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Early Launch or Further Development? A Timing and Scale Issue

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"We all have challenges. We have to face them, embrace them, defy them, and conquer them."

Victoria Arlen

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"Saying thank you is more than good manners, it is good spirituality."

Alfred Painter

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To God for not letting me give up.

Thank you.

Abstract

In this dissertation, we develop a dynamic model, using a real options approach, for a company in a monopoly situation with the purpose of finding the best decision between two possible alternatives. In the first alternative, the firm launches a new technology already developed and then the firm relaunches the same technology with improvements (to develop in the meantime through a Research and Development process); in the second alternative, the firm waits for the new technology to be improved and then it launches the improved technology. Through our model we find that (i) the best alternative depends on the changes in the inputs; (ii) the costs have a very important role in the decision, being the main reason to the change of choice; (iii) changes in more than one variable at the same time, being one of them a cost, do not lead necessarily to a different decision, it mainly makes to vary the time at which one alternative becomes more valuable than the other; (iv) despite the uncertainty present around our model, the alternative of waiting for the improved tech (alternative 2) is found to be the best decision more often, once it is the more valuable most of the times.

Keywords: Real Options; Innovation; Optimal timing; Scale of production; Monopoly.

Sumário

Nesta dissertação, desenvolvemos um modelo dinâmico, utilizando uma abordagem de opções reais, para uma empresa em situação de monopólio, com o objetivo de encontrar a melhor decisão entre duas alternativas possíveis. Na primeira alternativa, a empresa lança uma nova tecnologia já desenvolvida e, em seguida, relança a mesma tecnologia com melhorias (a desenvolver, entretanto, através de um processo de Investigação e Desenvolvimento); na segunda alternativa, a empresa espera que a nova tecnologia seja melhorada e, em seguida, lança-a. Através do nosso modelo, constatamos que (i) a melhor alternativa depende das mudanças nas variáveis; (ii) os custos têm um papel muito importante na decisão, sendo o principal motivo para a mudança de escolha; (iii) mudanças em mais de uma variável ao mesmo tempo, sendo uma delas um custo, não levam necessariamente a uma decisão diferente, maioritariamente fazem variar o momento em que uma alternativa se torna mais valiosa do que a outra; (iv) apesar da incerteza presente no nosso modelo, a alternativa em que se espera pela tecnologia melhorada (alternativa 2) é a melhor decisão mais frequentemente, uma vez que é mais valiosa na maioria das vezes.

Palavras-chave: Opções Reais; Inovação; Tempo ideal; Escala de produção; Monopólio.

Contents

Chapter 1

Introduction

> "When somebody has a breakthrough innovation, it is rarely one little thing. Very rarely, is it one little thing. It's usually a whole bunch of things that collectively amount to a huge innovation."
>
> Elon Musk

We live in a world where evolution is constant and where the companies must follow the quick evolutional pace in order to not stay behind its competitors. Nowadays, there is not only a lot of technology (tech) and evolution related to it, but also a huge number of companies, which are continuously trying to discover new ways to improve its activities, whether through new technologies or through the upgrade of the older ones; this is, all the firms are looking for something that revolutionizes the industry in order to gain some competitive advantage. However, in a world full of evolution and where every day it arises something new, the companies have to decide if, when and how they should improve their technologies, since this strategic decision may lead to really different outcomes. On one hand, if the companies' investors make a bad decision, such as taking too long to develop a cutting-edge technology or launching a new product at the wrong time, the consequences may be disastrous. On the other hand, a wise decision can make the firm's business to skyrocket to a new level. And so, some questions arise! Should a firm seize every moment to launch a new piece of technology? Or should it wait for another innovation? Should the company invest on Research and Development (R&D) every time an opportunity exists? Or should it wait for an optimal timing? These questions reflect the reality in all companies, no matter the activity or industry, and this is why we propose ourselves to study this topic: to answer these and other related questions, finding out what should be done in a specific situation in order to take advantage of the moment, increasing the benefits for the firm. For this, we decide to study this topic through a real options model, which differs from other authors' works since we consider a monopoly situation for which we have two possible alternatives, considering not only the optimal timing to invest, but also the optimal quantity.

As we know, the world is changing and we have to face that the technological evolution will not stop. Through the model herein, we will try to give a new insight regarding the topic of launching new technologies, by adding something to the existing literature and, hopefully, to find something useful that can be used to make a better decision.

This dissertation is organized as follows. Chapter 2 presents a relevant literature review about the topic. Chapter 3 refers to the model, more precisely, to the context, first insights and the setup. Chapter 4 exposes the numerical example and the comparative statics. Chapter 5 concludes and finishes the dissertation.

Chapter 2

Literature Review

2.1. Real Options

Contrarily to other finance areas, real options is a very recent topic in the finance world, feature that does not put this new hot topic behind the others, having more and more users worldwide.

Almost half a century ago, Black and Scholes (1973) developed a model for valuing financial options, becoming one of the most famous models in the finance field. This new model was a huge innovation, revolutionizing the options' world.

The concept of Real Options (RO) was born some years after the Black and Scholes (B&S) model in a time where it was needed to distinguish the assets a company held (real assets, i.e., assets in place) and all the possibilities that a company has to purchase other assets (real options) (Stewart Myers (1977)). This was the first step to a major change in the financial mindset that would lead to a new way to see a company's options.

Financial options are known to be the right but not the obligation to buy or to sell something at a later date (the maturity date) at a predetermined price (the exercise price) and to be the owner of this right it is needed to pay a premium, while having a real option means to be able to decide for something (or not), "without binding oneself up front" (Carlsson and Fullér (2011)). Also, there is an analogy between financial call options and real options in the sense that, until the maturity date, we can exercise the option, i.e., make the investment, if the conditions are propitious and we can delay our exercise if the conditions are not ideal. The option to delay is used in order to gather more information and to realize if a non-profitable situation can become a profitable one. Due to the similarities between financial and real options, we can use the B&S model to value real options (adjusting the model for the differences).

As it is known, finance is a very complex world where real tough decisions have to be made and an example of it are the investment decisions. There are different investment decisions, depending on the business and its characteristics and the majority of the investment decisions share the three characteristics which are linked to each other, interacting in order to lead to the optimal investment by the investors: irreversibility, uncertainty and flexibility (Dixit and Pindyck (1994)) The non-existence of these three factors together will constitute an exception and the Real Options approach would not be needed. Regarding the first one, in an investment, there is at least a part of it that can be considered a sunk cost, since it will not be possible to recover; if the investment can be fully recovered, the RO approach is no longer needed. Concerning uncertainty, as much as I make a good prevision and a good valuation of my project, there will always be some uncertainty about the variables that are present in the valuation and about the outcome of my investment, which is completely understandable if we take into account that the world is in constant mutation. At last, there is the possibility to postpone the investment or to adapt the initial plans in order to better study and to get more information about the future.

The main idea is that, in the economic/ finance world, people tend to believe and trust more on the older models and theories than in the more recent ones. Despite this and that not everyone is familiar with the RO approach yet, some managers, even if implicitly, make their decisions through this approach; those managers also can create comparative advantage by making small investments until they have the confidence to increase the scale of investment (McGrath and Nerkar (2004)).

2.2. Research and Development (R&D)

R&D is, as the name tells us, the section of the company where the research and development of new technologies are made, having a crucial role on the growth of the company. Investing in R&D makes the firm to be on the front of the innovation process, always with the goal of create something new and unique (McGrath and Nerkar (2004)).

Almost 20 years ago, the RO was a very young topic and, obviously, there was an informational void. The relation between Real Options and R&D was no exception, being the valuation of R&D investment an area with few studies. R&D requires a lot of resources, which creates a certain pressure that, added to the uncertainty that surrounds every process of R&D, leads the firm to try to find new ways of evaluating the projects with the purpose of understand their true value. Despite the lack of studies in that time, there were the notion that the Real Options approach would have an important role for the valuation of this type of investments, holding a huge potential for application on R&D projects evaluation (Perlitz, Peske and Schrank (1999)). In this sense, in order to try to understand the potential of this relation, some studies were made and things evolved along the time where new scenarios were added.

Concerning the investments in R&D, as in almost all investments (or even all), there are some characteristics to have into account which can change our decision, such as the scope of opportunity, which is related to whether an investment opportunity will be useful (if it can bring some advantages) to the firm or not, i.e., if the opportunity should be taken by the firm or not; the prior experience, which is related to the feedback from other investments; and the competitive effects, once "attractive opportunities tend to attract competition" (McGrath and Nerkar (2004)). Regarding competition, the most common context is to have a leader and one or more followers in the market and, when this happens, it is needed to consider all the pros and cons of making that investment: the more a firm waits, the more information it can gather, leading to a more conscient decision; however it can make the firm to lose the opportunity to a competitor, which can lead the leader to become a follower; to the advantage of being the first making the investment, we usually call First-Mover advantage (FMA), that can make this firm to make substantial profits at the expense of other firm (Reinganum (1981)). Despite this advantage of being the first making the decision, there is also a disadvantage: the cost decreases along the time, which means that the second firm making the decision (if both adopt the tech) will pay less than the first one. Thus, in the first decision-maker point of view, there is a trade-off between the opportunity to make profits earlier (that can be delayed) and the higher cost of adopting right away. Being the first can also make that firm to be well perceived by the market, improving its reputation. In most of the cases of investments in R&D, as the firms are competing for a patent, the firm tends to invest earlier and to see a decrease in its option value, since there are no "legal contracts guaranteeing the holder's rights" (Weeds, 2002).

Except for monopolies, which is not a so common case nowadays, there is competition in all sectors and activities and, obviously, it is also present in the "technology race". In order to gain some competitive advantage and to be the market leader, firms take different paths and apply different methods.

