can find the value of the option to invest and to reveal the investment at the same time, and its optimal trigger. In the benchmark setting, both options are considered an unique one. Let $B(X)$ represent the value of the option to invest and reveal. $B(X)$ should satisfy the following ODE:

$$\frac{1}{2}\sigma^2 X^2 B''(X) + \alpha X B'(X) - rB(X) = 0 \tag{3.5}$$

The solution for this ODE is well-known and is stated as follows:

$$B(X) = A_1 X^{\beta_1} + A_2 X^{\beta_2} \tag{3.6}$$

where, β_1 and β_2 are respectively the positive and negative roots of the fundamental quadratic equation:

$$\frac{1}{2}\sigma^2 \beta(\beta - 1) + \alpha\beta - r = 0 \tag{3.7}$$

Therefore, the equations of β_1 and β_2 are:

$$\beta_1 = \frac{1}{2} - \frac{\alpha}{\sigma^2} + \sqrt{\left(\frac{\alpha}{\sigma^2} - \frac{1}{2}\right)^2 + 2\frac{r}{\sigma^2}} > 1 \tag{3.8}$$

$$\beta_2 = \frac{1}{2} - \frac{\alpha}{\sigma^2} - \sqrt{\left(\frac{\alpha}{\sigma^2} - \frac{1}{2}\right)^2 + 2\frac{r}{\sigma^2}} < 0 \tag{3.9}$$

Since all the options we will value in this model are typically american call options, the first boundary condition of all models will be similar to the one in equation (3.10). Since β_2 is negative, we need to ensure that every time X increases, the value of the option will also increase, so we state the constant A_2 equal to 0.

$$B(0) = 0 \tag{3.10}$$

This assumption will follow us in all the models addressed henceforth. Thus the value of the option takes the form:

$$B(X) = AX^{\beta} \tag{3.11}$$

being $A \equiv A_1$ and $\beta \equiv \beta_1$ henceforth.

Since two unknowns are still remaining to be determined, $B(X)$, the value of the option, and X_B^*, the trigger which determines what is the optimal timing to exercise the option, we need to state the two additional boundary conditions. Equation (3.12) is the value-matching condition and represents the value of the option at the moment the firm invests and reveals. In other words, it is the value of the active project net of the fixed cost of investment, I, and the fixed cost of releasing information, K,[5] and also considering the incremental and discrete benefit of revealing the investment to the market, captured by the multiplier $(1+\gamma)$.[6] Equation (3.13) is the first derivative of equation (3.12) and it is the so-called smooth-pasting condition.

$$B(X_B^*) = (1+\gamma)\frac{h}{h+r-\alpha}\frac{X_B^*}{r-\alpha} - \frac{c+k}{r+h} - I - K \tag{3.12}$$

$$B'(X_B^*) = (1+\gamma)\frac{h}{(h+r-\alpha)(r-\alpha)} \tag{3.13}$$

[5]The fixed cost of releasing information has been discussed in literature. For instance, Suijs (2005) presented this parameter in his model.

[6]This incremental benefit from revealing an investment in R&D that impacts the firm's market value is well documented in the literature (Ba et al. (2013); Kelm et al. (1995); Woolridge and Snow (1990)). We will assume, for ease of exposition and without loss of generality, that the incremental benefit $(1+\gamma)$ will impact on the profit flow.

Applying both equations (3.12) and (3.13) to equation (3.11), we find the trigger X_B^* and the value function $B(X)$.

$$X_B^* = \frac{\beta}{\beta - 1}\frac{(h + r - \alpha)(r - \alpha)}{(1 + \gamma)h}\left(\frac{c + k}{r + h} + I + K\right) \tag{3.14}$$

$$B(X) = \begin{cases} \left((1 + \gamma)\frac{h}{h + r - \alpha}\frac{X_B^*}{r - \alpha} - \frac{c + k}{r + h} - I - K\right)\left(\frac{X}{X_B^*}\right)^{\beta} & , X < X_B^* \\ (1 + \gamma)\frac{h}{h + r - \alpha}\frac{X}{r - \alpha} - \frac{c + k}{r + h} - I - K & , X \geqslant X_B^* \end{cases} \tag{3.15}$$

3.2 The compound option setting

3.2.1 Monopoly

According to what was stated by Delaney and Thijssen (2015), we assume that the option to reveal the investment will only be received at the moment the firm invests, transforming this conundrum in a compound option problem. Consequently, the problem will be solved backwards, starting by valuing the option to reveal the investment.

Let $D(X)$ define the value of the option to reveal the investment, and X_D^*, the trigger value for revealing it. Moreover, both options to invest and reveal the investment are considered to take a similar form to equation 3.11, because they are american call options. The boundary conditions are the following:

$$D(X_D^*) = \gamma\frac{h}{h + r - \alpha}\frac{X_D^*}{r - \alpha} - \frac{k}{r + h} - K \tag{3.16}$$

$$D'(X_D^*) = \gamma\frac{h}{(h + r - \alpha)(r - \alpha)} \tag{3.17}$$

First, we should clarify why condition given by equation (3.10) also applies to the option to reveal an R&D investment. If the value of the profit flow of the project tends to zero, the project is worthless. So the option to reveal something without value is also worthless. Then, equations (3.16) and (3.17) are once again respectively the value-matching and smooth-pasting conditions. The former reflects the change in the firm's value when the optimal timing to reveal the investment arrives. Thus after revealing the investment, the firm receives the incremental value due to reputational benefits as a function of the state variable given by the parameter γ, but faces an additional reputational cost given by parameter k. The firm also needs to pay the fixed cost for disclosing information.

Substituting equations (3.16) and (3.17) in a equation similar to (3.11), we can determine the constants A and X_D^*. The solutions for the disclosing trigger value X_D^* and the value of the option to reveal the investment given by $D(X)$ are

$$X_D^* = \frac{\beta}{\beta - 1}\frac{(h + r - \alpha)(r - \alpha)}{\gamma h}\left(\frac{k}{r + h} + K\right) \tag{3.18}$$

$$D(X) = \begin{cases} \left(\gamma\dfrac{h}{h + r - \alpha}\dfrac{X_D^*}{r - \alpha} - \dfrac{k}{r + h} - K\right)\left(\dfrac{X}{X_D^*}\right)^{\beta} & , X < X_D^* \\ \gamma\dfrac{h}{h + r - \alpha}\dfrac{X}{r - \alpha} - \dfrac{k}{r + h} - K & , X \geqslant X_D^* \end{cases} \tag{3.19}$$

We already have the value of the option to reveal information and the trigger value to do it. Now we can move backwards and compute the value function for investing in the first place and its optimal timing. Let $F(X)$ define the value of the option to invest and X_F^* its trigger value. $F(X)$ takes a similar form to equation (3.11). The boundary conditions that will lead us to find the solutions for the unkown variables are defined as follows:

$$F(X_F^*) = \frac{h}{h + r - \alpha}\frac{X_F^*}{r - \alpha} - \frac{c}{r + h} - I + D(X_F^*) \tag{3.20}$$

$$F'(X_F^*) = \frac{h}{(h + r - \alpha)(r - \alpha)} + D'(X_F^*) \tag{3.21}$$

The equation (3.20) is the value-matching condition and states the NPV of this investment opportunity in the optimal timing to invest. The firm receives the expected profit flow plus the option to reveal the investment, but spends a given investment cost captured by parameter I, and R&D expenses given by parameter c.

Equation (3.21) represents the smooth-pasting condition. Applying the boundary conditions in the general solution, we find the equations for the trigger value X_F^* and the value function $F(X)$:

$$X_F^* = \begin{cases} \dfrac{\beta}{\beta-1}\dfrac{(h+r-\alpha)(r-\alpha)}{h}\left(\dfrac{c}{r+h}+I\right) & ,X_F^* < X_D^* \\ X_B^* & ,X_F^* \geqslant X_D^* \end{cases} \tag{3.22}$$

$$F(X) = \begin{cases} \left(\dfrac{h}{h+r-\alpha}\dfrac{X_F^*}{r-\alpha} - \dfrac{c}{r+h} - I + D(X_F^*)\right)\left(\dfrac{X}{X_F^*}\right)^{\beta} & ,X < X_F* < X_D^* \\ \dfrac{h}{h+r-\alpha}\dfrac{X}{r-\alpha} - \dfrac{c}{r+h} - I + D(X) & ,X_F^* < X < X_D^* \\ (1+\gamma)\dfrac{h}{h+r-\alpha}\dfrac{X}{r-\alpha} - \dfrac{c+k}{r+h} - I - K & ,X > X_F^* > X_D^* \end{cases} \tag{3.23}$$

Every time $X_F^* \geqslant X_D^*$, the firm will reveal the investment immediately after exercising the option to invest. At that moment the benchmark trigger is applied. The upper branch of X_F^* in equation (3.22) will be used when it is optimal to invest and still keep the option to reveal the investment alive.

