UNIVERSITA' DEGLI STUDI DI PADOVA

DIPARTIMENTO DI SCIENZE ECONOMICHE ED AZIENDALI
"M. FANNO"

CORSO DI LAUREA MAGISTRALE IN
ECONOMICS AND FINANCE

TESI DI LAUREA

AIRPORT PROJECT VALUATION THROUGH A REAL OPTION APPROACH: THE CASE OF FLORENCE AND PISA AIRPORTS

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ANNO ACCADEMICO 2019 – 2020

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Abstract

In this thesis we provide a real option model to evaluate if and when it is optimal to invest in the expansion on airport. The revenues are disaggregated in two stochastic processes: passengers and revenues per passenger. We incorporate two kinds of shocks in the model to take into account the exogenous events during the concession life. Moreover, we introduce the option to abandon the project once the investment is started. Then we study the effects of this exit option on the optimal timing and the value of the project. Finally, we apply the model to evaluate the expansion project of Pisa and Florence Airports, studying the value of their expansion projects.

Contents

Introduction

Projects aimed at expanding airport infrastructures usually involve significant irreversible investments. This kind of projects often has large negative net present value. Their realization, therefore, is based on the fact that usually there are social benefits deriving from these investments and thus financed by governments. Moreover, the airport sector has many sources of uncertainty. The most significant regards the evolution of air traffic in the future. Uncertainty, together with irreversibility, makes the project suitable for the analysis through the real option approach.

In this thesis, following Rodrigues (2006), we develop a continuous-time model. We consider the case of an operating airport which holds a long-term concession and considers the possibility, within the concession period, of investing in an expansion of its capacity. The main variable of the analysis is the revenues, which are disaggregated in two stochastic components: passengers and revenues per passenger, with their own evolution. Costs, instead, are assumed to evolve deterministically.

In order to take into account any possible event during the project life, we add two different kinds of shocks to the model: the first type represents the standard economic fluctuations, whereas the second one represents an unlikely event with a significant negative effect, such as pandemic. The presence of shocks allows us to examine the effects of exogenous events on the project value and understand the effect of the option to defer in these cases.

Lastly, we study the effect of the possibility to abandon the project once it is started. This case regards the possibility to exit the investment and recover a fraction of the capital. We study the optimal level of revenues which triggers the abandonment of the project and the value of the option itself. Moreover, we analyse the effect of the exit option on the timing of the investment and the overall value of the project.

We use this model to examine the expansion projects of two Italian airports: Pisa and Florence. We choose these two airports since they share the same territory, thus they face a similar demand and are subjected in the same way to exogenous events. Despite the similar framework, they have different characteristics: Pisa Airport is mainly focused on low-cost traffic, whereas Florence Airport is mainly served by full-service carriers. Furthermore, both the airports have expansion projects ongoing, which are chosen as references for the evaluation of the option value.

This thesis is organized as follows.

In Chapter 1 we provide an overview on the aviation sector. In Chapter 2 we present Società Toscana Aereoporti, which is the firm that manages Pisa and Florence Airports. In Chapter 3 we present the real option model. In Chapter 4 we estimate the parameters necessary for the analysis. Finally, in Chapter 5 we report the results of the analysis.

1 Overview of the aviation sector

1.1 History of european aviation

The first Common Transport Policies started with the Treaty of Rome (1957), but at first, they did not include aviation. For many years, domestic aviation in Europe was regulated by means of bilateral agreements starting with the Chicago Convention, which was drafted in 1944 by 54 states to promote cooperation and define some basic rules regarding international aviation.[1] These agreements were generally restrictive (fares charged were agreed by the two countries involved, usually on a 50-50 base) and excluded competitive pricing. In many cases, only one airline per country was allowed to operate a route, which was, in almost all cases, the state-owned "flag carrier". Only from the 1980s, there was a move towards liberalization in the aviation sector, starting from those countries that were more oriented to deregulation. The first reforms on licenses and fares within countries began to be made, starting from the UK These reforms were gradually accompanied by a greater involvement of private sector. In some instances, e.g. British Airways, there was a complete privatization at a fairly early stage. Many countries (as in Germany and The Netherlands) gradually sold off their stocks in the airlines, while airports and other fixed infrastructures, outside the UK, remained completely public.
From the mid-1980s there were also the first changes in bilateral agreements. Firstly, between UK and the Netherlands, which started to relax the rule on market entry and fares, then also between Germany, France and Spain. Another important impulse came from the agreements of the single European countries with the U.S., as part of the so-called "Open Skies" policy, which started in 1979.
The EU efforts to build up a common aviation market started in the late 1980s and were preceded by three judgments of the European Court of Justice. In the Reyners [2] and Van Binsbergen [3] cases (1974) the Court determined that the provisions of the Treaty of Rome regarding the competition policy also apply to aviation. In the Nouvelles Frontiéres case, (1985), regarding the fare-cutting activity of a French travel agent, the Court confirmed again that competition provisions apply to air transport and clarified the possibility that the EU enforces them. From that moment a staged liberalization through three " packages" of reforms made by the European union started. The first one (1987) introduced the possibility to apply the Antitrust measures to airline and more flexibility in pricing. The second one (1989) opened to the free competition of private companies and liberalized the cargo traffic. The third "package" (1992) abolished national restrictions on prices, removed limits for the flights between member states and allowed foreign ownership. Lastly, it promoted the creation of a European single market for aviation. [4]
The European Union has recently focused on the external aviation policy. This policy originated from legal action: indeed in 2002 the Court of justice concluded that member states cannot

[1] Convention on International Civil Aviation - Doc 7300

[2] CJEU, 21.6.1974, case 2/74, Reyners.

[3] CJEU, 3.12.1974, case 33/74, Van Binsbergen.

[4] Button, K. (1996). *Liberalising European aviation: is there an empty core problem?*. Journal of Transport Economics and Policy, 30, pp. 275-291.

conclude bilateral agreements with third countries ("Open Skies")[5] , being the external policy an interest of the Union as a whole.
In 2005 the EU defined the external policy based on a Road Map, which has two targets: firstly, to line up the agreement of the member state and third countries with European law; secondly, to create a common aviation area with EU's neighborhood. Finally in 2015 the EU presented a further aviation strategy, whose main aim was to complete the single European sky project. The large differences in the deregulation processes of EU countries have led to a huge variation in the growth of the air traffic. Since the 1980s some countries have successfully improved their international routes. In the first place England played a forerunner role in the process of deregulation in Europe and consequently had the highest air traffic growth.