Regarding price discrimination, there are some obvious things that everyone knows: a technology (not only physical products, but also other innovations, such as a new production system) is always more expensive when it is new than when it is not. The price, after the launch, always falls and this may be due to some factors. After the launching, and since technology evolves so fast, the tech can become obsolete, losing all its value, especially in today's world where the life cycle of a technology is getting smaller. The existing competition is another factor (a very relevant one) which can make the price to fall: when a similar technology is launched in the market by a rival firm, the price of the first tech will decrease due to the substitution effect, i.e., there is now two technologies which have the same (or almost the same) purpose. The decrease in the prices may be due to these factors or due to price discrimination. Regarding this last issue, besides illegal in some countries, price discrimination is found to be unprofitable (Stokey (1979)).

2.3. The New Technologies

After the new idea and its invention and development (the R&D part), the diffusion of the new tech, along with its commercialization, form a three phases process on which the introduction of the technologies on the market rests (Bronwyn Hall (2004)). This diffusion process, i.e., the way firms launch the tech into the market, may depend on some characteristics, not only from the company, but also from the market. The diffusion depends on the size of the company since, if it is a small one, the shot-callers have to consider the costs to launch and the impact that the new tech will have on the market; with this, it is not being said that large companies do not have to think about it too: on these firms, the new tech represents a smaller part in their business, so, if something goes wrong, the damage will be smaller. Another important factor is the confidence on the new tech, i.e., if the firm is confident that the market will approve the tech, once it will also be linked to the dimension of the diffusion, which can be local or global. This last feature leads us to a problem that may arise that is very relevant on the activity of a company: the reputation. The reputation is a very sensitive issue since it not only has to do about how the firm do its part, but mainly how the market perceives it. On one hand, a diffusion that is not well received by the market can lead to a lot of losses and costs, which can destroy years of good work; on the other hand, if the market reacts well, it can boost the firm to a higher level of activity; thus, the diffusion has to be well planned. Until here, all of what was said regarding the diffusion on the new technologies was from the firms' perspective, i.e., the suppliers of the new technologies, but it can be seen by the market's perspective, i.e., the demand of these new techs, which can also be firms.

In a world where there is a lot of competition and, whatever the business, it is needed to be in the front line in order to distinguish ourselves from our competitors and to have a competitive advantage. And, to do so, there are some things that are almost compulsory, among them, the adoption of new technologies that will help improving the activity, such as in reducing production costs or increasing the efficiency levels, for example. With this, a question arises. What is the optimal timing to adopt a new technology?

Until here, it was possible to understand the importance of the R&D in a company, which is the core of the development of new technologies. Without it the world would not continue to evolve. However, there is also another very relevant part without which it would not be possible to apply the innovations: the adoption of the new technologies.

With so much R&D investments, the adopters of new technologies have to decide which one it is the best for their activity: "the perfection of a new and superior technology confers neither private nor social benefit until that technology is adopted and employed by potential users" (Reinganum (1981)).

However, the adopters have to take into account the characteristics of the technology and the possible behavior of the competitors, which will influence the decision they will make. The competition can be by substitutes or complementary technologies and the uncertainty may be technical or strategic. The technical uncertainty is related to the performance of the new technology (and the profit associated to that performance) after the adoption with a ceteris paribus concerning competition; strategic uncertainty is related to the behavior of the competitors, which requires an anticipated planning, having into account the possible actions by the other firms. These uncertainties can be decreased with information: the more information firms gather, the less uncertainties they will have; though, with this option of wait and continue to gather information, the adopter will be more vulnerable to a competitor's adoption, leading to less profits. Thus, the main decision that has to be made by each firm is related to the optimal moment to make the investment (Mamer and McCardle (1987)). Other types of uncertainties that may be present and that may change the decision are the market revenue and the technological uncertainties: the first one related to the demand and price changes and the second related to the arrival of a new tech. This last uncertainty has a very important role in the decision-making since the adopters do not know when and if the new technology will arrive and they always have to anticipate the behavior of the competitors. This uncertainty balances with the advantage of being the first investing in determined market, being the decision made accordingly to what has a bigger weight for the investing company (Azevedo and Paxson (2008)). The decision maker also has to take into account that exist technologies that have high complementarity with others technologies, obliging the firm to invest and adopt more than one tech. This feature makes the decision tougher since there are more factors to deal with, leading the investors to invest earlier in the complementary tech when the other is already adopted (Azevedo and Paxson (2009)).

Chapter 3

The Model

We build a theoretical dynamic model using a Real Options approach. Our purpose is to find out, for a monopoly situation, the optimal timing to make the investment, the optimal scale of production at the optimal timing and the value of the investment opportunity for the two alternatives we consider. For that, we followed Huisman and Kort (2015).

By looking to what surrounds us, in a world full of technology and daily evolution, it is easy to find some examples of technologies that, as we will further explain, were designed to fulfill a purpose and then suffer an innovation process, becoming more complex and useful. There are a ton of examples from things we use on our daily basis to more complex fields such as finance or engineering. For instance, almost all the objects that have sensors were an upgrade since the original objects were designed without the sensors, such as the automatic doors and a water tap. These common objects were upgraded, becoming more complex and, in this case, easier to use. Most of the household appliances we use every day are also excellent cases of technologies that suffered an improvement: LG has washing machines that can be controlled using a smart phone. An exhaust fan could be upgraded with a sensor that regulates the fan intensity depending on the smoke. In the economic and finance world, we have systems that allow transactions in microseconds; this algorithm could be upgraded to prevent frauds. Regarding the automobile industry, we can look at Tesla: they are upgrading the Model X with an anti-rolling over system. The Apple's smartwatch is being updated: Apple improved the series 3 by adding steel to the watch and by making it thinner. These are only some examples of the thousands that exist, which guide us to the study of this topic.

3.1. The Context

Consider an industry composed by one company. That company is already active and running its activity normally, having as only concern to maximize its profits. This firm has a Research and Development (R&D) department where some projects are being created and developed. Let focus our attention on one of the company's projects, which is a new piece of technology.

The new technology is ready to be launched and commercialized in the market; however, the R&D department is still working on it and there is the possibility of improving this technology, creating a better tech, which is the same one with improvements. If the R&D department is able to create this better version, it will replace the first one. Thus, the firm is facing an investment opportunity with two alternatives. Both alternatives are composed by two phases: in the first alternative, the first phase is to launch the new tech (and to continue the R&D activity) and the second phase is to launch later on the improved tech, launching it when it is ready. In the second alternative, the firm keeps the R&D activity and waits for the improvement (phase one) and then launches the improved tech in the market (phase two). For both alternatives, the launch of the improved technology is made right after it is ready to be launched, this is, there is no chance of keeping the first technology when the second one is ready, which means that the optimal time to launch the second technology will not be something to have into account since it is whenever the improved tech is ready.

At the time when the firm has to decide whether to go for the first alternative or to go for the second one, the first technology is fully developed and it is ready to be launched by the firm. Here, the firm can launch the technology immediately, continuing, simultaneously, to improve the technology (alternative 1) or it can delay its investment, waiting for the improved version of the technology (alternative 2). The next timeline (figure 3.1) illustrates the situation.

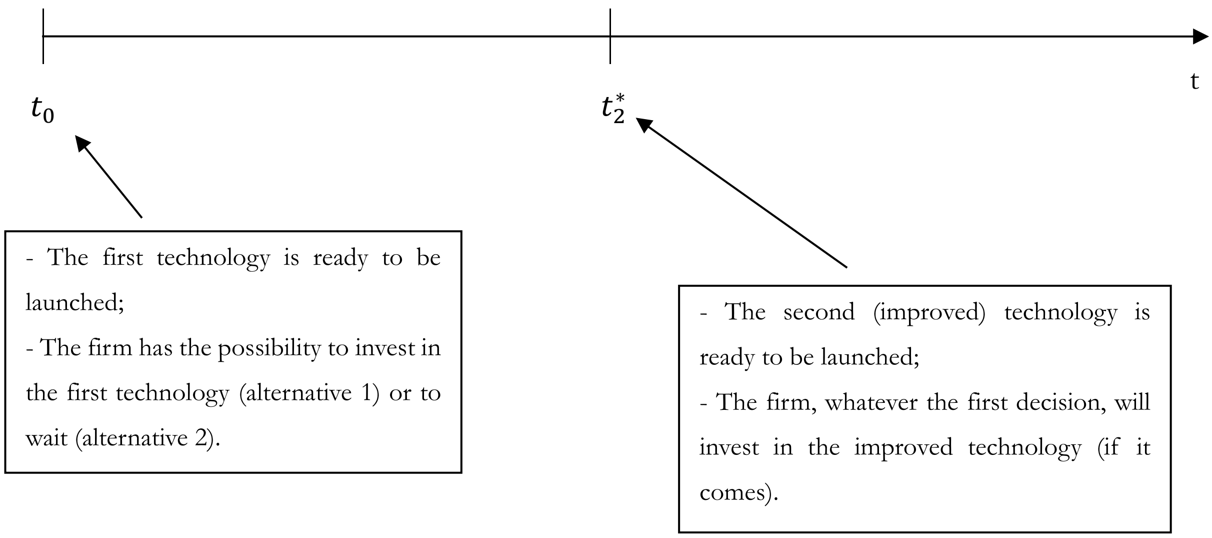

Figure 3.1: Decision timeline for the firm.

Here, a choice has to be made in order to maximize the value for the company and, in order to make the best possible decision, both cases have to be studied and analyzed.

3.2. The Model – The alternatives

This model will show us which alternative is the best depending on some factors that have impact on the choice. It is possible that, due to the number of factors and assumptions, there will not be one alternative that is unequivocally better than the other. The results may also be different by joining or removing some characteristics that we will assume.