Sensitivity analysis to monopoly setting

After introducing the first step of the model, we find it interesting to present a sensitivity analysis to this monopoly setting, in order to check how the model works in a dynamic way. Our decision factors are the trigger values, since the firm should take the respective action whenever the correspondent trigger value is achieved. Table 3.1 summarizes our numerical assumptions for the basic parameters of the model. The assumptions are arbitrarily chosen and based on our best economic intuition.

Applying the numerical assumptions, we find the value of the benchmark trigger, X_B^*, equal to 27.58. In the monopoly setting, we find the investment trigger, X_F^*, equal to 27.25 and the revealing trigger, X_D^*, equal to 30.29. As one may see, since $X_F^* < X_D^*$, the firm should invest and hide the investment from the market until it is optimal to reveal it.

Parameters	Symbol	Assumption
Risk-free rate of return	r	5%
Growth rate of profit flow	α	2%
Profit flow uncertainty	σ	30%
Hazard rate	h	0.35
R&D cost	c	50
Investment cost	I	100
Incremental benefit from revealing	γ	12%
Reputational cost	k	10
Fixed cost of revealing information	K	5

Table 3.1: Numerical assumption for model application

Once the basic parameters of the model can vary within a reasonable range of values, we will run an analytical sensitivity analysis in order to check the behavior of the triggers, when each parameter varies and the implications in the optimal strategy for the firm.

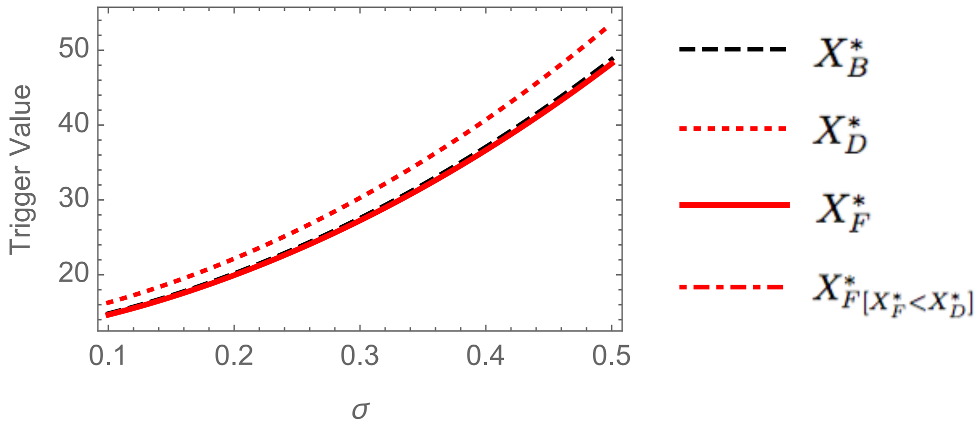

Figure 3.1: Impact of volatility on trigger values in monopoly setting

Figure 3.1 presents a sensitivity analysis where we allow the uncertainty about the profit flow to vary. As it is well established in the real options literature, as the uncertainty increases, the trigger value of an American call option should also increase. It is what happens in this Figure 3.1. Moreover, applying these values, no matter how much the level of uncertainty about the profit flow is, within the considered range of values, the firm should always invest and wait to reveal the investment to the market.

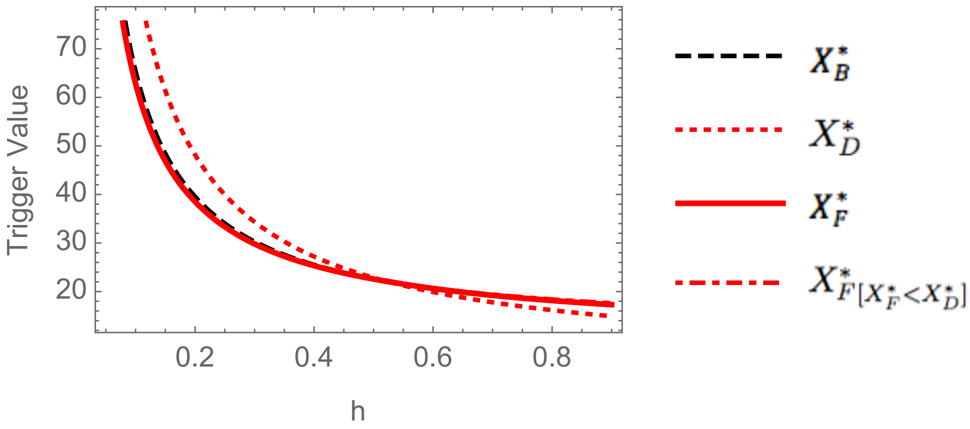

Figure 3.2: Impact of hazard rate on trigger values in monopoly setting

In figure 3.2, the parameter analyzed is h, the mean arrival rate of innovation that captures the technological uncertainty of the project, the so called hazard rate. As h increases, all triggers decrease, since it is more likely the R&D process will generate profit in the future. An interesting conclusion of this analysis is linked to the existence of two regions. For lower values of h, the firm will invest and wait to reveal that to the market. However, for higher values of h, it becomes optimal to reveal as soon as the investment is made. The result is economically intuitive, because higher values of h represent lower technological uncertainty. Thus, the innovation is imminent and there is no advantage in hiding the investment from the market.

Figure 3.3 analyses the behavior of the R&D cost, given by the parameter c. In analytical terms, this parameter present a similar behavior to the fixed investment cost I and, consequently, similar graphics. For that reason, henceforth we will only analyze one of them.

As one should be expecting, X_D^* is absolutely independent of the R&D cost. X_F^* and X_B^* increase as c increases. Therefore, whenever $X_F^* < X_D^*$, the firm will invest

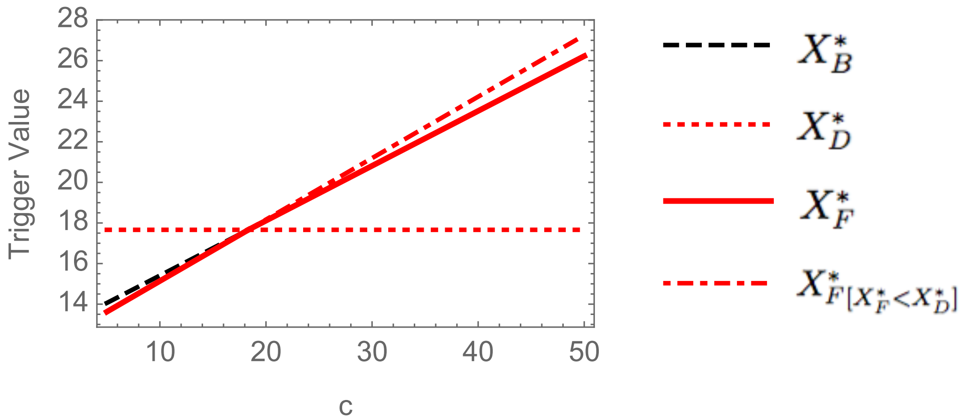

Figure 3.3: Impact of R&D cost on trigger values in monopoly setting

and keep the option to reveal alive until it is optimal to do so. Otherwise, X_B^* is optimally applied.

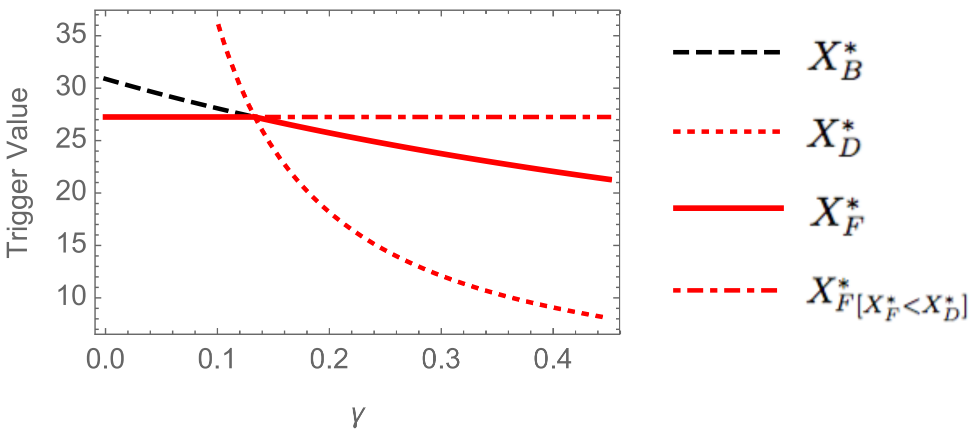

Figure 3.4: Impact of incremental benefit from disclosing on trigger values in monopoly setting

The parameter γ, the incremental benefit from disclosing information, is analyzed in figure 3.4. The upper branch of X_F^* is totally independent of γ. So, every time $X_F^* < X_D^*$, the firm should invest and wait to reveal and, in this region, X_F^* is constant. Otherwise, X_B^* is applied and X_F^* starts decreasing as γ increases.