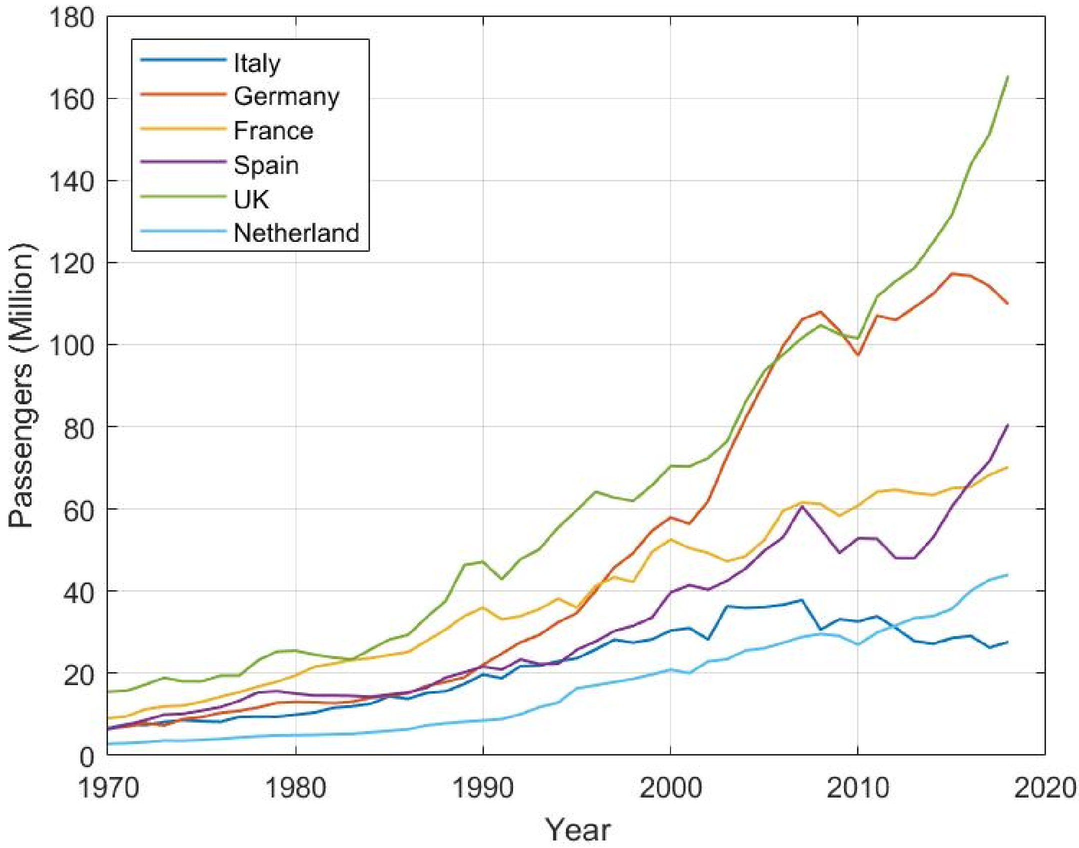


Figure 1.1: Air traffic growth of european countries.
Own elaboration based on Eurostat data.

[5]Case C-471/98, Open Skies.

1.2 Differencies with the U.S.

In the United States, the process of air traffic deregulation started in the 1970s, but already from the previous decade started to be evident the positive effect from deregulation. At the end of the 1960s intrastate air travels in California, which were not subject to Federal regulation, were 47% cheaper than interstate travels, which were subject to fixed fares.[6] The liberalization of the sector at a Federal level began in 1975, when Civil Aeronautical Board started to allow competitions on some routes, allowing certain companies to offer discounts up to 45% on fixed fares. Then in 1978 the U.S. Congress issues the Airline Deregulation Act [7] , which eliminate the Board control over routes and fares. From that moment, the U.S. airline industry experienced a rapid growth and a steep decrease in prices, mainly connected with internal growth. Passengers went up from 250 million in 1978 to 670 million in 2000, and the average fare diminished of 40% in real terms in the same period. By 1985, the average fare per passenger mile in the U.S. was 25% lower than regulated fares per passenger mile in the E.U.[8] Moreover, the higher number of routes brought important benefits to the economy. Morrison and Winston (1986) estimated that U.S. deregulation led to a 6 billion dollars annual improvement in travellers' welfare and a 2.5 billion annual increase in industry profits. [9]

Distance(km)	250	500	1000	2000	4000
Europe	36.3	27.9	21.5	16.6	12.8
North America	25.3	19.1	14.4	10.9	8.2
World average	28.7	23.6	19.4	16	13.2

Table 1.1: European, North American and International Air Fares 1985 per passenger , kilometre (US cents). Annual Survey of International Air Transport Fares and Rates, International Civil Aviation Authority, Montreal.

In Europe, the deregulation process did not have the same impact. Nevertheless, after the third "package" of reforms the air transport experienced a great boost and the number of licenses and routes increased. By 1996 the EU routes subject to the competition were 30% cheaper than the ones without.[10]

[6] Jordan W. (1970). *Airline Regulation in America.* Johns Hopkins, Baltimore, p. 226.

[7] Airline Deregulation Act of 1978, Pub. L. No. 95-504, § 10(a), 92 Stat. 1713.

[8] Barrett, S.D. (1989).*Deregulating European aviation —A case study.* Transportation 16, pp. 311–327.

[9] Morrison S. and Winston C. (1986). *The Economic Effects of Airline Deregulation.* Brookings Institution, Chap. 1.

[10] Moritz F.S. (2001). *Consequences of E.U. Airline Deregulation in the Context of the Global Aviation Market.* 22 NW. J. INT'L L. & BUS. 91.

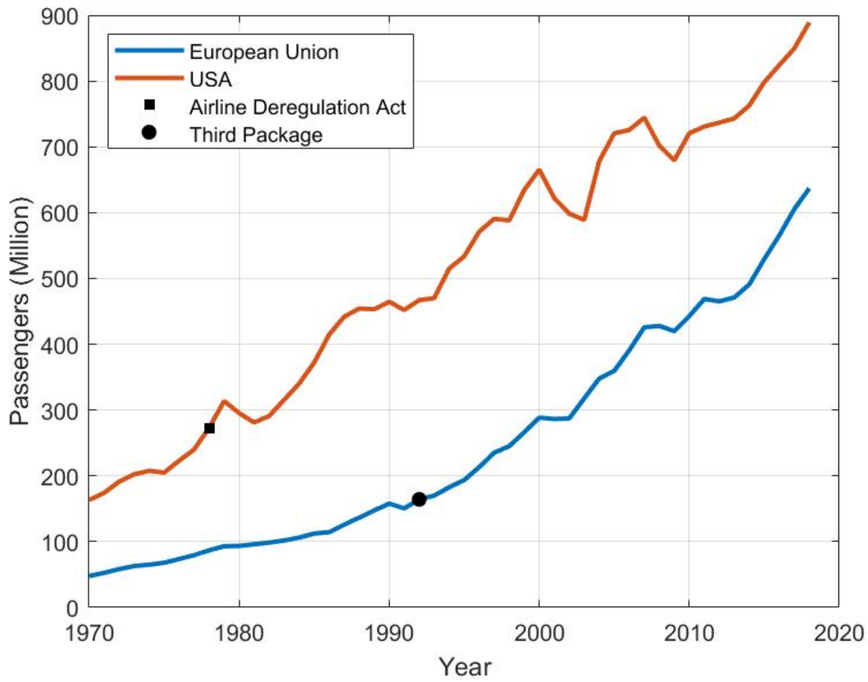


Figure 1.2: Air traffic evolution in thevU.S. and the EU after the deregulation.
Own elaboration based on Eurostat data.