As previously said, the model was built based on the one introduced by Huisman and Kort (2015) and, as they did in their paper, we considered not only the trigger to invest, this is, the optimal timing to make the investment, but also the optimal quantity that will be produced in order to maximize the value for the company in that trigger.

From now on, to the first (new) technology we will call technology 1.1 and to the improved one we will call it technology 1.2.

3.2.1. Alternative 1 – The Two Launches

In this first alternative, the firm launches the new technology before the improvement (technology 1.1); simultaneously, the firm invests in the R&D department and then launches the improved technology. To launch the tech 1.1 in the market, the firm has to invest in order to, for example, build the factory, to buy equipment, but also has to invest depending on the scale of production that maximizes the value for the company. With the purpose of simplifying things, we will assume that these investment costs only depend on the quantity produced and that the other costs are embedded in that investment cost. The firm will also have other costs during this process, which are the continuous costs to develop and to reach the tech 1.2.

At the time of the launch of the tech 1.1, this is, when the trigger is reached, the firm will make two actions simultaneously: the launch of the technology 1.1 and the investment in the R&D, in order to reach tech 1.2. At this time, i.e., at the trigger, it will be needed to define the optimal quantity, which will be the same for the technology 1.1 and for the technology 1.2 (if it comes), this is, the firm will only have to decide the quantity one time if it decides to choose the first alternative. The firm will receive the price at which will sell the tech times the quantity produced (to simplify, we assume that the quantity produced will be equal to the quantity sold) and the option to invest later in the tech 1.2. Despite the efforts of the R&D team, it is not sure that the tech 1.2 will come and so, everything that is linked to the tech 1.2 (cash in and out flows) are just a possibility; to incorporate that uncertainty we used a factor, which is the mean arrival rate, i.e., the probability of the tech 1.2 arrives. By investing in the technology 1.2, the firm, conditional to the arrival of the new tech, will receive the cash flows from the sale of the tech and will pay the new operational costs, such as the new machines (or the adaptation of the older ones) or the upgrade of the previous facilities.

3.2.2. Alternative 2 – To Wait and To Launch

In the second alternative, the firm will not launch the tech 1.1. Instead, the firm will invest in the R&D department by paying the continuous costs and will also define the optimal quantity to produce when and if the technology 1.2 arrives; the continuous costs will be the same as in the first alternative once the R&D department will continue to work on the improvement even the company does not launches the first tech. As it will not launch the tech 1.1, there will not be neither the cash in flows that come from the sale of the tech 1.1 nor the investment costs related to this tech. Concerning the investment on the tech 1.2, the probability of the arrival of the improved tech is the same as in the first alternative; the firm will receive the same by the sale of the technology 1.2 and will pay the operational costs needed to invest, whose amount will be different in this alternative. Naturally, by launching the tech 1.2, the company will lose the option to invest later on since it is exercising the option when launching.

To give an intuition about our alternatives, by comparing with the information we got so far, there seems to be no perfect alternative, since both have pros and cons. In the first alternative the firm will have more cash flows (in and out) than in the second one. This issue leads us to think about the probability of the innovation to arrive since the previous sentence it is only true if it arrives. Summing up, admitting the innovation arrives, the firm will receive cash flows earlier, but it will also pay the investment costs (alternative 1); for the second alternative, none of the situations happen: it will not pay but it will not receive either. Still with the same assumption regarding the arrival of the new tech, in the first alternative, the firm will face a cannibalization process when it launches the new tech, since the market will want to have the improved tech instead of the first one.

If the new tech does not arrive, despite the initial investment, the firm will continue to receive the cash flows from the tech 1.1 (alternative 1), while, in the alternative 2, it will continue to not receive any cash flows, ending up only having a loss from the development costs. Thus, if the tech does not arrive, the alternative 1 seems to be the best choice.

3.2.3. Alternatives Summary

	Alternative 1	**Alternative 2**
Name	The two launches	To wait and to launch
Description of phases	Phase 1: to launch the new technology (keeping the R&D activity) Phase 2: to launch the improved technology (if it comes)	Phase 1: to wait for the improved technology (keeping the R&D activity) Phase 2: to launch the improved technology (if it comes)
Tech 1.1	To launch	To not launch
Tech 1.2	To launch (when ready)	To launch (when ready)

Table 3.1: Alternatives Summary.

In order to make it simple, in the equations of the next section, we decide to use tech 1 (instead of tech 1.1) and tech 2 (instead of tech 1.2).

3.3. The Model – Setup

As in Huisman and Kort (2015), let us consider the price at time *t* as:

$$P(t) = X(t)(1 - \eta Q(t)) \quad (3.1)$$

where *P(t)* is the price at time *t*, *X(t)* is an exogenous factor, η is a constant (>0) and *Q(t)* is the quantity at time *t*. *X(t)* evolves stochastically and follows a Geometric Brownian Motion (gBm):

$$dX(t) = \mu X(t)dt + \sigma X(t)d\omega(t) \quad (3.2)$$

where μ is the drift rate, $d\omega(t)$ is the increment of a Wiener process, and σ is the instantaneous volatility (consider as constant). We also considered the firm is risk neutral with a discount rate of *r*.

3.3.1. Alternative 1 - The Two Launches

Back to the alternative 1, at time t_0 (figure 3.1), where the technology 1.1 is ready to be launched and to go to the market. Here, the firm, by investing in the tech 1.1, also receives the option to invest in the tech 1.2 later on ($H(X_1)$). Once we are using a real options approach, this option has to respect the standard arguments from Dixit and Pindyck (1994), which means that $H(X_1)$ has to satisfy the following standard second order ordinary differential equation (ODE):

$$\frac{1}{2}\sigma^2 {X_1}^2 H''[X_1] + \mu X_1 H'[X_1] - rH[X_1] + X_1(1 - \eta Q_1)Q_1 - k + \lambda(\frac{X_1(\alpha - \eta Q_1)Q_1}{r - \mu} - K_2^1 Q_1 - H[X_1]) = 0 \quad (3.3.)$$

Where $X_1(1 - \eta Q_1)Q_1$ is the price at which the produced quantity (Q_1) will be sold; *k* that are the continuous costs required to try to improve the technology 1.1 (the R&D costs); $\lambda(\frac{X_1(\alpha - \eta Q_1)Q_1}{r - \mu} - K_2^1 Q_1 - H[X_1])$ which is related to the investment in the tech 1.2, being λ the mean arrival rate, i.e., the probability of the innovation arrives; $\frac{X_1(\alpha - \eta Q_1)Q_1}{r - \mu}$ the present value of the cash flows that may come from the sale of the tech 1.2; α the factor that captures the effect of the innovation on the selling price; $-K_2^1 Q_1$ the incremental operational investment cost to invest in tech 1.2; $-H[X_1]$ the loss of the opportunity to adopt tech 1.2 later in time since the option is already exercised when the firm invests in 1.2.

The α factor is very important since it captures the "innovation" effect, changing the price and, consequently, the demand function. This means that the consumer is willing to pay more for the product due to the specifications and the perceived higher value.

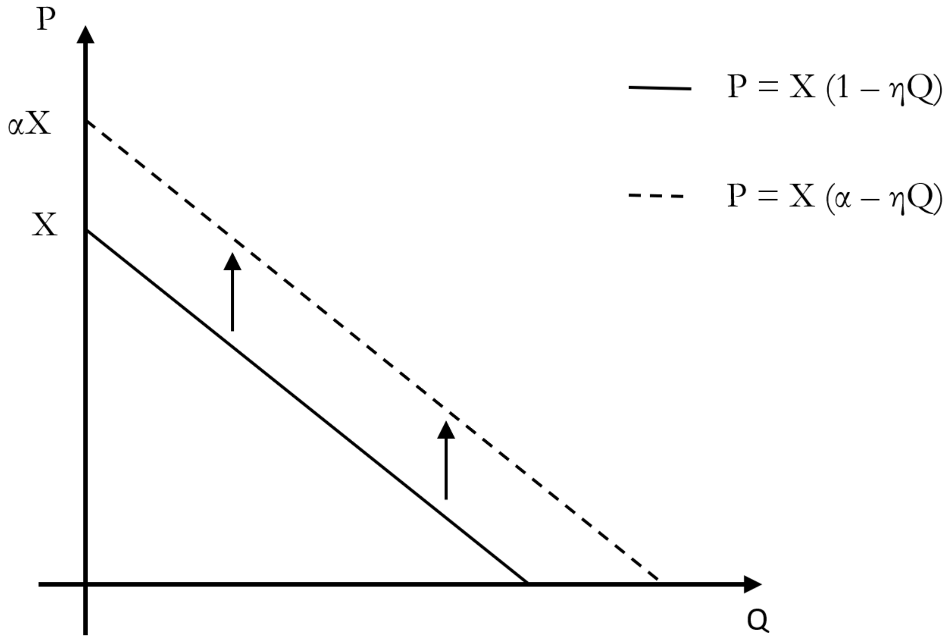

Figure 3.2: The influence of the price factor on the demand function.