Both parameters k and K also have similar analysis and plots, so we will only present the analysis of one of them henceforth. As expected, figure 3.5 shows that

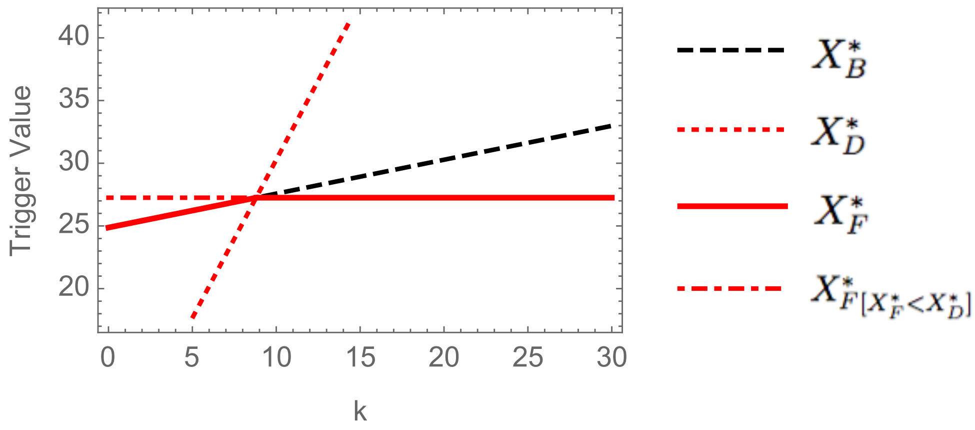

Figure 3.5: Impact of reputational cost on trigger values in monopoly setting

X_D^* increases with k. For lower values of k, X_B^* is applied. When $X_F^* < X_D^*$, the firm will invest, hiding the information until it is optimal to reveal.

3.2.2 Exogenous competition setting

Competition is a very important field within real options literature. So important we cannot ignore it. The focus of our model is clearly to find the optimal timing to reveal the investment to the market. Until now, we have been assuming the firm does not face any competition. Nevertheless, this might not be a fully realistic assumption. If there is any chance of a competitor to arrive and become the innovator from the viewpoint of the market, the firm should clearly adapt the timing of revealing the investment. Intuitively, facing competition the firm should reveal sooner than in the monopoly setting. In other words, the firm will anticipate the announcement, requiring a lower trigger value for revealing the investment.

How should we accommodate this possible competition over the option to reveal the investment? This option no longer satisfies the ODE in equation (3.5). Let $D_C(X)$ be the new value function for the option to reveal an investment in R&D, in presence of exogenous competition. $D_C(X)$ should satisfy the new ODE that is presented in equation (3.24):

$$\frac{1}{2}\sigma^2 D_C''(X) + \alpha X D_C'(X) - rD_C(X) + \lambda(0 - D_C(X)) = 0 \tag{3.24}$$

The solution for this ODE is

$$D_C(X) = W_1 X^{\eta_1} + W_2 X^{\eta_2} \tag{3.25}$$

where W_1 and W_2 are constants to be determined and η_1 and η_2 are respectively the positive and negative roots of the fundamental quadratic equation:

$$\frac{1}{2}\sigma^2 \eta(\eta - 1) + \alpha\eta - (r + \lambda) = 0 \tag{3.26}$$

Therefore, the equations of η_1 and η_2 are

$$\eta_1 = \frac{1}{2} - \frac{\alpha}{\sigma^2} + \sqrt{\left(\frac{\alpha}{\sigma^2} - \frac{1}{2}\right)^2 + 2\frac{r+\lambda}{\sigma^2}} > 1 \tag{3.27}$$

$$\eta_2 = \frac{1}{2} - \frac{\alpha}{\sigma^2} - \sqrt{\left(\frac{\alpha}{\sigma^2} - \frac{1}{2}\right)^2 + 2\frac{r+\lambda}{\sigma^2}} < 0 \tag{3.28}$$

The boundary conditions are stated as follows:

$$D_C(0) = 0 \tag{3.29}$$

$$D_C(X_{D_C^*}) = \gamma \frac{h}{h + r - \alpha} \frac{X_{D_C^*}}{r - \alpha} - \frac{k}{r + h} - K \tag{3.30}$$

$$D_C'(X_{D_C^*}) = \gamma \frac{h}{(h + r - \alpha)(r - \alpha)} \tag{3.31}$$

Equation (3.29) has a similar interpretation of equation (3.10). The second and third boundary conditions are equal to the previous setting. But, this time, equations (3.29), (3.30) and (3.31) are applied in equation (3.25). Thus, we find the disclosing trigger value $X_{D_C^*}$ and the value function for revealing the investment in the presence of exogenous competition $D_C(X)$,

$$X_{D_C}^* = \frac{\eta}{\eta - 1} \frac{(h+r-\alpha)(r-\alpha)}{\gamma h} \left(\frac{k}{r+h} + K \right) \tag{3.32}$$

$$D_C(X) = \begin{cases} \left(\gamma \frac{h}{h+r-\alpha} \frac{X_{D_C}^*}{r-\alpha} - \frac{k}{r+h} - K \right) \left(\frac{X}{X_{D_C}^*} \right)^{\eta} & , X < X_{D_C}^* \\ \gamma \frac{h}{h+r-\alpha} \frac{X}{r-\alpha} - \frac{k}{r+h} - K & , X > X_{D_C}^* \end{cases} \tag{3.33}$$

being $\eta \equiv \eta_1$.

Now we need to proceed backwards as in the previous setting in order to compute the value of the option to invest. Boundary conditions similar to the ones presented in the previous setting apply again, but this turn, we need to use the value function for revealing in equation (3.33) instead of equation (3.19). Then, both the second and third boundary conditions are stated as follows:

$$F_C(X_{F_C}^*) = \frac{h}{h+r-\alpha} \frac{X_{F_C}^*}{r-\alpha} - \frac{c}{r+h} - I + D_C(X_{F_C}^*) \tag{3.34}$$

$$F'_C(X_{F_C}^*) = \frac{h}{(h+r-\alpha)(r-\alpha)} + D'_C(X_{F_C}^*) \tag{3.35}$$

The reasoning behind these equations is the same as in the previous setting. Applying equation (3.34) and (3.35) in a similar equation to (3.11), we find the investing trigger $X_{F_C}^*$ and the value function $F_C(X)$. The investing trigger, in the region $X_{F_C}^* < X_{D_C}^*$, should be found numerically by solving the equation:

$$(\beta - 1) \frac{h}{h+r-\alpha} \frac{X_{F_C}^*}{r-\alpha} + (\beta - \eta) D_C(X_{F_C}^*) = \beta \left(\frac{c}{r+h} + I \right) \tag{3.36}$$

In the region $X_{F_C}^* > X_{D_C}^*$, as one may expect, X_B^* is applied. The value function is given by:

$$F_C(X) = \begin{cases} \left(\frac{h}{h+r-\alpha} \frac{X_{F_C}^*}{r-\alpha} - \frac{c}{r+h} - I + D_C(X_{F_C}^*) \right) \left(\frac{X}{X_{F_C}^*} \right)^{\beta} & , X < X_{F_C}^* < X_{D_C}^* \\ \frac{h}{h+r-\alpha} \frac{X}{r-\alpha} - \frac{c}{r+h} - I + D_C(X) & , X_{F_C}^* < X < X_{D_C}^* \\ (1+\gamma) \frac{h}{h+r-\alpha} \frac{X}{r-\alpha} - \frac{c}{r+h} - I - K & , X_{D_C}^* < X_{F_C}^* < X \end{cases} \tag{3.37}$$

		INVEST	
		NO	YES
REVEAL	NO	$F_C(X)$	$\frac{h}{h+r-\alpha}\frac{X}{r-\alpha}-\frac{c}{r+h}-I+D_C(X)$
	YES	$B(X)$	$(1+\gamma)\frac{h}{h+r-\alpha}\frac{X}{r-\alpha}-\frac{c+k}{r+h}-I-K$

Table 3.2: Considering the four optimal stopping regions, this is the corresponding firm's value at each stage

As one should realize, depending on the optimal stopping regions for both options, the value of the project for the company varies according to what is exposed in Table 3.2.