1.3 Low cost carriers as a deregulation outcome

The concept of low-cost firm was firstly introduced in 1973 by Southwest Airlines, which became the first ”low-cost carrier” (LCC, in opposition to ”full service carrier” - FSC). The original low-cost business in the U.S. was a niche market which focused on intra-Texas routes and secondary airports. The company reached its peak after the Airline Deregulation Act of 1978 and expanded from a small regional airline to a national one, serving 30 states. After the successful example of the Southwest Airlines, in the early 1980s the low-cost carrier model spread all over North-America with the creation of many new companies like AirTran, Jetblue and Westjet. The low-cost model was adopted in Europe only in 1991 with Ryanair, which became the first LCC in Europe, followed by EasyJet in 1995. Both companies experienced steady growth in the early 2000s, reaching respectively 26.4 and 24.3 million people transported in 2004.[11] Even though the two companies are both low-cost carriers, they adopt two different policies: Ryanair focuses on markets without direct competition, serving secondary regional airports, while Easyjet concentrates on primary high-cost airports. Despite their differences, their primary aim is to operate with a lower cost structure than traditional operators in order to be able to apply lower fares. It is interesting to notice that the two major low-cost carriers in Europe were created in Ireland and the UK, namely the countries that led the way in Europe towards deregulation.

[11] Dobruszkes F. (2006) *An analysis of European low-cost airlines and their networks.* Journal of Transport Geography, 14, pp. 249-264.

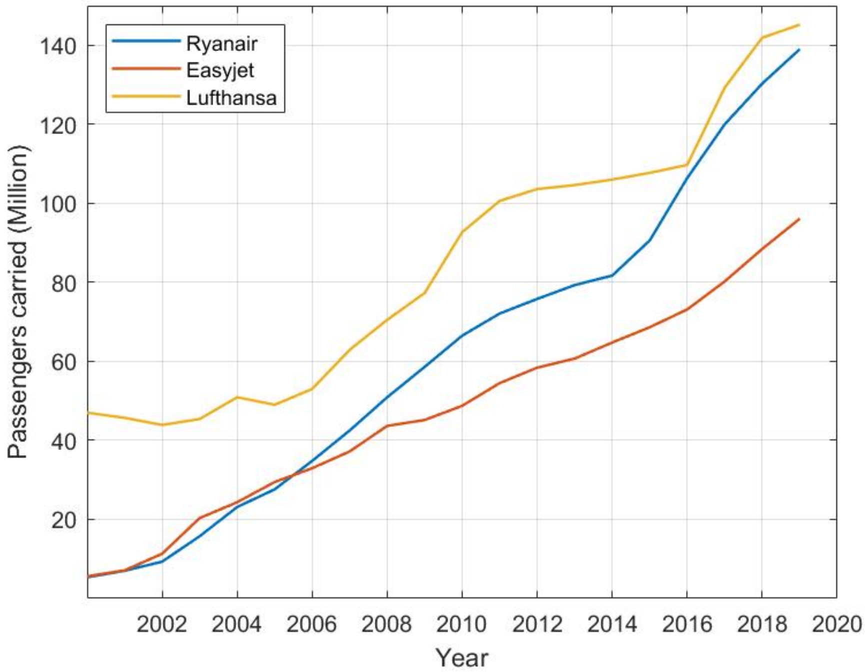


Figure 1.3: Growth of the two major low cost carriers compared to a legacy carrier in Europe. Own elaboration

We can distinguish four main features in the low-cost carrier model: the first one is to offer the most basic service package, which means to eliminate every kind of side service; secondly, low-cost carriers operate in a point-to-point basis, in opposition to the hub-and-spoke structure. The latter is characterized by the presence of a central hub for the company, from which all routes originate. This system allows to maximize the number of connections. The point-to-point structure, on the other side, provides direct routes between the cities, which is less time consuming. Thirdly, LCCs use of short routes with a high density of traffic. Lastly,they are characterized by quick turnarounds and short breaks between two flights.[12] Another important feature is the use of secondary airports, following the business model of Ryanair. These infrastructures are usually reconverted by military fields and have many benefits. They have a little initial cost with respect to traditional airports, mainly because many infrastructures are not needed to be built from zero. Secondary airport are usually located far from cities and provide fewer facilities than a standard airport. For these reasons, they offer low airport charges and are less congested. Generally, low-cost airports avoid expenditures on services that are not strictly necessary for the core air transport product. Secondary airports also bring benefits to the regional economy, in terms of connection and tourism[13] and provide a more homogenous presence of travellers in a territory.

[12]Maxim, L. (2012). *The Evolution of the European Low-cost Airlines‘ Business Models. Ryanair Case Study.* Procedia - Social and Behavioral Sciences, 62, pp. 342–346.

[13]Francis, G., Humphreys, I. and Ison, S. (2004). *Airports’ perspectives on the growth of low-cost airlines and the remodeling of the airport–airline relationship.* Tourism Management, 25, pp. 507-514.

1.4 The impact of LCC in Italy

Before the deregulation process, the Italian air transport sector was entirely dependent on its former "flag carrier" Alitalia, operating mainly from its main airport in Rome. After the liberalization, Italy experienced a considerable growth in terms of number of passengers and of airports. The air traffic has grown by 4.46% yearly on average from 1999 and 2018[14], driven mostly by the growth in international traffic, which is nearly tripled in twenty years, while the domestic market has grown by 2.5% on average. In this context low-cost carriers have improved their market share from early 2000s, when it was near 0, to 51.1% in 2018 (figure 4). Low-cost traffic grows on average over 10% yearly and can be seen as the real driving factor in the steep growth of international passengers. Indeed, even though Italy is one of the European countries with less small airports, it is also is the one with most airports served by LCC. Low cost traffic is mainly located in small catchment areas. More precisely, 40% of these airports is located in areas with less than 500.000 inhabitants,[15] even though half of the traffic is concentrated in the first five airports.[16]