The next step is to solve the ODE in order to find out the value of the option to invest (*H(X₁)*). The solution presents the following form:

$$H(X_1) = -\frac{k+K_2^1 Q_1 \lambda}{r+\lambda} + \frac{Q_1 X_1(\alpha - Q_1 \eta)}{r-\mu} - \frac{Q_1 X_1(\alpha-1)}{r+\lambda-\mu} + A_1 X^{\beta 1} + A_2 X^{\beta 2} \quad (3.4)$$

where

$$\beta 1 = \frac{1}{2} - \frac{\mu}{\sigma^2} + \sqrt{(\frac{1}{2} - \frac{\mu}{\sigma^2})^2 + \frac{2(r+\lambda)}{\sigma^2}} > 1 \quad (3.5)$$

$$\beta 2 = \frac{1}{2} - \frac{\mu}{\sigma^2} - \sqrt{(\frac{1}{2} - \frac{\mu}{\sigma^2})^2 + \frac{2(r+\lambda)}{\sigma^2}} < 0 \quad (3.6)$$

The expression of the function $H(X_1)$ (equation (3.4)) includes not only the solution for the standard ODE, but also the solution for the part we added. The two last terms are the standard solution, while the three first terms are related to the other part.

Looking to the three first terms, if we analyze them attentively, and even if we run some tests, we will be able to better understand what they mean. Regarding the first one, it is related to the continuous costs and the costs of investing in the tech 1.2. If we test this term when the arrival rate tends to infinite, this is, when the innovation comes at the next infinitesimal period, the outcome will be $-K_2^1 Q_1$, which makes sense since, if we launch right now the tech 1.2, the firm only has to pay this cost and will not have to pay more R&D costs. If we test the arrival rate tending to 0, this is, if the innovation does not come at all, we obtain $-\frac{k}{r}$, which also makes sense once, if the tech does not come, the firm will pay the costs of R&D perpetually.

The analysis for the second term is much easier than for the first since it represents the present value of the cash flows that will come from the sale of the tech 1.2 (quantity times the price with the factor alpha on it).

The third factor is the trickier of all, since it is not so obvious as the others. By doing some tests, such as the ones did for the first term, it is possible to understand that this term represents the present value of the amount the firm will not be earning until the tech 1.2 arrives. If the tech does not arrive at all, this is, if the arrival rate tends to zero, this cost will remain; if the tech 1.2 arrives in the next infinitesimal period, i.e., if the arrival rate tends to infinite, this cost will be zero, since the firm will sell the tech at the new (higher) price.

Besides what we have so far, we also need to find out some unknows in the equation (3.4), namely A_1, A_2 and the value of X, which is possible through three conditions known as boundary conditions (b.c.):

$$\lim_{X_1 \to 0}[H(X_1)] = 0 \tag{3.7}$$

$$\lim_{X_1 \to X_1^*}[H(X_1)] = X_1^* - K \tag{3.8}$$

$$\lim_{X_1 \to X_1^*}[H'(X_1)] = 1 \tag{3.9}$$

The first boundary condition (equation (3.7)) says that as the factor X tends to zero, the value of the options also tends to zero, i.e., when the exogenous shock process reaches zero, the option becomes worthless. The second condition (equation (3.8)), usually called "value-matching condition", says that for the value of X that is optimal to invest, this is, when the X reaches the trigger to undertake the project, the value of the option is equal to the Net Present Value (NPV) of the project. The last boundary condition (equation (3.9)) is known as "smooth-pasting condition" or "high contact condition" and it is needed to ensure that the option $H(X_1)$ and its NPV tangentially meet at the trigger to invest (X_1^*).

By applying the first boundary condition (equation 3.7)) to the solution of $H(X_1)$ (equation (3.4)), it is possible to see that when X tends to zero, $A_2X^{\beta 2}$ tends to $+\infty$, so we must set A_2 equal to zero. With this, we were able to reduce the option value, obtaining:

$$H(X_1) = -\frac{k+K_2^1 Q_1 \lambda}{r+\lambda} + \frac{Q_1 X_1(\alpha - Q_1\eta)}{r-\mu} - \frac{Q_1 X_1(\alpha-1)}{r+\lambda-\mu} + A_1 X^{\beta 1} \tag{3.10}$$

After using the first b.c. to find out A_2, we still need to find the other unknowns, A_1 and the trigger X_1^*, and, to do so, we are going to use the other two boundary conditions. After some calculus, it was possible to reach the value of the option before and after X_1 reaches the trigger:

$$H(X_1) = \begin{cases} \left(-\frac{k+K_2^1 Q_1^* \lambda}{r+\lambda} + \frac{Q_1^* X_1^*(\alpha - Q_1^*\eta)}{r-\mu} - \frac{Q_1^* X_1^*(-1+\alpha)}{r+\lambda-\mu} - K_1^1 Q_1^*\right)\left(\frac{X}{X_1^*}\right)^{\beta 1} & X_1 < X_1^* \\ -\frac{k+K_2^1 Q_1^* \lambda}{r+\lambda} + \frac{Q_1^* X_1(\alpha - Q_1^*\eta)}{r-\mu} - \frac{Q_1^* X_1(-1+\alpha)}{r+\lambda-\mu} - K_1^1 Q_1^* & X_1 \geq X_1^* \end{cases} \tag{3.11}$$

where

$$X_1^* = \frac{1}{(\beta_1 - 1)J^2L^2}[\beta_1 J(2k\eta M + K_2^1\lambda L + K_1^1 JL)NM + \tag{3.12}$$

$$+\sqrt{\left(J^2\left(4k^2{\beta_1}^2\eta^2M^2 + 2K_1^1 J\left(2k{\beta_1}^2\eta M + K_2^1\lambda L\right)L + 4kK_2^1{\beta_1}^2\eta\lambda ML + (K_2^1)^2\lambda^2L^2 + {K_1^1}^2J^2L^2\right)N^2M^2\right)}]$$

with $J = r+\lambda$, $L = r + \alpha\lambda - \mu$, $M = r+\lambda-\mu$ and $N = r-\mu$.

Now that we have found the trigger to invest, i.e., the optimal timing, there is still missing a very important part of this issue: what is que optimal quantity to produce when *X* reaches the trigger? Remember that the quantity of tech 1.1 that will be chosen to produce at this trigger will also be the quantity that the firm will produce of the tech 1.2 (if it arrives).

Right after we discover the value function ($H(X_1)$) (equation (3.11)), we also found out the Net Present Value, which is the sum of the cash in flows and the cash out flows:

$$NPV_1 = -\frac{k+K_2^1 Q_1 \lambda}{r+\lambda} + \frac{X_1(\alpha - Q_1\eta)Q_1}{r-\mu} - \frac{Q_1 X_1(\alpha-1)}{r+\lambda-\mu} - K_1^1 Q_1 \qquad (3.13)$$

Where the three first terms are the same as in the expression of $H(X_1)$ (equation (3.4)) and the last one is the cost for investing in the tech 1.1: K_1^1, which is similar to K_2^1, represents the operational costs to start the production, with the difference that the first is an initial cost and the second is an incremental cost; Q_1 is the quantity to produce and then to sale.

By using a maximization method on equation (3.13) we were able to find out $Q_1^*(X_1)$, which is the optimal quantity for any value of *X*:

$$Q_1^*(X_1) = -\frac{\left(K_1^1 + \frac{K_2^1\lambda}{r+\lambda} - \frac{X_1\alpha}{r-\mu} + \frac{X_1(\alpha-1)}{r+\lambda-\mu}\right)(r-\mu)}{2X_1\eta} \qquad (3.14)$$

Using a substitution method, we reached the optimal quantity to produce when *X* reaches the trigger, $Q_1^*(X_1^*)$:

$$Q_1^*(X_1^*) = -\frac{\left(K_1^1 + \frac{K_2^1\lambda}{r+\lambda} - \frac{X_1^*\alpha}{r-\mu} + \frac{X_1^*(\alpha-1)}{r+\lambda-\mu}\right)(r-\mu)}{2X_1^*\eta} \qquad (3.15)$$

3.3.2. Alternative 2 - To Wait and To Launch

Returning to the alternative 2, let continue to be at time t_0 (figure 3.1), where the technology 1.1 is ready to be launched and to go to the market. In this alternative, the firm will not launch tech 1.1, but it will also have to make a decision: since we established that the firm will invest in the very moment when the improved technology is ready, that will not be the decision the firm has to make; instead, the firm has to decide the moment when it will invest in the R&D department (by paying the continuous costs), this is, the moment when the R&D experts will start to try to improve the technology. At the same time, the quantity will also be defined. Despite not launching tech 1.1, the firm, at this point, as in alternative 1, also has the option to invest later on ($G(X_2)$) in the tech 1.2. Once again, the option $G(X_2)$ has to satisfy the following ODE:

$$\frac{1}{2}\sigma^2 {X_2}^2 G''[X_2] + \mu X_2 G'[X_2] - rG[X_2] - k + \lambda(\frac{X_2(\alpha-\eta Q_2)Q_2}{r-\mu} - K_2^2 Q_2 - G[X_2]) = 0 \qquad (3.16)$$

This ODE is similar to the one in the first alternative, having only a few differences. Here, the firm will not have neither the cash in flows from the sale of the tech 1.1, nor the operational costs. The possible cash flow from the conditional investment in tech 1.2 are the same, except the costs (K_2^2), since it is an initial investment.

It is needed to have into consideration that $K_1^1 + K_2^1 > K_2^2$, which means the costs of the alternative 1, i.e., to launch the tech 1.1 and then the tech 1.2, are higher than the costs of the alternative 2, i.e., to only launch tech 1.2, since in the first case the firm is going to have two investment costs, even one of them being incremental, while in the second alternative the firm is going to have only one investment cost related to the launch of the technologies. To illustrate the situation, imagine that to launch the first tech in the first alternative (related to the K_1^1 factor) it is needed to build a factory and to buy equipment; to launch the technology 1.2, also in the first alternative (related to the factor K_2^1), which is an incremental cost, it is needed to buy new equipment (upgraded) to change for the first one; finally, to launch the technology 1.2 in the second alternative (related to the factor K_2^2), it is needed to build the factory and to buy the upgraded equipment. After this example, it is possible to understand the above relation between the cost factors: to build the factory and to buy equipment plus the new equipment ($K_1^1 + K_2^1$) is more expensive than to build the factory and to buy only one equipment.