Sensitivity analysis to exogenous competition setting

At this moment it is interesting to apply the model again, adding the new equations for trigger values in the exogenous competition setting and assess the effect of competition in our model. We will assume again all the values presented in Table 1 and make an additional assumption: λ is equal to 0.05. Applying those values, the new result for $X_{F_C}^*$ is 27.58 and for $X_{D_C}^*$ is 18.4. The benchmark trigger, X_B^*, is 27.58.

The optimal timing for revealing the investment drastically decreases, because now the firm faces competition over this option and, consequently, X_B^* is optimally applied. In this numerical example, the investment will be undertaken later than in the previous setting.

An analytical sensitivity analysis will allow us to scrutinize the dynamics and robustness of the model.

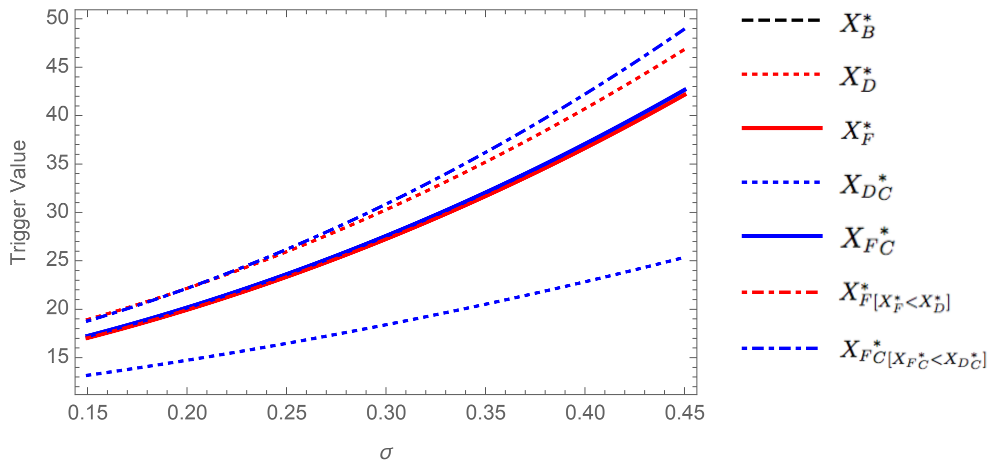

Figure 3.6: Impact of volatility on trigger values - comparison between monopoly and exogenous competition settings

Figure 3.6 represents a sensitivity analysis allowing σ to vary from 15% to 45%. The first conclusion is that all triggers increase as the uncertainty level increases. But in this analysis, more interesting than that, is to check the impact competition has in the decision the firm should make. Comparing X_D^* with X_{DC}^*, one can easily realize that the optimal timing to release information drastically drops. So, in the monopoly strategy the firm should invest and wait to reveal. In the exogenous competition setting, X_B^* is optimally applied.

In figure 3.7, we analyze the trigger's behavior, allowing h to vary. In the exogenous competition setting, X_B^* is always applied. The same does not happen in the monopoly setting where X_B^* will only be applied for high values of h.

Figure 3.8 reflects the analysis of the parameter I, the fixed investment cost.

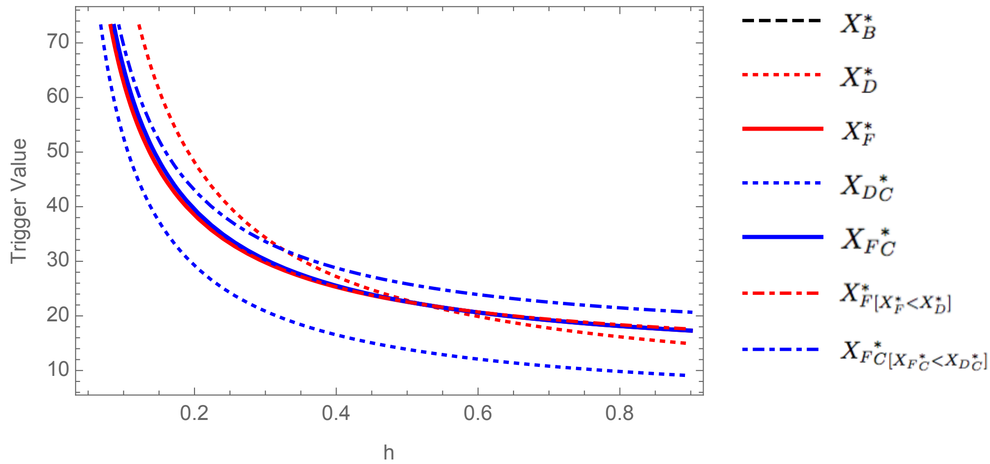

Figure 3.7: Impact of hazard rate on trigger values - comparison between monopoly and exogenous competition settings

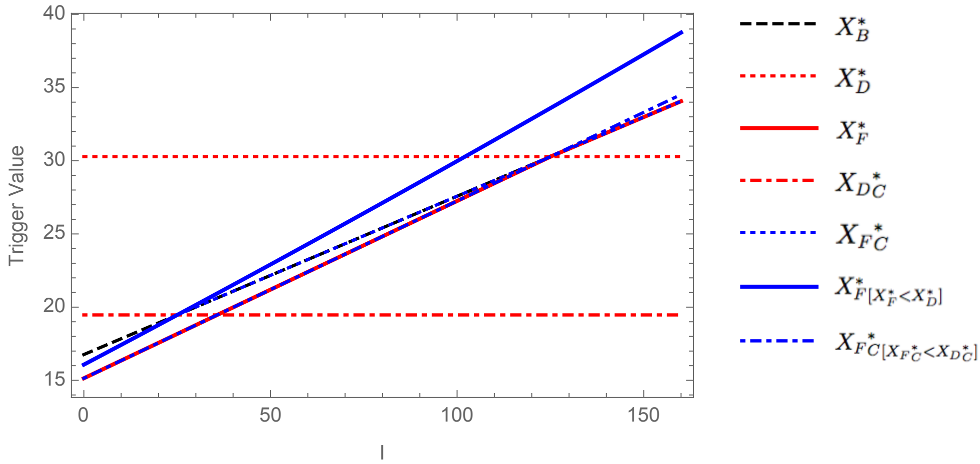

Figure 3.8: Impact of investment cost on trigger values - comparison between monopoly and exogenous competition settings

Both X_D^* and X_{DC}^* are independent of I. X_B^*, X_F^* and X_{FC}^* increase as I increases. Due to the effect of competition, $X_D^* > X_{DC}^*$, so X_B^* is applied sooner in the exogenous competition setting.

Our basic parameter γ is analyzed in figure 3.9. The upper branch of X_F^* is the only line independent of γ. Once again, X_B^* is applied sooner in the exogenous competition setting. The option to reveal will only be kept alive after investing, for really low values of γ.

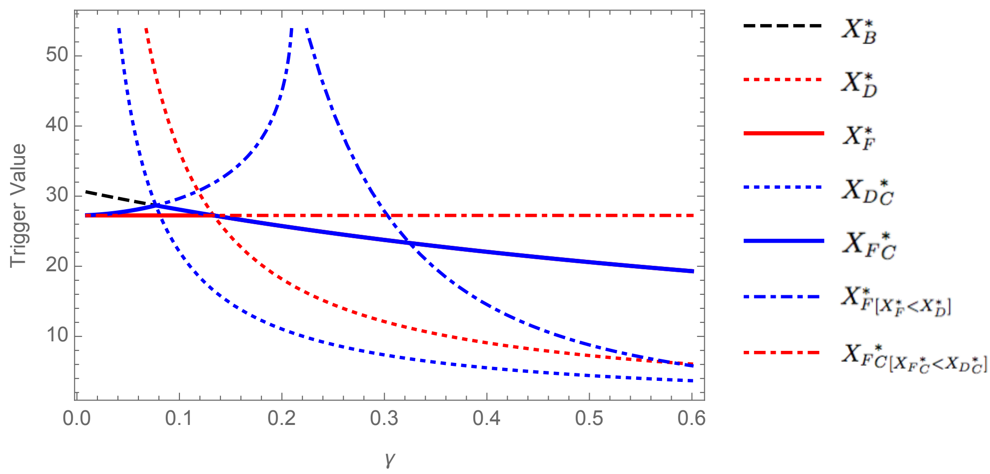

Figure 3.9: Impact of incremental benefit from disclosing on trigger values - comparison between monopoly and exogenous competition settings