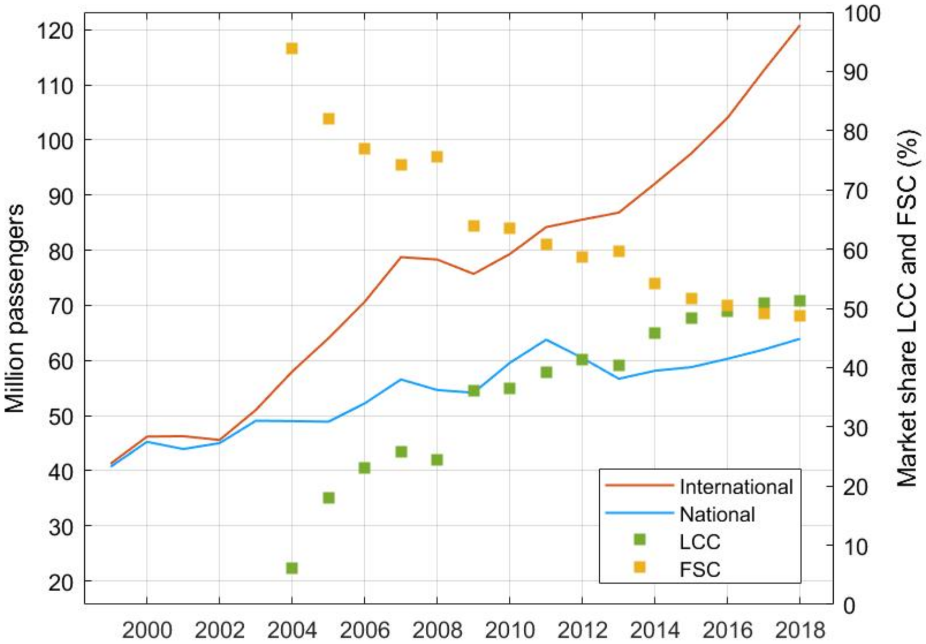


Figure 1.4: Evolution of international and national traffic in Italy and market share of LCC. Own elaboration based on Enac data.

Following the deregulation, some medium/small airports have gained growing importance due to the presence of low-cost carriers. Usually, there are costs associated with the presence of this kind of airlines: in the first place airports are usually demanded to apply discounts on

[14]ENAC annual statistics 2000–2018.

[15]KPMG (2011). Evoluzione del traffico low cost a livello europeo e nazionale. Report prepared on the request of ENAC.

[16]Laurino A., Beria P. (2014). *Low-cost carriers and secondary airports: Three experiences from Italy.* Journal of destination marketing & management, 3 , pp. 180–191.

charges, which is usually compensated by a greater flux of tourists. This kind of situation has led airports to focus on non-aviation revenues. In some cases airports have been subsided by public administrations. This choice has induced local airports to compete to obtain low-cost routes. One interesting example in this sense is the Emilia Romagna case, which has three small airports competing, Parma, Forlí and Rimini, in addition to a medium one, Bologna. These airports have experienced high volatility in traffic because LCC frequently changed their location. For this reason, these airports have registered high losses, often covered by the local administrations, and in some cases have declared bankruptcy.[17] This case shows the bargaining power that low-cost carriers have, which sometimes leads to a bidding war with no long-term benefits. On the other side, there are evident rewards for areas that success in obtaining a long term presence of LCC. It is demonstrated that the presence of these carriers creates a new demand in addition to the existing one on a route, and this addition represents over the half of the new traffic.[18] Moreover, the presence of these operators reduce the seasonality of tourism drastically. It has been calculated that the seasonal variation reduced up to 50% in some cases.[19] Some researches have found out that presence of a LCC airport produces an important direct and indirect effects on the economy. Donzelli (2010), studied the economic effects of low cost airports in southern Italy, finding that the presence of single routes generates effects for 14.6 million euro in the reference area. A similar research, regarding Bergamo Orio Al Serio airport, has found an effect of 2.2 billion euro in ten years and 17000 people employed.[20]

[17] Laurino A., Beria P. (2014). *Low-cost carriers and secondary airports: Three experiences from Italy.* Journal of destination marketing & management, 3 , pp. 180–191.

[18] Skeels, J. (2005). *Is airport growth a necessity or a luxury? Overall view of market growth.* Report Presented to ACI Annual Congress 2005, Munich.

[19] Donzelli, M. (2010). *The effect of low-cost air transportation on the local economy: Evidence from Southern Italy.* Journal of Air Transport Management - 16, pp. 121-126.

[20] Gruppo CLAS (2005). *Gli effetti economici dello sviluppo dell'aeroporto di Milano Orio Al Serio.* Working paper.

2 Società Aereoporti Toscani

2.1 Company overview

Società Toscana Aereoporti is the company that manages Pisa and Florence airports. It was created in 2015 by the merge of the companies of the two airports. The aim of the new society is to improve the air traffic in the region creating the biggest hub in central Italy after Rome. It is mainly detained by private investors:

- 62.28% by Corporacíon America Italia S.p.a .
- 5.79% by SO.G.IM S.p.A.
- 5.03% by Regione Toscana .
- 26.9% by others.

Pisa This airport is mainly focused on low-cost traffic. Indeed, 81% of its traffic comes from LCC. The orientation towards low-cost traffic allowed the airport to experience a steep growth in traffic in the last 15 years, with an average yearly growth of 7.6%. Moreover the costs and the revenues in the same period experienced a similar annual growth, respectively of 6.7% and 6.3%. On the other side the revenues per passenger experienced a mild decline in the same period, which is coherent with the rise of low-cost carriers. The actual concession for Pisa Airport started in 2006 and will end in 2046.

Year	Passengers (Mln)	Revenues (Mln)	Costs (Mln)	Revenues per pax
2004	2.032	32.256	24.834	15.875
2005	2.334	36.430	28.665	15.603
2006	3.015	43.533	34.095	14.441
2007	3.726	51.265	40.819	13.759
2008	3.964	55.098	45.399	13.901
2009	4.019	56.111	45.717	13.963
2010	4.067	60.172	48.102	14.795
2011	4.527	65.088	50.943	14.378
2012	4.495	67.332	51.524	14.979
2013	4.479	65.469	52.906	14.615
2014	4.684	68.676	55.290	14.662
2015	4.805	70.615	57.251	14.697
2016	4.989	73.104	58.111	14.652
2017	5.233	74.379	59.385	14.213
2018	5.463	77.713	64.483	14.225

Table 2.1: Historical data on passengers, revenues, costs and revenues per passenger.
Own elaboration.