It is also needed to note that $K_2^1 < K_1^1 < K_2^2$, which means that the cost of launching the tech 1.2 is higher in the second alternative than in the alternative one: the amount the firm pays in the alternative 2 is an initial cost, while the amount payed in the alternative 1 is incremental, since the initial cost was already made when the firm launched the tech 1.1. The relation also means that the first cost in the first alternative (K_1^1) is higher than the second cost in the same alternative (K_2^1). Returning to the previous example, these relations say that to buy the new equipment to launch the tech 1.2 in the first alternative (K_2^1), which is the incremental cost, is the lower cost of all; the initial cost of the second alternative (K_2^2) (to launch the tech 1.2) is higher than the initial cost of the first alternative (K_2^1) (to launch the tech 1.1) since, despite the cost of the factory is the same, the cost of the new (upgraded) equipment is higher than the cost of the first equipment due to the degree of complexity.

Similarly to what we made in the alternative 1, by solving the previous ODE (equation 3.16), we reach to the following result:

$$G(X_2) = -\frac{k}{r+\lambda} + Q_2\lambda\left(\frac{X_2(\alpha - Q_2\eta)}{(r-\mu)(r+\lambda-\mu)} - \frac{K_2^2}{r+\lambda}\right) + A_1X^{\beta 1} + A_2X^{\beta 2} \tag{3.17}$$

Where:

$$\beta 1 = \frac{1}{2} - \frac{\mu}{\sigma^2} + \sqrt{\left(\frac{1}{2} - \frac{\mu}{\sigma^2}\right)^2 + \frac{2(r+\lambda)}{\sigma^2}} > 1 \tag{3.18}$$

$$\beta 2 = \frac{1}{2} - \frac{\mu}{\sigma^2} - \sqrt{\left(\frac{1}{2} - \frac{\mu}{\sigma^2}\right)^2 + \frac{2(r+\lambda)}{\sigma^2}} < 0 \tag{3.19}$$

The expression of the function $G(X_2)$, as $H(X_1)$, include not only the solution for the standard ODE, but also the solution for the part we added. The two last terms are the standard solution, while the other terms are related to the "new" part.

Regarding the added part, after analyzing and running some tests, it was possible to understand that, by tending the arrival rate to zero, i.e., when the technology 1.2 will not arrive, the only output the firm will have is the perpetuity of the continuous costs, since it will not receive any cash flows and will not invest in the tech 1.2. If the arrival rate tends to infinite, i.e., the innovation is eminent, the continuous costs disappear, since it will not be needed anymore; the firm will have to pay the investment costs to launch the tech 1.2 and will receive the cash flows coming from the sale of this tech. Thus, $-\frac{k}{r+\lambda}$ is related to the investment in R&D and $Q_2\lambda(\frac{X_2(\alpha-Q_2\eta)}{(r-\mu)(r+\lambda-\mu)}-\frac{K_2^2}{r+\lambda})$ is related to the investment in the innovation.

After this step, we also need to find out the variables we do not know in equation (3.17) and, to do so, we used the same boundary conditions, adjusted to this new situation:

$$\lim_{X_2\to 0}[G(X_2)] = 0 \tag{3.20}$$

$$lim_{X_2\to X_2^*}[G(X_2)] = X_2^* - K \tag{3.21}$$

$$lim_{X_2\to X_2^*}[G'(X_2)] = 1 \tag{3.22}$$

All the boundary conditions have the same meaning as they have in the alternative 1 and will be used to determine the same unknowns (applied to this alternative).

By applying the first boundary condition (equation (3.20)) to the solution of $G(X_2)$ (equation (3.17)), it is possible to see that, equally to what happened before, when X tends to zero, $A_2X^{\beta 2}$ tends to $+\infty$, so we must set A_2 equal to zero. With this, we were able to reduce the option value, obtaining:

$$G(X_2) = -\frac{k}{r+\lambda} + Q_2\lambda(\frac{X_2(\alpha-Q_2\eta)}{(r-\mu)(r+\lambda-\mu)} - \frac{K_2^2}{r+\lambda}) + A_1X^{\beta 1} \tag{3.23}$$

Using the same method, after some calculus, we reached the value of the option before and after X_2 reaches the trigger:

$$G(X_2) = \begin{cases} \left(-\frac{k}{r+\lambda} + Q_2^*\lambda\left(-\frac{K_2^2}{r+\lambda} + \frac{X_2^*(\alpha-Q_2^*\eta)}{(r-\mu)(r+\lambda-\mu)}\right)\right)\left(\frac{X}{X_2^*}\right)^{\beta 1} & X_2 < X_2^* \\ -\frac{k}{r+\lambda} + Q_2^*\lambda\left(-\frac{K_2^2}{r+\lambda} + \frac{X_2(\alpha-Q_2^*\eta)}{(r-\mu)(r+\lambda-\mu)}\right) & X_2 \geq X_2^* \end{cases} \tag{3.24}$$

where

$$X_2^* = \beta_1 JNM(2k\eta + \alpha\lambda K_2^2) + \frac{\sqrt{J^2N^2M^2(4k^2{\beta_1}^2\eta^2+\alpha\lambda K_2^2(4k{\beta_1}^2\eta+\alpha\lambda K_2^2))}}{\alpha^2(\beta_1-1)\lambda J^2} \tag{3.25}$$

with $J = r + \lambda$, $M = r + \lambda - \mu$ and $N = r - \mu$.

After finding the trigger for the alternative 2, we have to find out the optimal quantity for this trigger, likewise in alternative 1. By discovering the NPV_2, which is given by

$$\mathrm{NPV}_2 = -\frac{k}{r+\lambda} + Q_2\lambda\left(-\frac{K_2^2}{r+\lambda} + \frac{X_2(\alpha-Q_2\eta)}{(r-\mu)(r+\lambda-\mu)}\right) \tag{3.26}$$

we maximized this function, originating

$$Q_2^*(X_2) = \frac{-K_2^2r^2+rX_2\alpha-K_2^2r\lambda+X_2\alpha\lambda+2K_2^2r\mu+K_2^2\lambda\mu-K_2^2\mu^2}{2X_2\eta(r+\lambda)} \tag{3.27}$$

and, by substitution, we reached the optimal quantity to produce when X reaches the trigger, $Q^{2*}(X^{2*})$

$$Q_2^*(X_2^*) = \frac{-K_2^2r^2+rX_2^*\alpha-K_2^2r\lambda+X_2^*\alpha\lambda+2K_2^2r\mu+K_2^2\lambda\mu-K_2^2\mu^2}{2X_2^*\eta(r+\lambda)} \tag{3.28}$$

Chapter 4

Numerical Example

4.1. Base Case Analysis

This numerical example shows the value of our dependent variables (table (4.2)) by using the base-case values (table (4.1)). These values were previously defined by us in order to try to create a realistic context which could represent a real-world situation; despite our efforts, it is possible, and even normal, that some of the values are different from what they would be in reality.

Parameter	Value	Description
r	5%	Risk-free Interest Rate/ Discount rate
μ	2%	Drift
η	1	Constant
λ	50%	Mean Arrival Rate
α	2	Price factor
k	30	Continuous Costs
σ	25%	Instantaneous volatility
K_1^1	200	Investment cost of tech 1.1 (alt 1)
K_2^1	100	Investment cost of tech 1.2 (alt 1)
K_2^2	250	Investment cost of tech 1.2 (alt 2)

Table 4.1: Base-case values.

Parameter	Value	Description
X_1^*	10,95	Trigger - alternative 1
$Q_1^*(X_1^*)$	0,57	Optimal quantity on the trigger - alternative 1
$H(X_1)$	3,15	Value of the option to invest - alternative 1
X_2^*	9,40	Trigger - alternative 2
$Q_2^*(X_2^*)$	0,62	Optimal quantity on the trigger - alternative 2
$G(X_2)$	5,40	Value of the option to invest - alternative 2

Table 4.2: Outputs from base-case values.

From this example, it is possible to see, from the table (4.2), that the alternative 2 has a lower trigger, a higher quantity to produce and worthies more. This means that the firm will choose the alternative 2, since it is more valuable; it will also invest earlier than it would if it decided to opt for alternative 1 and it will produce a higher quantity.

From this example, it seems that the alternative 2 is better than the alternative 1. To be sure, in the next chapter, we will analyze the results and to do some tests.

4.2. Comparative Statics

After presenting the results for the base case, let us now perform a comparative statics analysis in order to study the impact of various inputs in the main outputs.

4.2.1. Volatility (σ)

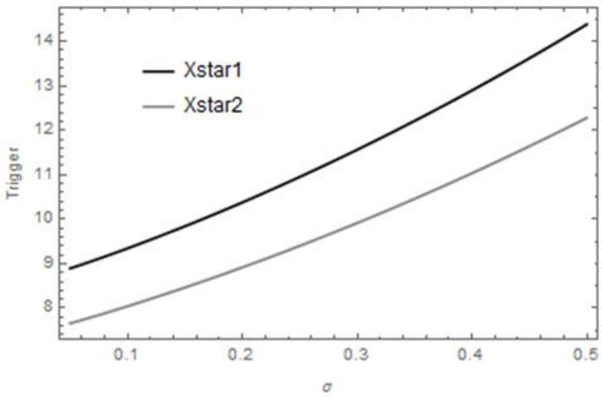

Figure 4.1: Trigger of both alternatives, depending on the volatility.