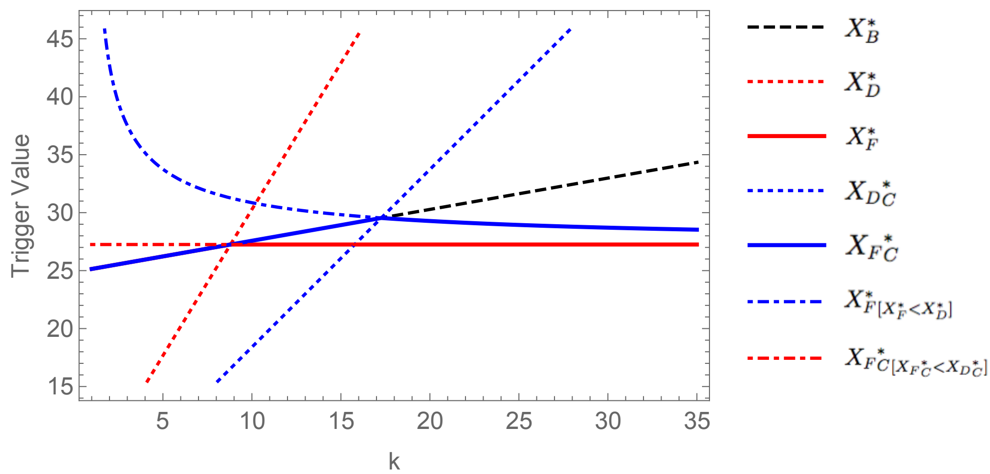

Figure 3.10: Impact of reputational cost on trigger values - comparison between monopoly and exogenous competition settings

Figure 3.10 shows the triggers' behavior depending on the value of the disclosing costs. According to what would be intuitive and expected, the lower these costs are, the sooner the firm will be able to reveal information about the R&D investment, so X_B^* is optimally applied. As disclosing costs increase, it becomes optimal to invest and keep the option to reveal alive. Due to the existence of the parameter λ, X_B^* is applied during more time in the exogenous competition setting.

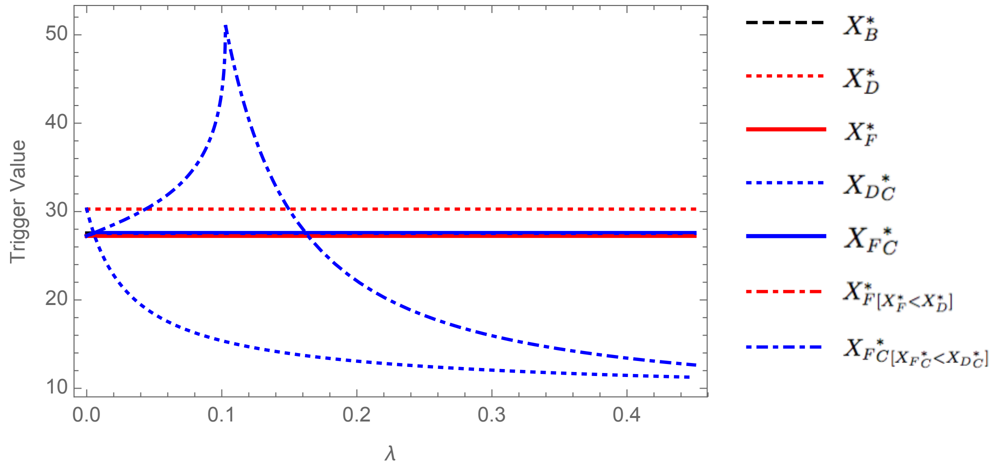

Figure 3.11: Impact of likelihood of exogenous competition on trigger values - comparison between monopoly and exogenous competition settings

Both figures 3.11 and 3.12 analyze the effect λ, the likelihood of exogenous competition appear and make the option to reveal worthless for the firm, has on triggers. For λ equal to 0, X_D^* and X_{DC}^* have the same value. Then, as λ increases X_{DC}^* decreases and X_D^* remains constant. The optimal strategy for the firm is determined by the behavior of investment triggers. In figure 3.11, it seems that it is always optimal to invest keeping the option to reveal alive in the monopoly setting, and X_B^* is almost always optimal for the exogenous competition setting. For that reason, we present figure 3.12, where we increase the parameter K, the fixed cost of producing and releasing information, from 5 to 25. The goal is to increase disclosing triggers when compared with figure 3.11. In figure 3.12, in the exogenous competition setting, for low values of λ, the firm should invest and wait to reveal the investment.

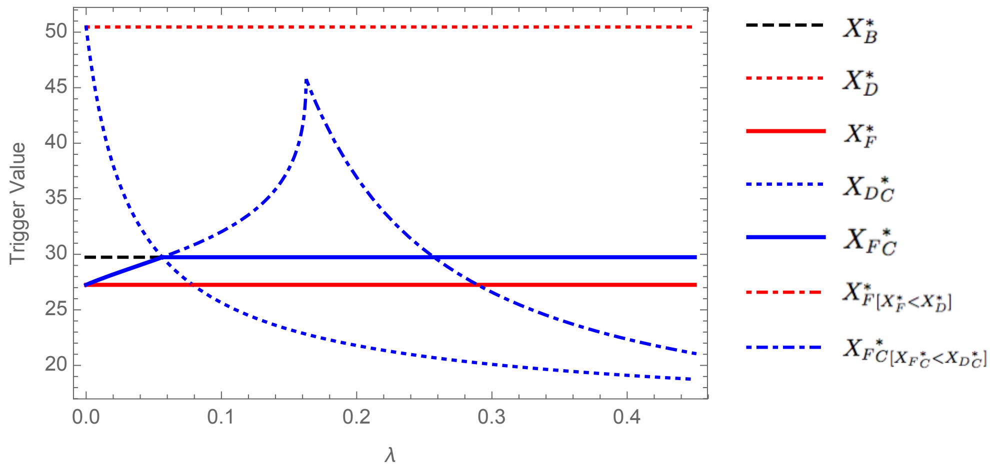

Figure 3.12: Impact of likelihood of exogenous competition on trigger values - comparison between monopoly and exogenous competition settings, with a numerical assumption changed

3.3 Independent options setting

So far, one of the most important assumptions of our model is linked to the compound option inspired in Delaney and Thijssen (2015). The option to reveal the investment is received when the firm exercises the option to invest. Therefore, the firm will both invest and reveal at the same time, in the case the benchmark trigger is applied or wait for revealing the investment, keeping the option alive. Until now we have been implicitly assuming that a firm will never reveal information about an R&D investment opportunity before exercising the option to invest. However, this is not fully realistic. A firm might optimally disclose information about an R&D investment opportunity, even before investing, for instance when it acquires a patent, revealing it and waiting for the optimal timing to invest, or simply publicly announces the will of investing in a specific project. Therefore, a firm has two different options in the first place: an option to reveal information about the investment opportunity and an option to invest and start the research process. Both options are linked but they can be considered independent.

Let's start by addressing the option to reveal information and see what happens when this option is the first one to be exercised. When both options are still alive and it is optimal to reveal information about the investment opportunity to the market, the incremental benefit given by the parameter γ impacts in the value of the option to invest, $f(x)$. Moreover, the firm not only has to pay a fixed cost of revealing information, but also faces an additional reputational cost that this time takes the form of a perpetuity, since it is not guaranteed the firm will ever invest. If the firm actually invests afterwards, it will save on this reputational cost due to the probability of becoming an innovator once the product is ready, captured by the parameter h, as we will see later. In the case of the firm only reveals information about the project after investing, the value of the project, at the moment it is optimal to invest, takes the form of the active project without the parameter k. So let $d(x)$ be the value function for revealing and x_d^* the trigger value for revealing information. The boundary conditions are:

$$d(0) = 0 \tag{3.38}$$

$$d(x_d^*) = \begin{cases} \gamma f(x_d^*) - \dfrac{k}{r} - K & , x_d^* < x_f^* \\ \gamma \dfrac{h}{h+r-\alpha} \dfrac{x_d^*}{r-\alpha} - \dfrac{k}{r+h} - K & , x_d^* > x_f^* \end{cases} \tag{3.39}$$

$$d'(x_d^*) = \begin{cases} \gamma f'(x_d^*) & , x_d^* < x_f^* \\ \dfrac{\gamma h}{(h+r-\alpha)(r-\alpha)} & , x_d^* > x_f^* \end{cases} \tag{3.40}$$