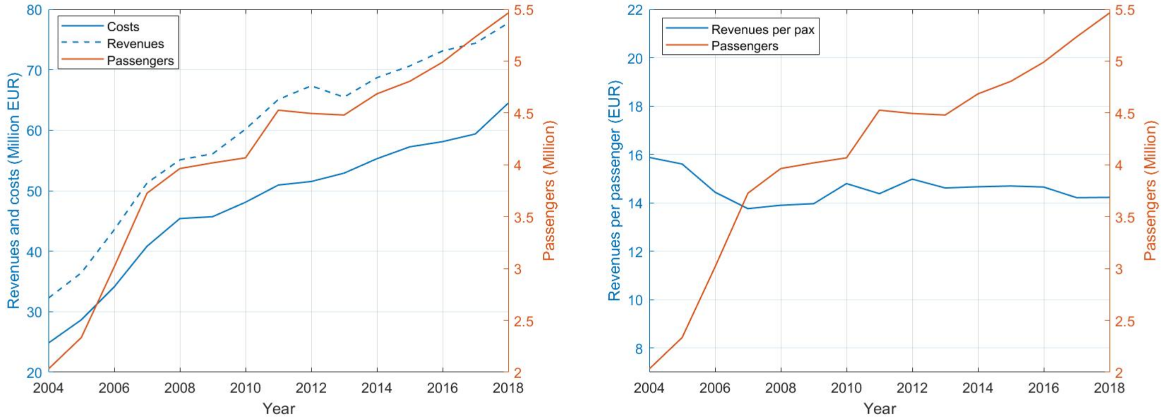


Figure 2.1: Evolution of passengers, costs, revenues and revenues per passenger.
Own elaboration.

Florence Looking at the table below we can see that the passengers evolution experienced a steady growth with two interruptions in 2006 and 2012, the former caused by the closing of the airport for airway maintenance. Overall the number of passengers between 2004 and 2018 grew of 4.8% yearly on average. Costs and revenues in the same period grew on average respectively of 4.7% and 5.8% yearly. Furthermore, the revenues per passenger in this period had a mild increase, contrarily to Pisa. This is mainly due to the "traditional" nature of this airport, since 58% of its actual traffic consist of legacy traffic. This orientation explains the different behaviour of the revenues per passenger in the two airports. The concession for this airport started in 2003 and will end in 2043.

Year	Pax (Mln)	Revenues (Mln)	Costs (Mln)	Revenues per pax
2004	1.495	27.496	19.304	18.387
2005	1.703	31.456	19.630	18.468
2006	1.531	27.146	19.913	17.725
2007	1.919	35.361	24.119	18.429
2008	1.928	37.236	27.287	19.309
2009	1.689	34.913	24.816	20.674
2010	1.738	35.515	25.936	20.436
2011	1.906	37.871	27.800	19.868
2012	1.853	36.74	28.107	19.831
2013	1.983	36.679	29.046	18.494
2014	2.252	40.319	32.292	17.904
2015	2.419	43.358	32.101	17.918
2016	2.515	47.375	33.992	18.836
2017	2.658	49.681	35.534	18.691
2018	2.719	56.885	35.721	20.921

Table 2.2: Historical data on passengers, revenues, costs and revenues per passenger.
Own elaboration.

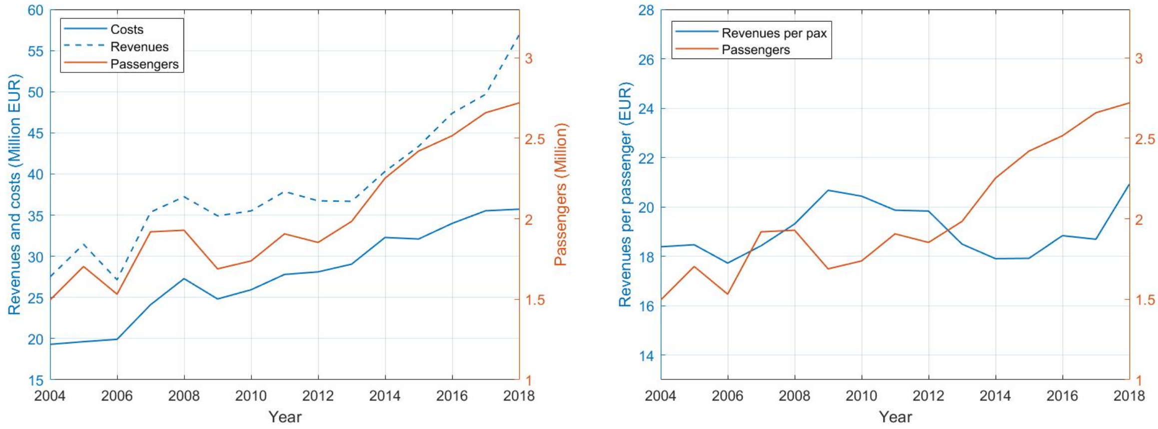


Figure 2.2: Evolution of passengers, costs, revenues and revenues per passenger.
Own elaboration.

2.2 History of Pisa and Florence Airports

The quite large difference in the success of the two airports also depends on their capacity and the area in which they are located. Indeed, the main issue of Florence Airport, and the subsequent success of Pisa, is mainly due to the expansion capacity of the area in which they are.

Florence The location of Florence Airport was chosen in the 1920s and the airport was built in 1931. At the time the area was mostly undeveloped and still had good road infrastructure. In the 1950s it was necessary to expand the runaway for the first time. Even then it was clear that the area presented some criticism because of the strong urban development. Between the 80s and 90s both the runaway and the infrastructures were expanded and the airport opened to international traffic. At that moment it became clear that it was impossible to continue to expand. The main problem was linked to the runaway, which is oriented perpendicularly to the highway A1. Moreover, the presence of mountains on the other side limits the development and, in addition, poses serious problem for the departure of the bigger aircrafts.[21]

Pisa The history of the airport started in the 1920s when it was utilized for military purposes. Only in the 1960s the airport was converted into a commercial scale and the passenger terminal was built. Later in the 80s some improvements in the infrastructure were made. Unlike Florence airport, the area in which Pisa Airport is located leave room for improvement. Indeed, even though the airport is a few kilometers far from the city centre, it has a great availability of military spaces in the south-est area. On the contrary the expansion is impossible on the other two sides, because of the presence of the highway at north and the city itself at west. Furthermore, it has two runaways of 3000m and 2700m that allow the departure of nearly every kind of aircraft.[22]

[21]Environment assesment, Masterplan 2018-2029, Florence.
[22]Environment assesment, Masterplan 2018-2028, Pisa.

2.3 Pisa and Florence airports expansion plan

The necessity of an improvement in the infrastructure has been discussed for many years. The main point of the discussion on a regional basis has been the decision to invest in both airports or to create a single hub in Pisa, which have a better opportunity in term of expansion capacity. In recent years has become crucial because both the airport have reached their limit in passengers capacity. The turning point was in 2012 when Enac, the national airport authority, enacted the national plan of airports. The plan aims to enforce the national system of air infrastructure to deal with the increasing number of passengers.