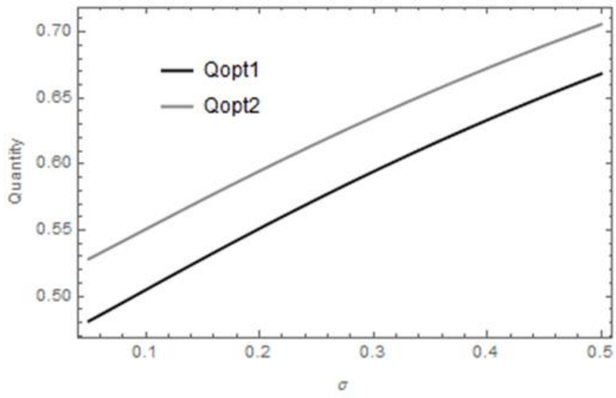

Figure 4.2: Quantity of both alternatives, depending on the volatility.

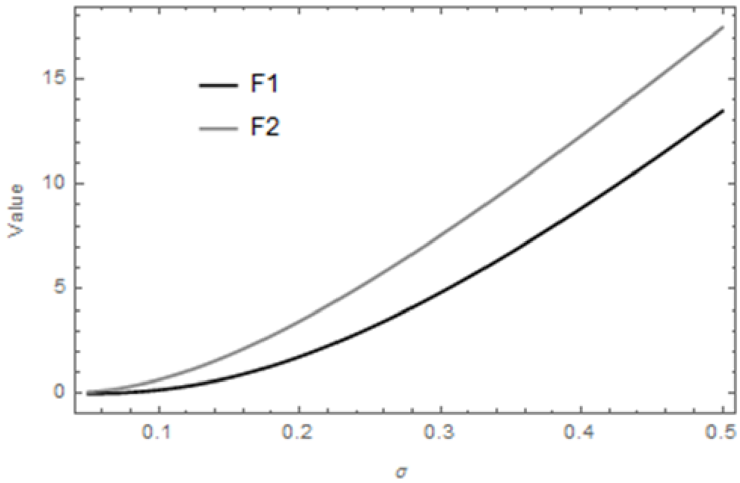

Figure 4.3: Value of both functions, depending on the volatility.

For this variable, it is possible to see that the trigger is always lower for alternative 2 than for 1 and the quantity is always higher for the second alternative as well as the options' value. The higher the volatility, the higher are the triggers, the quantities and the value of both alternatives, this is, there is a positive relation between volatility and these three dependent variables. This means that, for more uncertain industries, it is optimal to invest later and in a higher quantity. Yet, for any value of volatility, it is better to invest in the alternative 2, since it is more valuable.

4.2.2. Mean Arrival Rate (λ)

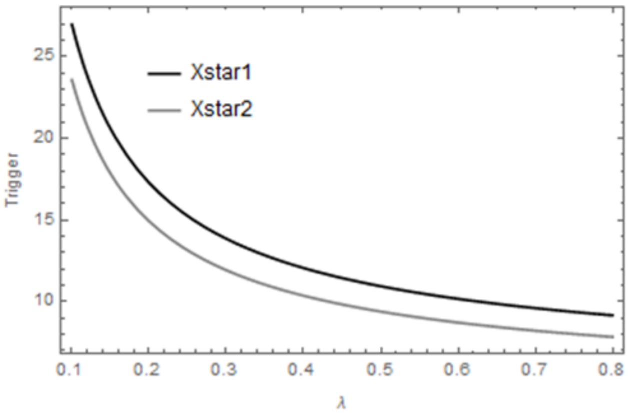

Figure 4.4: Trigger of both functions, depending on the mean arrival rate.

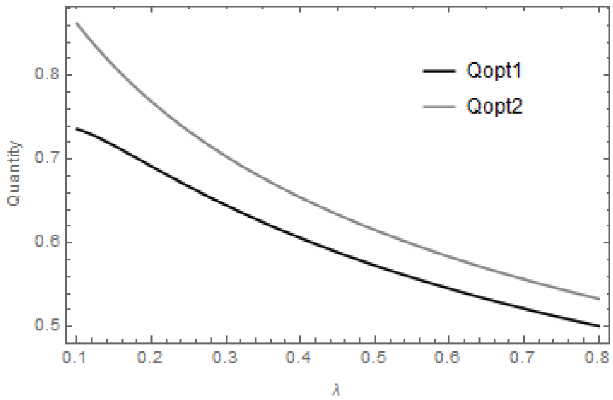

Figure 4.5: Quantity of both functions, depending on the mean arrival rate.

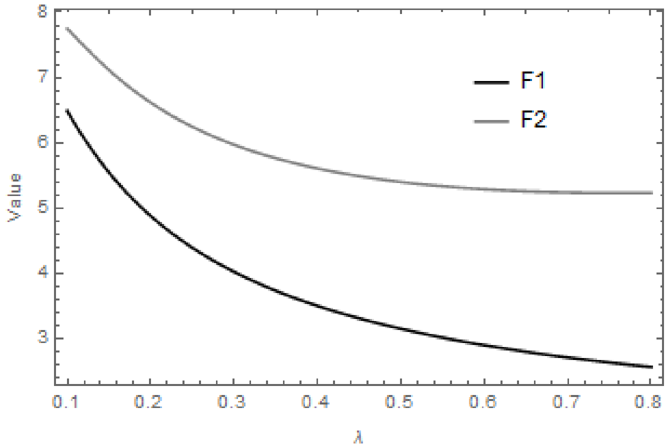

Figure 4.6: Value of both functions, depending on the mean arrival rate.

For the mean arrival rate, it is expected that, as the probability of the new technology increases, the firm wants to invest earlier. That is, for firms where the confidence in the arrival of the new tech is low, the investment tends to be made later, which makes sense since the probability of incurring in costs and do not have cash in flows is higher. In fact, when λ increases, the trigger decreases along with quantity and a lower value. For every values of the arrival rate, the trigger is lower for the alternative 2, the quantity is higher and the options' value is also higher. For every value, the alternative 2 represents the best investment.

4.2.3. Price Factor (α)

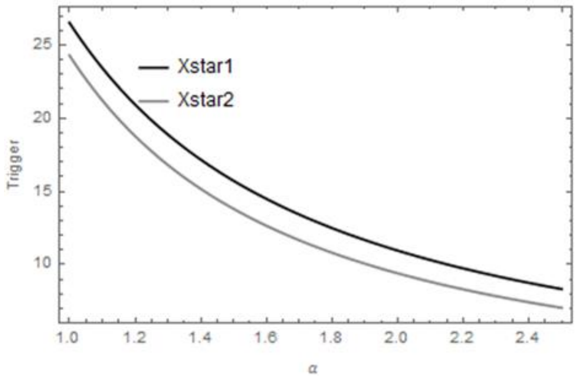

Figure 4.7: Trigger of both functions, depending on the price factor.

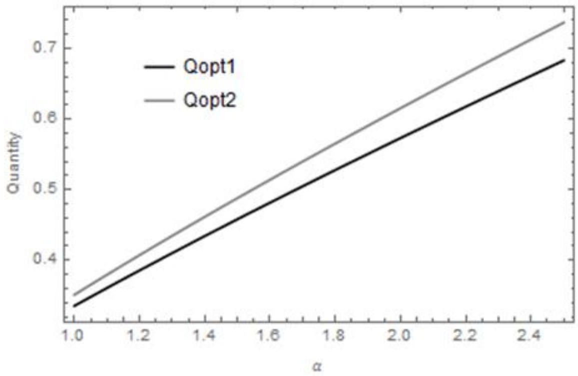

Figure 4.8: Quantity of both functions, depending on the price factor.

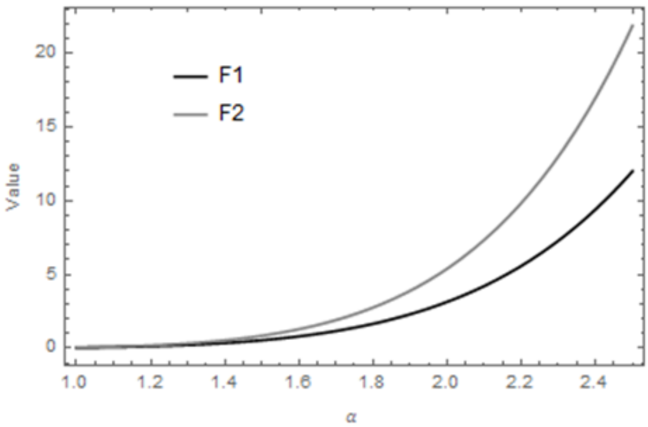

Figure 4.9: Value of both functions, depending on the price factor.

Regarding the price factor, we can see that, as α increases, the trigger decreases and both the quantity and the option value increase for both alternatives. This goes according to the expectations since this variable influences the price at which the second technology will be commercialized. A higher price leads the company to invest earlier in a larger scale, increasing its profit; and is more valuable because of the same reason. The trigger is always lower for the second alternative and the quantity is higher also for alternative 2. For the price factor, it is always better to choose alternative 2.

4.2.4. Continuous R&D Costs (k)

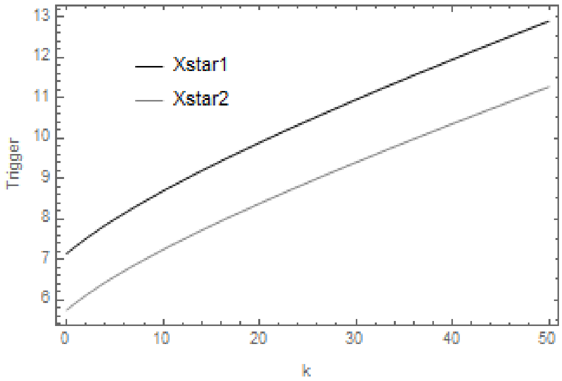

Figure 4.10: Trigger of both functions, depending on the continuous costs.