These equations should be applied to equation (3.25), so we can find the revealing trigger and the value function for revealing information. In the region $x_d^* < x_f^*$, the trigger, x_d^*, must be found by solving the following equation numerically:

$$(\eta - \beta)(1+\gamma) f(x_d^*) = \eta \left(\frac{k}{r} + K \right) \tag{3.41}$$

On the other hand, in the region $x_d^* > x_f^*$, the trigger is the same as in the equation (3.32), so $X_{D_C^*}$. Then, the value function for the option to reveal is:

$$d(x) = \begin{cases} \left(\gamma f(x_d^*) - \frac{k}{r} - K\right)\left(\frac{x}{x_d^*}\right)^{\eta} & , x < x_d^* < x_f^* \\ \left(\gamma \frac{h}{h+r-\alpha}\frac{x_d^*}{r-\alpha} - \frac{k}{r+h} - K\right)\left(\frac{x}{x_d^*}\right)^{\eta} & , x < x_f^* < x_d^* \\ \gamma f(x) - \frac{k}{r} - K & , x_d^* < x < x_f^* \\ \gamma \frac{h}{h+r-\alpha}\frac{x}{r-\alpha} - I & , x_f^* < x_d^* < x \end{cases} \tag{3.42}$$

After addressing the option to release information, we need to find the value function of the option to invest alone and find its optimal trigger. Similar equations to (3.5), (3.10) and (3.11) are applied again. Let x_f^* be the trigger value and $f(x)$ the value function for investing. The boundary conditions are stated as follows:

$$f(x_f^*) = \begin{cases} \frac{h}{h+r-\alpha}\frac{x_f^*}{r-\alpha} - \frac{c}{r+h} - I + k\frac{h-r\gamma}{r(r+h)(1+\gamma)} & , x_d^* < x_f^* \\ \frac{h}{h+r-\alpha}\frac{x_f^*}{r-\alpha} - \frac{c}{r+h} - I & , x_d^* \geqslant x_f^* \end{cases} \tag{3.43}$$

$$f'(x_f^*) = \frac{h}{(h+r-\alpha)(r-\alpha)} \tag{3.44}$$

Once again, we need to consider the two different regions: the region where information is revealed before investing and otherwise. The second and third boundary conditions must accommodate both situations, since the firm's wealth will be different depending on which of the regions the firm is. In the first region, where it is optimal to release information before investing, at the moment the firm invests, not only receives the value of the active project paying a fixed investment cost, but also saves in the reputational cost, which before investing is a perpetuity, and after investing is reduced by $k\frac{h-r\gamma}{r(r+h)(1+\gamma)}$. In the case, where it is optimal to invest without saying anything to the market, the value-matching condition is equal to the value of the active project without k and net of the fixed investment cost. Substituting equations (3.43) and (3.44) in a similar equation to (3.11), we obtain the trigger value, x_f^* and the value function $f(x)$:

$$x_f^* = \begin{cases} \dfrac{\beta}{\beta-1}\dfrac{(h+r-\alpha)(r-\alpha)}{h}\left(\dfrac{c}{r+h}+I-k\dfrac{h-r\gamma}{r(r+h)(1+\gamma)}\right) & ,x_d^* < x_f^* \\ \dfrac{\beta}{\beta-1}\dfrac{(h+r-\alpha)(r-\alpha)}{h}\left(\dfrac{c}{r+h}+I\right) & ,x_d^* \geqslant x_f^* \end{cases} \tag{3.45}$$

$$f(x) = \begin{cases} \left(\dfrac{h}{h+r-\alpha}\dfrac{x_f^*}{r-\alpha}-\dfrac{c}{r+h}-I+k\dfrac{h-r\gamma}{r(r+h)(1+\gamma)}\right)\left(\dfrac{x}{x_f^*}\right)^\beta & ,x_d^* < x < x_f^* \\ \left(\dfrac{h}{h+r-\alpha}\dfrac{x_f^*}{r-\alpha}-\dfrac{c}{r+h}-I\right)\left(\dfrac{x}{x_f^*}\right)^\beta & ,x < x_f^* < x_d^* \\ \dfrac{h}{h+r-\alpha}\dfrac{x}{r-\alpha}-\dfrac{c}{r+h}-I+k\dfrac{h-r\gamma}{r(r+h)(1+\gamma)} & ,x_d^* < x_f^* < x \\ \dfrac{h}{h+r-\alpha}\dfrac{x}{r-\alpha}-\dfrac{c}{r+h}-I & ,x_f^* < x < x_d^* \end{cases} \tag{3.46}$$

Equation (3.45) points out a very important conclusion. As triggers are constants, every time the optimal stopping region is $x_d^* < x_f^*$, which will lead the firm to reveal information before investing, x_f^* will be lower than in the opposite region $x_d^* > x_f^*$. This lead us to conclude that when the firm reveals information before investing, the investment will be anticipated when compared to the situation when the firm would only reveal after investing, due to the reputational costs saving.

Sensitivity analysis to exogenous competition and independent options setting

Now, the firm can release information about the investment opportunity before investing if it is optimal to do so. We will apply the model again to check the dynamics of these independent triggers and establish comparisons with the exogenous competition setting, since both disclosing options are assumed to face exogenous competition given by the parameter λ. Applying the numerical assumption, we find the value for x_f^* equal to 27.25 and for x_d^* equal to 18.4. Comparing these results with the previous ones, the first conclusion is that x_d^* and $X_{D_C}^*$ present the same value. This will always happen, regardless the values of all parameters. In the exogenous competition setting, the optimal strategy is to apply X_B^*, when X is equal to 27.58. This time the firm should invest when the expected profit flow is equal to 27.25, the value of x_f^*, so the investment is anticipated when compared to the previous setting for these numerical application.

Running an analytical sensitivity analysis is considered important in order to check the way compound option (exogenous competition) and independent options settings match. The difference between both approaches might be linked to the internal policy of releasing information of the firm. Here we show that flexibility on this policy adds value to the firm because sometimes it can be optimal to reveal information before investing.

The parameter σ is analyzed in both figure 3.13 and 3.14. The first one results directly from the numerical application. As expected, all triggers increase, as the uncertainty increases. Once again, $X_{D_C}^*$ and x_d^* are the same line and this will happen for all graphics we present here, regardless the region triggers are. In the case of Figure 3.13, in the compound option exogenous competition setting, X_B^* will always be applied. In the independent options setting, the firm will start by revealing information about the project when x equals x_d^*, and then invests later in x_f^*.

The goal of Figure 3.14 is to increase the amount of K, in order to increase both disclosing triggers. Consequently, now we have two different regions. There is a first region, for low values of uncertainty, in which the firm should invest and keep the option to reveal information alive. For high levels of uncertainty, the firm adopts the benchmark strategy in the compound option exogenous competition setting and reveals the information before investing in the independent options setting. The interlacement between disclosing and investing trigger happens sooner in the compound option exogenous competition setting. As the uncertainty increases, the difference between $X_{F_C}^*$ and x_f^* also increases, and x_f^* is always lower than $X_{F_C}^*$.

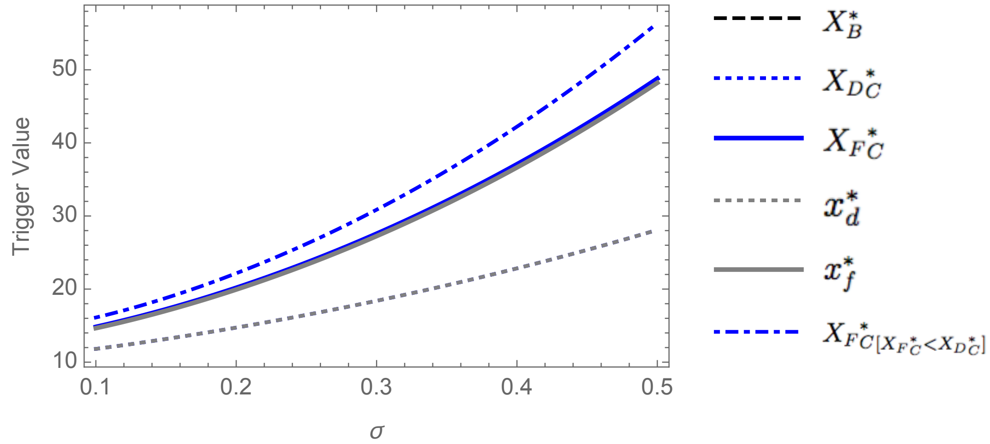

Figure 3.13: Impact of likelihood of volatility on trigger values - comparison between exogenous competition and independent options settings