The plan comes along with the implementation of the ”Single European Sky 2”[23] program, which aims to improve the air transport inside the European Union. This need of improvement in the regional air connection changes the ways the air traffic has been thought. The national strategy has always been to implement a ”hub and spoke” model, which means that a large part of the investments were concentrated in the improvement of the main airports, Fiumicino and Malpensa. The success of low-cost carriers in last years, however, requires to rethink the importance of the small hubs, along with the success of LCC in regional airports.[24]

Florence expansion The plan for the improvement of Florence Airport was released in a masterplan for the period 2014-2029. The project is divided in three main phases and five interventions:

- The construction of a 2400m new runaway of parallel to the highway, in substitution of the actual one (1600m).
- The realization of a new passenger terminal of 48.500mq and the improvement of the actual terminal of 17900mq. The new complex will improve the capacity to 4.5 million passengers.
- The realization of a new cargo terminal.
- The enlargement of the actual apron and the construction of a new one, for a total surface of 20500 mq.
- The improvement of the parking system and of the viability outside the terminal.

[23] Regulation EC n 549/2004 of 10/03/2004.
[24] Enac, Piano nazionale degli aereoporti.

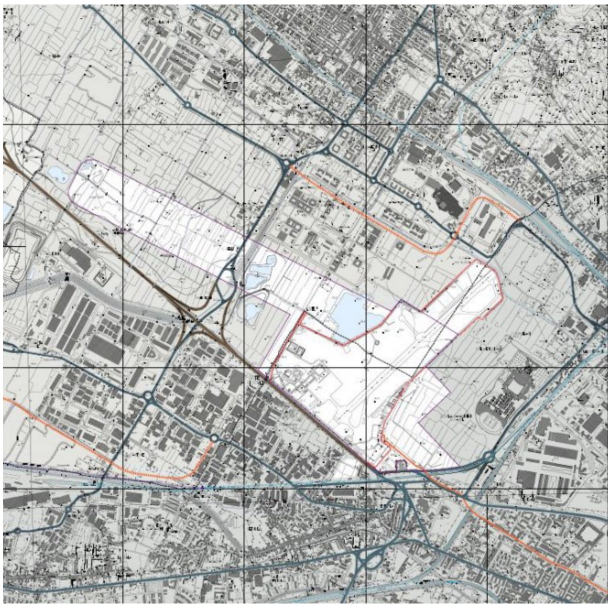


Figure 2.3: View of the planned expansio (in purple the new runaway).

Originally the masterplan indicated a period of 15 years as necessary to complete all the structures and a total cost of almost 300 million euro. Almost half of the project (140 million euro), is financed by the public administration. The original timeline of the plan is summarized in the table below.

	2014-2018	2019-2023	2024-2029
Runaway	X		
Passengers terminal		X	
Cargo terminal	X		
Aprons	X		X
Infrastructures	X		
	200	50.6	27.5

Table 2.3: Timeline of expenses.
Own elaboration based on Florence Masterplan 2014-2029.

Pisa expansion The plan for the improvement of Pisa Airport was released in a masterplan for the period 2014-2024. The project is divided in three main phases and four interventions:

- The improvement of the apron and flight infrastructure, including the enlargement of the cargo terminal.
- The expansion of the actual passenger terminal from the actual 37000 mq to 52000mq. This intervention will improve the capacity up to 8 million passengers.
- The creation of a new system of infrastructure for the passengers.
- The realization of new parking lots and empowerment of the road network of the airport.

The plan was divided in a period of 14 years and a total cost of 258.8 million euro, of which 151 million euro charged to Società Toscana Aereoporti, and the remaining divided between the public administration and private investors. The timeline of the expenses is summarized in the table.

	2014-2018	2019-2023	2024-2029
Flight infrastructures	X		
Parking, road network	X		
Services		X	X
Terminal	X		
	144.5 (56.5)	58.5 (58.5)	55.5 (36)

Table 2.4: Timeline of expenses.
Own elaboration based on Pisa Masterplan 2014-2028.

3 The real options approach

The investment in infrastructure can be seen as setting the paths to release the growth potential of the firm. In a broader sense, an investment is to incur into an immediate cost in exchange for a future reward. Typically investment decision have three characteristics: firstly they are partially or completely irreversible, which means that the cost is at least partially sunk; secondly, the future gains deriving from the investment are uncertain, because of the risk on future revenues; lastly, there is some room for manoeuvre about the timing of investment[25]. The main implication of the first and the third characteristic is that the possibility of waiting is a valuable option and then should be taken into account.
In the classical framework, the DFC method was dominant in this kind of analysis. The main critic choices are the discount rate suitable for the cash flows, the inflation and the estimation of an unknown cash flow. After having resolved these issues it is possible to calculate the net present value and to determine if it is greater than zero. Therefore the choice to invest is two-sided: invest now or never. In reality, the possibility of delay is an essential characteristic. The reason is that a firm with an investment opportunity implicitly holds an option to invest, analogous to a financial one. Thus when the firm invests it exercise this option and gives up the possibility to wait for new information. This value could be significant, and thus, the standard NPV rule could lead to a severe underestimation of the project. Thus, the classical methods usually favour short-term project with low uncertainty over long-term and uncertain one.

3.1 Real options and financial options

The financial option literature started in 1969 when Black, together with Scholes, found out the single equation to calculate the option value, the Black-Scholes equation. However only in 1973, they published the equation to value a European financial option. Later in 1979 Cox, Ross, and Rubinstein simplified the option valuation through the use of a binomial approach in discrete time. Myers(1977) was the first to use the term ”real options”, to describe the financial opportunity that arises from an investment decision of corporations. [26] Later Ross (1978) discuss the analysis of risky projects through the RO valuation. He claims that the focus of the analysis goes to the risk and how to cope with it[27]. Trigeorgis and Manson (1987) pointed out that when the managers used traditional NPV approach to make a decision, their theories are based on the assumption that the future cash flows can be estimated on the premise of certainty about the future. Dixit and Pindyck (1995) argued that traditional NPV method do not include the possibility to defer the investment. This makes the entire investment a decision-making error.
Similarly to financial option RO depends on five variable plus the dividends:

[25]Dixit A. and Pindyck R. (1994). *Investment Under Uncertainty.*, Princeton University Press.
[26]Myers, S. (1984). *Finance theory and financial strategy.* Interfaces, 14, pp. 126-137.
[27]Ross, S. (1978). *A simple approach to the valuation of risky income streams.* Journal of Business, 51, 3, pp. 453-475.