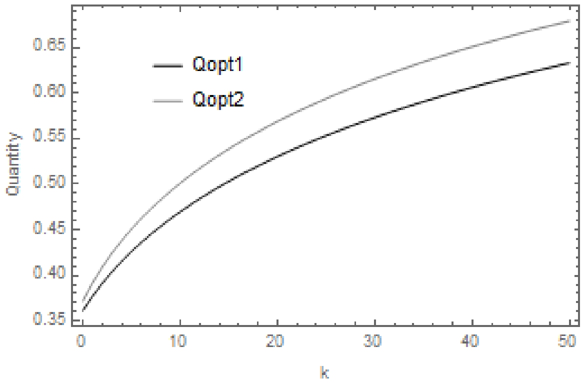

Figure 4.11: Quantity of both functions, depending on the continuous costs.

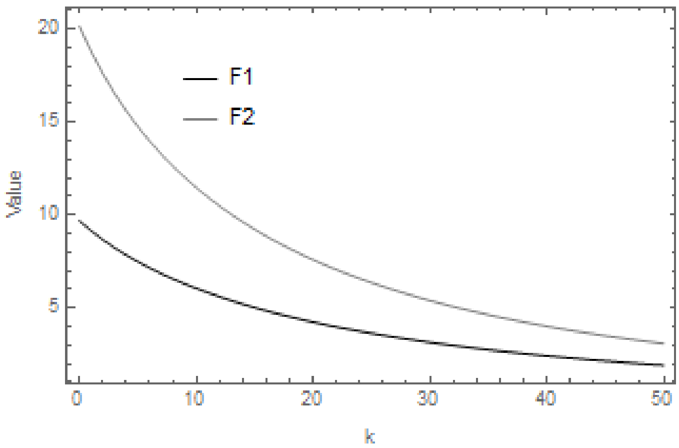

Figure 4.12: Value of both functions, depending on the continuous costs.

The continuous R&D costs have the expected influence the output values. More costs tend to delay the investment, i.e., they increase the trigger, which, in this case, are higher in alternative 1. The quantity also increases with higher costs, being higher in the alternative 2 for every level of continuous costs. As expected, the value of both options decreases for higher costs, being the option 2 more valuable than the option 1 for every level of k. This means that, in industries where it is more expensive to create and develop new products, the firms tend to invest later and in a larger scale. This said, the second alternative is always the best one, regarding this variable.

4.2.5. Investment Cost in Tech 2 – alternative 2 (K_2^2)

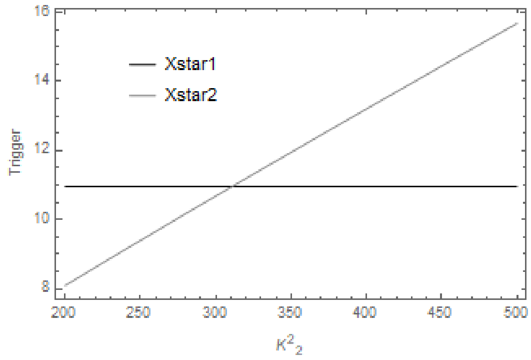

Figure 4.13: Trigger of both functions, depending on the costs of investing in technology 1.2 (alternative 2).

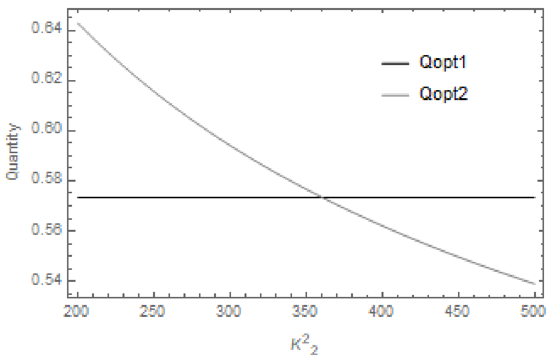

Figure 4.14: Quantity of both functions, depending on the costs of investing in technology 1.2 (alternative 2).

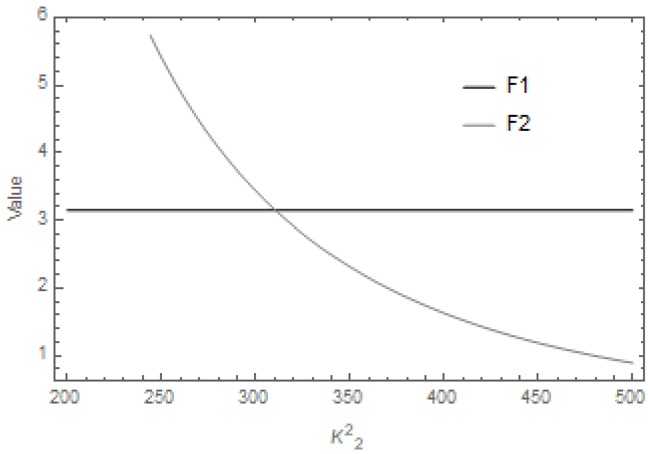

Figure 4.15: Value of both functions, depending on the costs of investing in technology 1.2 (alternative 2).

The study of this variable is a little different from the others since these investment costs only affect the alternative 2, not having any influence in the alternative 1. This means that all the graphics that represent alternative 1 will be a straight line that will intersect the functions of the second alternative at some point. The higher the costs, the higher will be the trigger, the lower will be the quantity and the lower will be the value of the option, all as expected. The trigger of the alternative 2 becomes higher than in the alternative 1 from the value 310.58. The quantity to produce will be equal at the point 360.63 and, for values above this point, the quantity is lower for the second alternative. Regarding the options' value, at the point 310.49, it is equal to choose any alternative, being better to choose alternative 1 for costs above that value. For low K_2^2, alternative 2 is more valuable for the firm; the decision will be to invest in the alternative 2, which occurs sooner at a higher scale. After a certain level of K_2^2 (310.49), alternative 1 becomes the preferable decision.

To note that, despite the proximity between the intersection point of the trigger functions and the value functions, it is not possible to decide through the trigger, since there is a little range, where the decision is not the same; thus, it is needed to decide having into account the more valuable option.

4.2.6. Investment Cost in Tech 2 – alternative 2 (K_2^2) - 1.2 σ

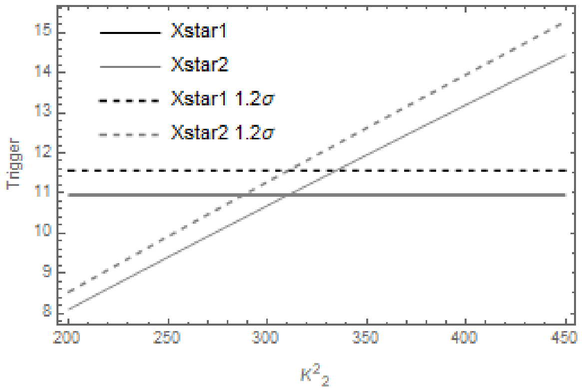

Figure 4.16: Trigger of both the original and the changed (1.2σ) functions, depending on the costs of investing in technology 1.2 (alternative 2).

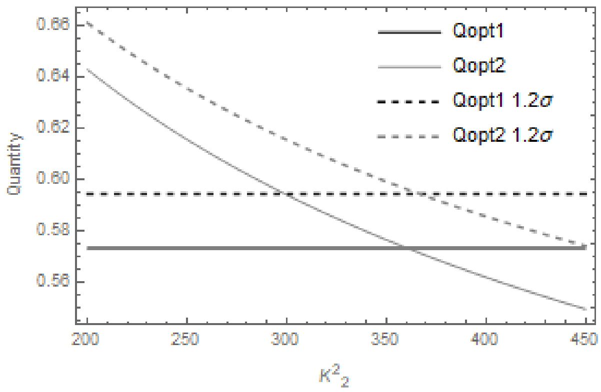

Figure 4.17: Quantity of both the original and the changed (1.2σ) functions, depending on the costs of investing in technology 1.2 (alternative 2).

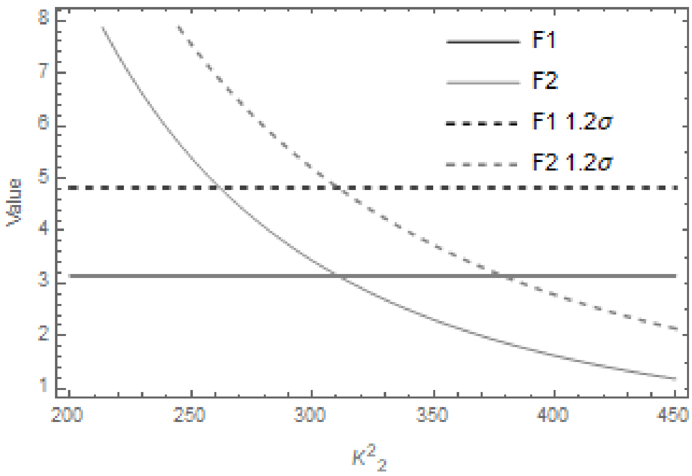

Figure 4.18: Value of both the original and the changed (1.2σ) functions, depending on the costs of investing in technology 1.2 (alternative 2).

In this case, we made vary the instantaneous volatility in 1.2 times the base case volatility. The increase in the volatility have the same effect as previously, making the trigger, the quantity and the value to increase, in both alternatives. The increase in the costs, as before, makes the trigger to increase and both the quantity and makes the value to decrease.