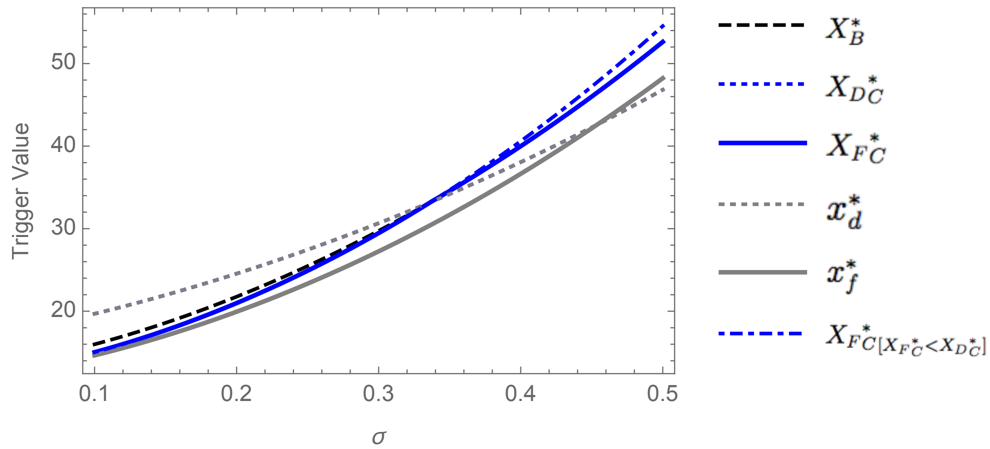

Figure 3.14: Impact of likelihood of volatility on trigger values - comparison between exogenous competition and independent options settings

The parameter h is addressed in Figure 3.15. As it should be expected, as the likelihood of innovating increases, all triggers decrease. The strategies to be adopted in this particular case derive from the numerical assumptions of the other parameters.

The behavior of investment costs is well represented in Figure 3.16, where we allow the parameter c to vary. The disclosing triggers are totally independent of the value of investment costs. Both $X_{F\,C}^*$ and x_f^* increase, as c also increases. For

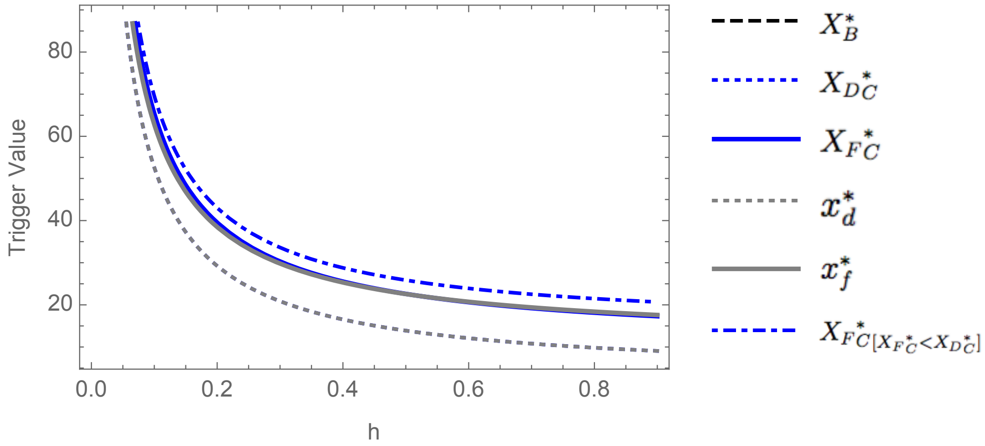

Figure 3.15: Impact of likelihood of hazard rate on trigger values - comparison between exogenous competition and independent options settings

high values of c, X_B^* will be optimally applied, in the compound option exogenous competition setting.

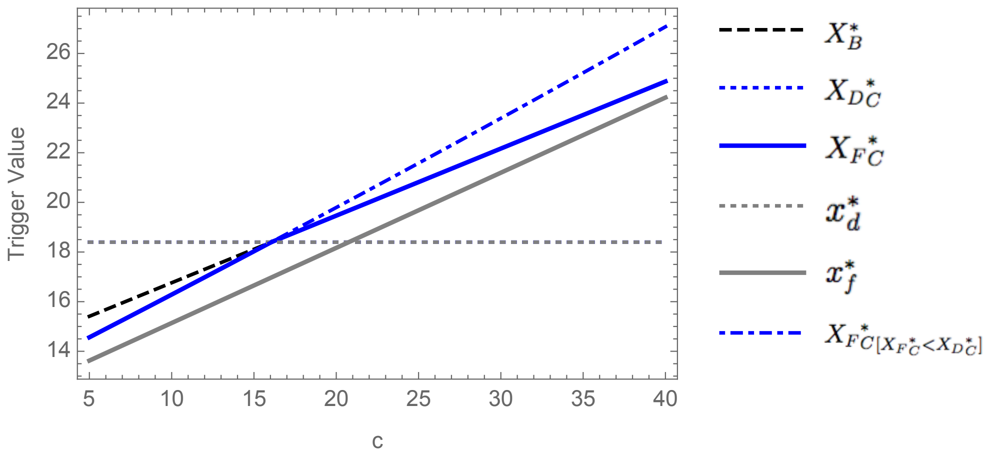

Figure 3.16: Impact of likelihood of R&D cost on trigger values - comparison between exogenous competition and independent options settings

Figure 3.17 gives us the sensitivity analysis to the parameter γ. As it is expected and it was proved already, disclosing triggers decrease, as γ increases. x_f^* is totally independent of γ. Thus, the analysis of the independent options setting is straightforward. In the compound option exogenous competition setting, the firm should invest and wait to reveal that investment, for low values of γ. For high values of γ,

X_B^* will be applied, since the opportunity cost of keeping the option to reveal alive increases.

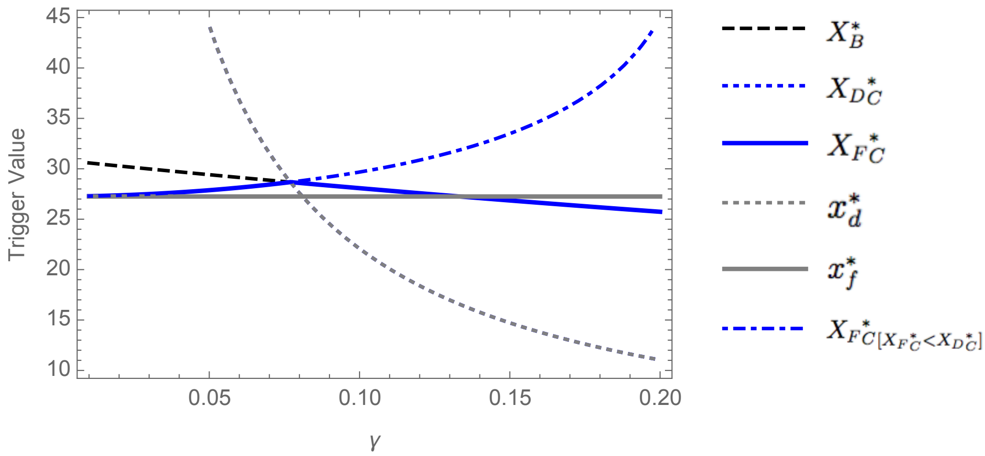

Figure 3.17: Impact of likelihood of incremental benefit from disclosing on trigger values - comparison between exogenous competition and independent options settings

The disclosing costs are analyzed in Figure 3.18. Both disclosing triggers, X_{DC}^* and x_d^*, have a positive relation with parameter K. x_f^* is totally independent of K, which divides the independent options setting within two regions and makes the interpretation very simple: one where the firm reveals information about the option to invest and only invests afterwards , and the other where the investment is done in the first place and then disclosed. Regarding the compound option exogenous competition setting, it is easy to conclude that for low values of K, X_B^* will be applied, whereas for higher values of the same parameter, the firm should invest and reveal it later.

The parameter λ is analyzed in both figures 3.19 and 3.20. Figure 3.19 derives from the direct application of the numerical example. We can conclude from this figure that x_d^* decreases as λ increases due to the competition effect. X_B^* and x_f^* are independent of λ, and so X_{FC}^* remains constant across the range of values presented here.