- Value of the underlying risk asset: projects, investments or acquisitions in RO case. An important difference is that the owner of FO cannot affect the value of the underlying asset, while managers operating a real asset can increase its value;
- Exercise price: money invested to exercise the option in case of buying the asset; alternatively the money that the company will receive if it sells the asset;
- Time to expiration of the option: investment opportunity is valid until the expiration date;
- Standard deviation of the value of the underlying risky asset: uncertainty over future cash flows related to the asset;
- Risk-free rate over the life of the option: interest rate returned in case of risk-free investment;
- Dividends: the cash outflows and inflows over the asset's life. These cash flows are similar to dividends on a stock;

Infrastructure investments are similar to exercising an option or a share of stock. Firstly, the investment is composed for a certain amount of money, which corresponds, in this case, to the exercise price of the option. Secondly, the asset present value that will be acquired corresponds to the stock price. Thirdly, the time for which each investment can be deferred without losing the opportunity resemble the option's time to expiration. The uncertainty concerning future value of project cash flow corresponds to the standard deviation. Finally, the value of money is represented by the risk-free rate of return in both cases.[28]

3.2 Types of real options

Trigeorgis (1993) divided real options into seven broad categories summarizing the main characteristics and the field of application :

Option to defer It regards the situation in which the firm hold an investment opportunity. The possibility to wait let the firm to gain more information on the value of the output. This allows to improve the value of the investment.

Application fields: all natural resources, extraction industries and real estate development, farming.

Staged Investment option Investments can be staged in order to create growth and abandonment options. This concerns the possibility to consider each stage as an option on the value of subsequent stages, and evaluate the project as a compound option.

Application fields: R&D intensive industries, Capital-intensive projects and start-up ventures.

[28] Luehrman, T. A. (1998). *Investment opportunities as real options: getting started on the numbers.* Harvard Business Review, 76, pp.51–67.

Option to Alter Operating Scale It regard the possibility to change the production with respect to changing market conditions.Thus, it is possible to accelerate or decelerate resource utilization depending on the state of the market.

Application fields: natural resource industries, commercial real estate and other cyclical industries.

Option to Abandon Possibility to abandon current operations if market conditions decline and to resale equipment on second-market.

Application fields: capital-intensive industries (e.g. airline industry, railroad and financial services).

Option to Switch Possibility to change the output according to changing demand conditions ("product" flexibility). Alternatively, change the input mix to produce the same output ("process" flexibility).

Application fields: consumer electronics, toys, specialty paper, autos (Output shift). Oil, electric power, chemical (Input shift).

Growth Option Possibility to improve future revenues or opportunities in general through early investment.

Application fields: all-infrastructure based industries, especially high tech or R&D .

Interacting Option It involves the combination of the options above. The interaction of these options can give an overall value different to the sum of the separate options.

Application fields: all the sectors described above.

3.3 Application to the airport industry

The massive growth in air traffic in the last thirty years has brought with them the necessity to rethink the airport infrastructures. The airport planning of the second half of the 20th century depends on the needs of legacy carriers and long term forecasting. The central assumption has always been the predictability of future traffic. The rise of low-cost carriers has led to greater volatility in air traffic. Thus, it is appropriate to take into account this uncertainty.
In this respect the real options framework seems particularly suitable for the analysis of the investment in this kind of infrastructures. Indeed the need for new significant infrastructures well suits with the flexibility associated with real option analysis. In the first place, the investments of this kind are usually conspicuous and firm-specific: indeed, they represent a significant sunk cost [29]. Moreover, the rise of LCC has led to the rise of low-cost airports. This kind of airports has a low level of services and thus low construction cost. The rise of this kind of infrastructure

[29] Smit, H. (2003). *Infrastructure investment as a real options game: the case of European airport expansion.* Financial Management Journal, 32, pp.27-57.

led to the under usage of some ”legacy” airports, some examples are Bangkok Airport, Frankfurt terminal 2 and Kansas City Airport[30]. These significant investments were usually justified by social benefits deriving from higher air traffic and thus were largely subsidised by public administrations.
The real options approach help to give a better representation of the value of these kind of investments. Furthermore, the deriving flexibility is necessary to cope with the high degree of uncertainty usually associated with air traffic. Passengers growth has become even more volatile because a large part of the traffic is dependent on the choices of the carriers. Now we are going to review some literature on airport infrastructure investment in a real options background.

3.4 Literature on airport industry

Smit (2003) combined a binomial and a game theory approach to analyse investments in infrastructures. The author focused on the expansion of Schiphol Airport. The author describe the discrete-time binomial model as the most appropriate way to value this kind of investment, because of its easy application and the possibility to consider various growth scenarios. Furthermore, the combination with the game theory framework helps in making corporate decisions about locations or strategic alliances. Thus the presence of competitive asymmetries helps in explaining differences in the valuation of expansion options.

Rodrigues, Pereira, Armada (2006) studied the investment in an airport with two stochastic factors and the presence of exogenous shocks. The authors investigated the effects of uncertainty and concession time on investment value and found out that finite concessions are very unlikely to induce investments.

De Neufville (2007) analysed the shift in airport planning caused by the decline of traditional airlines and the rise of the low-cost carriers. The author proposed a new approach of flexible design to deal with increasing uncertainty. The key element is the use of real options to allow airport management to adjust their facilities in order to cope with the rapid changes of air transport.

Ohama (2007) elaborated a runway extension project at the Tokyo International Airport through a RO analysis. This project intended to increase the airport capacity, bringing a major impact on the overall economy of the country. In order to evaluate this project, three types of designs were considered (two without flexibility and one with flexibility). The author concluded that flexible design allows project optimization as well as reducing losses in airport systems.

Gil (2007) developed a multiple case-study of twelve options related to five projects part of an airport expansion program. The option relates to expansions of the airfield, the train system, the baggage system, the car park and the terminal building. The analysis uncovered a trade-off

[30]De Neufville, R. (2008), *Low-cost airports for low-cost airlines: Flexible design to manage the risks.* Transportation Planning and Technology, vol. 31, pp. 35-68.

commonly seen in the real option world. The author concluded that passive safeguarding is more appropriate in a high uncertainty scenario and low modularity, opposed to active safeguarding, which is preferable in case of high modularity and low uncertainty.

Huber (2009) studied the strategic planning in presence of uncertainty in the emerging market. In particular he examined the uncertainties connected with the type of traffic in addition to those related to the rate of traffic itself. The author analysed airport development in India, a market of low-cost vectors.

Morgado et al. (2011) used the example of Mexico City International Airport (AICM) to analyse an expansion investment. AICM was working close to its capacity limit and in a scenario where demand kept growing. According to the authors the major sources of uncertainty over the life span of the investment project are political issues and government policy, construction and environmental issues and the demand during the operations. The binomial lattice model was used, modelling demand uncertainty, to demonstrate the potential of RO.