By putting both effects together, regarding the trigger, the point at which the optimal timing to invest is equal for both alternatives, is the same for both scenarios (310.58). Concerning quantities, the intersection point increases from 360.60 (base case scenario) to 367.10

(changed scenario). The point where the alternatives have the same value, this is, it is indifferent to choose one or another, slightly decreases from the base case scenario (310.49) to the changed scenario (310.47).

Thus, for industries where the volatility is higher, the alternative 1 becomes more valuable earlier and the best choice will depend on the amount of the investment costs.

4.2.7. Investment Cost in Tech 2 – alternative 2 (K_2^2) - 2 λ

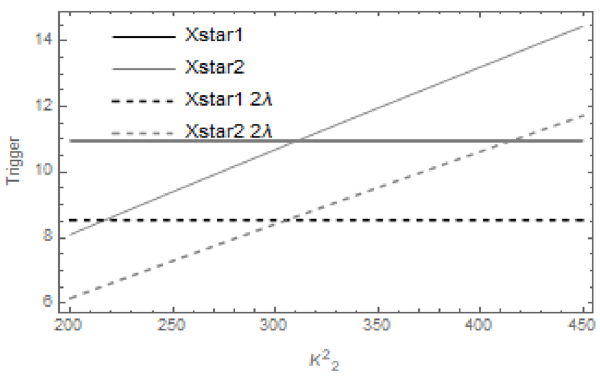

Figure 4.19: Trigger of both the original and the changed (2λ) functions, depending on the costs of investing in technology 1.2 (alternative 2).

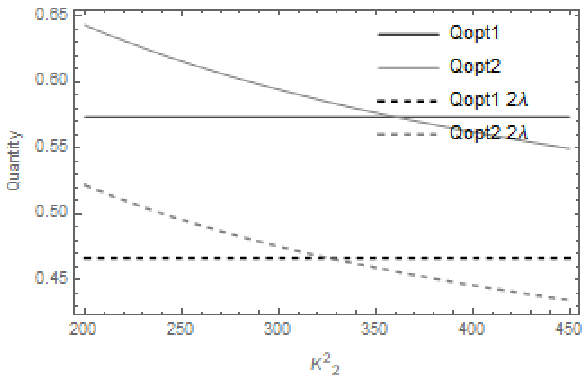

Figure 4.20: Quantity of both the original and the changed (2λ) functions, depending on the costs of investing in technology 1.2 (alternative 2).

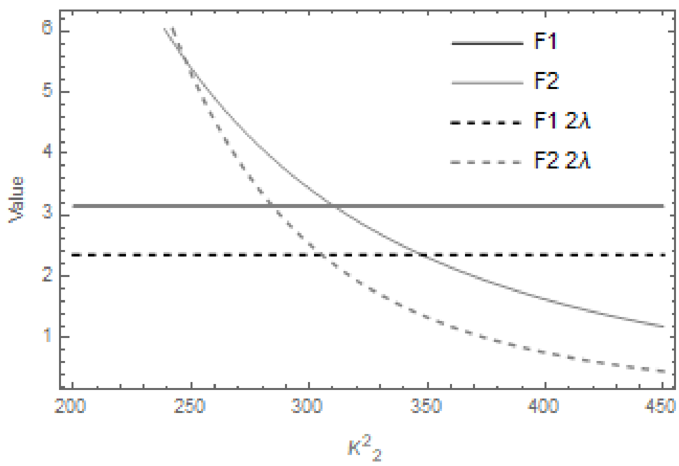

Figure 4.21: Value of both the original and the changed (2λ) functions, depending on the costs of investing in technology 1.2 (alternative 2).

Here, we doubled the probability of the new tech arrives, which means it is more likely that the innovation will come. The increase of this variable, as seen before, decreases the trigger, the quantity and the value. The costs' behavior is the same as before.

By analyzing the effects together, it is possible to observe that the triggers intersection decreases from 310.58 (base case scenario) to 305.40 (changed scenario); the quantity for which is indifferent to choose any alternative, with this change in the mean arrival rate, decreases from 360.63 (base case scenario) to 326.09 (changed scenario); regarding the value, the point also decreases from 310.49 (base case scenario) to 305.39 (changed scenario). To note that there is a point where the original function of the second alternative and the one with the new arrival rate (also from alternative 2) intersect (247.39), which means that, for this cost, the mean arrival rate does not have any influence on the value.

Hence, the more certain the arrival of the innovation is, the earlier the alternative 1 becomes more valuable.

4.2.8. Investment Cost in Tech 2 – alternative 2 (K_2^2) - 1.5 α

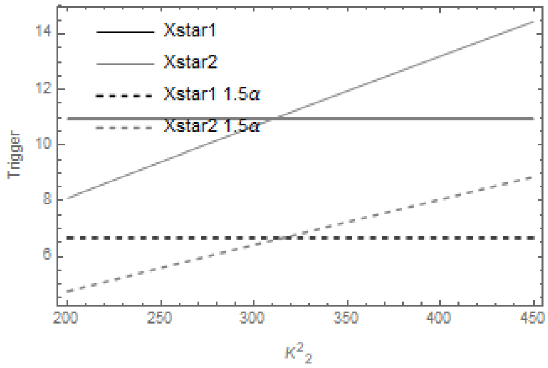

Figure 4.22: Trigger of both the original and the changed (1.5α) functions, depending on the costs of investing in technology 1.2 (alternative 2).

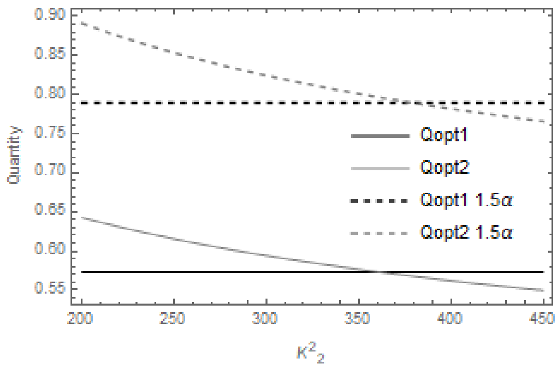

Figure 4.23: Quantity of both the original and the changed (1.5α) functions, depending on the costs of investing in technology 1.2 (alternative 2).

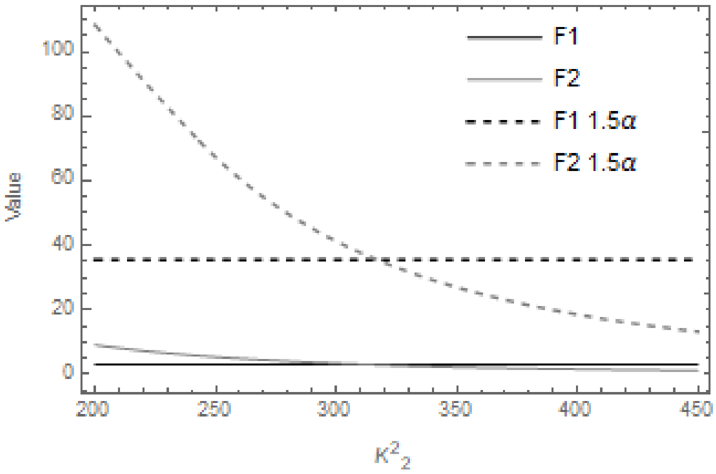

Figure 4.24: Value of both the original and the changed (1.5α) functions, depending on the costs of investing in technology 1.2 (alternative 2).

In this analysis, the factor that influences the price of the improved technology, α, was increased 1.5 times, which means that the price at which the new tech will be sold is higher. This change has the effect previously seen, i.e., the higher this factor, the lower will be the trigger and the higher will be both the quantity and the value.

Looking to the graphics, the trigger intersection increases from 310.58 (base case scenario) to 315.43 (changed scenario); regarding the quantities to produce, it also increases from the base case scenario (360.63) to the changed scenario (379.27); the values intersection goes from 310.49 (base case scenario) to 317.26 (changed scenario).

Therefore, by increasing the amount at which the new product will be sold, the alternative 1 becomes more valuable late in time, i.e., selling the new product at a higher price makes the second alternative more valuable for longer.

Chapter 5

Conclusion

In this dissertation was studied the best course of action when a firm has to decide which of two alternatives it should adopt. In the first alternative, the firm decides when to launch the tech 1.1, which is ready to be launched in the market and, simultaneously, invests on the R&D department to try to develop and to improve this tech in order to create a better version (tech 1.2). In the second alternative, the firm does not launch the technology 1.1, however it has to decide when to invest in the R&D department. In both alternatives, the firm, at the trigger, has to decide the capacity level, i.e., the optimal quantity that maximizes the value for the company; it also has to launch the improved tech (1.2) right after it is ready (conditional to the arrival of this tech). This decision had to be made in a monopoly situation, using a real options approach, which comprehends uncertainty, flexibility and irreversibility during all the process.

After building the model and doing all the tests and analysis needed, it is possible to see that the different variables have influence on both alternatives and, because of that, the optimal decision. By using the values present in the numerical example, which, despite we try to make it the more realistic as possible, are made up values, we analyze the more relevant variables alone, obtaining an almost uniform result, being the second alternative the best one for all the changes in all the variables, except for the costs. This last variable has a great influence on the choice, being the one that can lead to a change on the decision. By combining the changes in more than one variable at the same time, being one of them a cost, the decision may or may not be changed: that change is more oriented to when one alternative becomes more valuable than the other. Despite the changes that can occur by varying the variables, the alternative 2 was found to be the one that is more valuable more often.

It is clear that this topic has potential and a lot more can be done. For future research, some assumptions can be relaxed or added. The introduction of the competition factor would be an interesting extension of this work by joining a competitor, creating a leader/follower case, for instance. The adding of more technologies, not only on the first part, but also after the improvement or even the existence of complementary technologies, can also be an exciting change in the context.

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