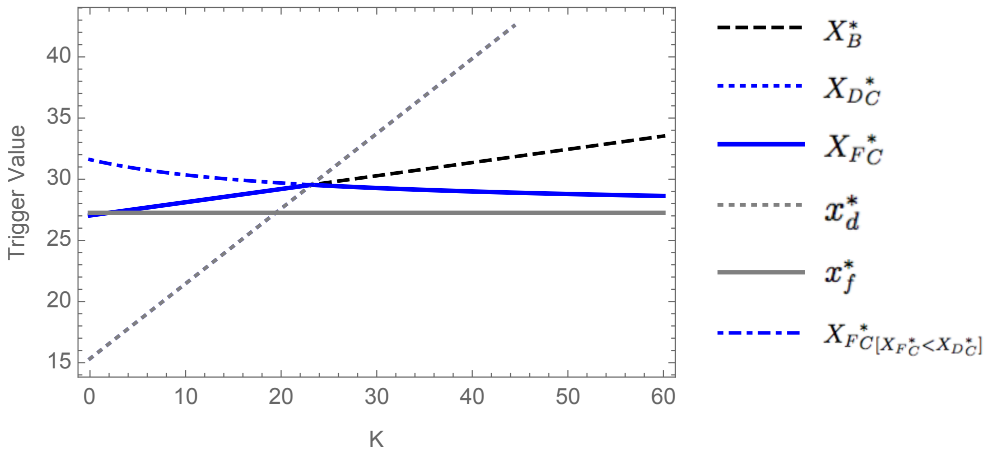

Figure 3.18: Impact of likelihood of fixed cost of releasing information on trigger values - comparison between exogenous competition and independent options settings

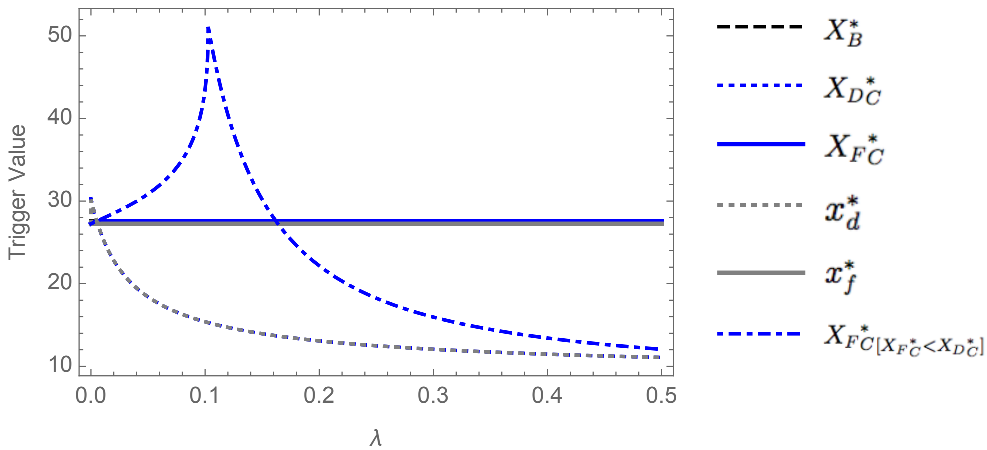

Figure 3.19: Impact of likelihood of likelihood of exogenous competition on trigger values - comparison between exogenous competition and independent options settings

But, what would happen if we increase the parameter K in order to increase both disclosing triggers? Figure 3.20 represents that experiment and we can observe that X_{FC}^* changes with λ. Thus, for low values of λ, the firm should invest and keep the option to reveal alive.

Table 3.3 presents a summary of the behavior of the trigger values when we change the parameters of the model, presenting the sign of the derivatives, in accor-

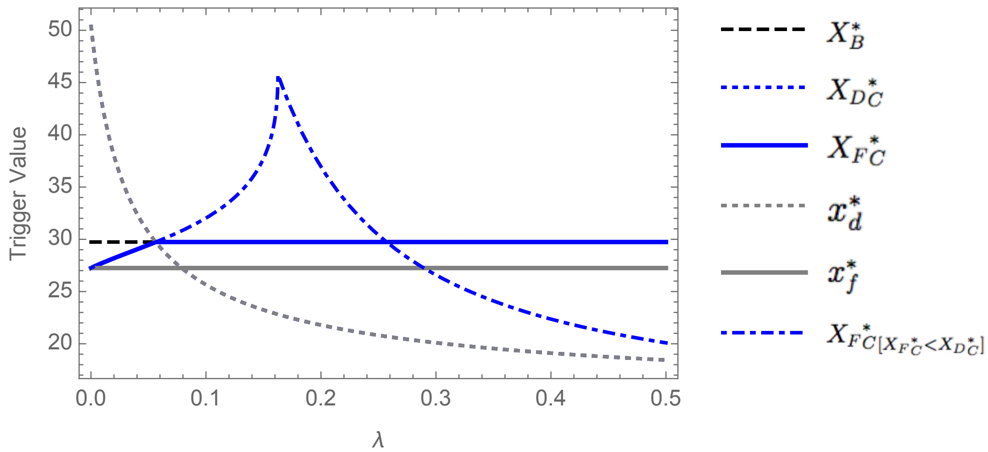

Figure 3.20: Impact of likelihood of likelihood of exogenous competition on trigger values - comparison between exogenous competition and independent options settings, with a numerical assumption changed

dance with what was already discussed in the analysis of the figures.

The numerical application of the model shows that depending upon the assumptions we consider, several strategies might be optimal. Therefore, managers should consider all the possible strategies for revealing an investment in R&D and take the best decision based on the prediction of the trigger values. Adding flexibility to the releasing information policy increases the value of the firm. We proved that sometimes it might be optimal to reveal the information about an R&D project before the investment itself.

	X_B^*	X_{FC}^*	X_{DC}^*	x_f^*	x_d^*
σ	+	+	+	+	+
h	-	-	-	-	-
c/I	+	+		+	
γ	-	$\pm$	-		-
k/K	+	$\pm$	+		+
λ		$\pm$	-		-

Table 3.3: Summary of the analytical sensitivity analysis

Chapter 4

Conclusions

The aim of the dissertation was to build a theoretical model under real options methodology, to explain the optionality about revealing an investment in R&D. As it has been demonstrated over the last decades, revealing information is a powerful tool for managers. When we are beyond an R&D investment opportunity, which might be hidden from the market, the timing of revealing the investment is a strategic decision that should be taken by the manager in the best interest of the firm and its shareholders. The most intuitive strategy to follow is to reveal any investment immediately after investing. The result is in accordance to the equilibrium found in models of Grossman (1981) and Milgrom (1981). However, it has been demonstrated, and empirical evidence supports, that managers have flexibility to decide upon other strategic timings to reveal investments.

Taking into consideration the relevant parameters that lead managers to choose different strategies, according to the literature and using our best economic intuition, we built a real options model with three different settings, showing that there are several optimal stopping regions for revealing an investment. The first setting, we stated as the benchmark. It is the simpler one, since both options are considered an unique one. The firm invests and it is obliged to reveal at the same time. Both the second and third settings came to be compared with this benchmark strategy. The second setting was defined as a compound option approach. We considered that the firm, after investing, receives an option to reveal the investment. This assumption was inspired in Delaney and Thijssen (2015). In the third setting, we added flexibility to the policy of information disclosure of the firm, allowing announcements about investment opportunities before the investment being undertaken.

The results of our model are conclusive. First of all, managers have incentives to hide information from the market, when the benefits do not compensate the disclosing costs. Then, in the presence of exogenous competition over the option to reveal the investment to the market, managers have incentives to anticipate the announcement, to guarantee the innovator position from the viewpoint of the market. Finally, when we extended the model to the third setting where both options to invest and reveal are considered independent, we observe that managers also might have incentives to reveal information about an investment opportunity, even before investing. We also proved that every time the firm rationally reveals information before investing, the timing to invest will be anticipated due to reputational costs saving.

Future research over this topic should incide in the effect of proprietary costs, when the firm reveals information. Proprietary costs has been discussed in the literature and were defined as the ones that affect the firm's value, in consequence of the behavior of the opponents, after an announcement made by the firm (Suijs 2005). Thus, it would be interesting to continue this investigation, trying to capture how the decision of announcing by the firm will impact the behavior of peer companies and therefore the firm's market value. Literature has proven that this is not a linear relation. For instance, if the firm is R&D intensive and has technological advantage, by revealing an investment in R&D, the firm can avoid proprietary costs. On the other hand, if the technological advantage is on the side of peers, revealing the investment might be a bad strategy for the firm (De Fraja 1993). Nevertheless, other features can also affect this relation as we discussed in the literature review. Thus, incorporating the effect of proprietary costs in the analytical analysis of revealing an investment in R&D is a complex task.

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