Xiao et al. (2017) used real options to study airport capacity choices. The author took into account various factor as prior capacity and reserve, necessary for future expansions. The results showed that the value of the option depends directly on uncertainty and capacity cost and that a profit-maximizer airport would choose small prior capacity and reserve. At the same time, competition promotes capacity and options value.

3.5 The model

The expansion of an airport involves various sources of uncertainty that need to be taken into account. As mentioned earlier, this kind of projects involves significant and irreversible investments. For these reasons, the real options framework is particularly suited. We are going to analyse the value of an airport expansion, taking into account the possibility to defer the investment. In order to obtain an accurate representation of the value of this kind of project, we follow Rodrigues' (2006) model, which analyses the optimal timing for the expansion of an airport. The model disaggregates profits in passengers and cash flow per passenger, and treats them as a stochastic processes and, besides, consider the possibility of exogenous shocks. We extend this model, disaggregating profits in three components : passengers, revenues per passenger and costs. The first two variables are treated as stochastic, resulting in the overall revenues, while costs are assumed to move deterministically. In addition, we consider the presence of jumps of two kinds: the first one, which can be both positive and negative, mainly reflects the effect of economic cycles; the second one represents the possibility of a pandemic shock, thus only on the negative side. Finally, we analyse the effect of an option to abandon on the value of the project and on the optimal timing of investment. This case represents the possibility to exit the concession contract when the revenues lower to a trigger level, receiving a predetermined amount from the resale of the asset. For sake of simplicity we assume that the length of the concession is long enough to be considered as perpetual, which seems reasonable considering that the airport concession usually have a length of 40 years. Moreover, we treat the firm as idle during the time before the construction, which means that our valuation regards only the expansion itself.

3.5.1 Base case

In the base case, we are going to look for the optimal timing for the expansion taking into account revenues as variable of interest, and we are going to find the related value of the option to defer. As mentioned above passengers are assumed to move according to a geometric Brownian motion with expected growth rate α_x and standard deviation σ_x :

$$dx = \alpha_x x dt + \sigma_x x dZ_x \tag{1}$$

In addition also revenues per passenger follow a similar process.

$$dR_p = \alpha_{R_p} R_p dt + \sigma_{R_p} R_p dZ_{R_p} \tag{2}$$

The overall process for profits depends on revenues and costs: $P = xR_p - C$
Costs are assumed to grow deterministically:

$$dC = \alpha_C C dt \tag{3}$$

Revenues is a stochastic factor itself because it is the product of two stochastic factors . $R = XR_p$ follow a GBM process, similar to passengers and revenues per passenger:

$$dR = \alpha_R R dt + \sigma_R R dZ_R \tag{4}$$

Thus we can decompose the revenues into their components:

$$dR = \frac{\partial R(x,R_p)}{\partial x}dx + \frac{\partial R(x,R_p)}{\partial Rp}dR_p + \frac{1}{2}\left[\frac{\partial^2 R(x,R_p)}{\partial x^2}(dx)^2 + \frac{\partial^2 R(x,R_p)}{\partial R_p^2}(dR_p)^2\right] + \frac{\partial^2 R(x,R_p)}{\partial x \partial R_p}dxdR_p \tag{5}$$

Noting that $\frac{\partial^2 R(x,R_p)}{\partial x^2} = \frac{\partial^2 R(x,R_p)}{\partial R_p^2} = 0$ and $\frac{\partial^2 R(x,R_p)}{\partial x \partial R_p} = 1$, the equation becomes:

$$dR = xdR_p + R_p dx + dxdR_p \tag{6}$$

Substituting equations (1) and (2) in (6) we obtain:

$$dR = x(\alpha_{R_p}R_p dt + \sigma_{R_p} dZ_{R_p}) + R_p(\alpha_x x dt + \sigma_x x dZ_x) + (\alpha_x x dt + \sigma_x x dZ_x)(\alpha_{R_p} R_p dt + \sigma_{R_p} R_p dZ_{R_p}) \tag{7}$$

Noting that $xR_p = R_p x = R$, the equation becomes:

$$dR = \alpha_{R_p} R dt + \sigma_{R_p} R dZ_{R_p} + \alpha_x R dt + \sigma_x R dZ_x + (\alpha_x x dt + \sigma_x x dZ_x)(\alpha_{R_p} R_p dt + \sigma_{R_p} R_p dZ_{R_p}) \tag{8}$$

The term $(\alpha_x x dt + \sigma_x x dZ_x)(\alpha_{R_p} R_p dt + \sigma_{R_p} R_p dZ_{R_p})$ is equal to $\rho \sigma_x \sigma_{R_P} R dt$. We ignore the terms dt of order $3/2$ [31] or higher, since they go faster to zero as dt goes to zero. Additionally,

[31] $dZ_{R_p} dt = \varepsilon_t \sqrt{dt} dt = \varepsilon_t dt^{3/2}$ where ε_t is a random variable that follows a normal distribution with the first two moments being (0,1).

$dZ_x dZ_{R_p} = \rho dt$. According to this , after rearranging:

$$dR = (\alpha_x + \alpha_{Rp} + \rho\sigma_x\sigma_{Rp})Rdt + (\sigma_x dZ_x + \sigma_{Rp} dZ_{Rp})R \tag{9}$$

Where $E[dZ_x dZ_{Rp}] = \rho dt$

Now let's define with $F(R)$ the value of the opportunity to invest as a function of R, which is driven by a GBM process as in equation(9). To do so we construct a risk-free portfolio, then we determine its expected rate of return and equate that expected rate of return to the risk-free rate. We start considering a portfolio which consists in holding the option to invest which worths $(F(R))$ and in a short position on $\frac{\partial F(R)}{\partial R}$ unit of the project (or a perfectly correlated asset or portfolio). The value of the portfolio is:

$$\Pi = F(R) - \frac{\partial F(R)}{\partial R} R \tag{10}$$

The short position in this portfolio demands the payment $\delta_R R \frac{\partial F(R)}{\partial R}$ where $\delta_R = k - \alpha_R$ and k is the equilibrium rate of return for revenues[32]. Otherwise no rational investors will enter the long position in the project. Taking this into account, the total return for the portfolio Π during the period dt is:

$$dF(R) - \frac{\partial F(R)}{\partial R} dR - \delta_R R \frac{\partial F(R)}{\partial R} dt \tag{11}$$

In order to obtain the expression for $dF(R)$ we apply the Ito's Lemma.[33] F(R) must follow the ODE:

$$dF(R) = \frac{1}{2} \frac{\partial^2 F(R)}{\partial R^2} (dR)^2 + \frac{\partial F(R)}{\partial R} dR \tag{12}$$

[32]Dixit, Avinash K and Pindyck, Robert S (1994) Investment Under Uncertainty, Princeton University Press, New Jersey

[33]The process of R is continuous in time but non-differentiable. The identity found out by the Japanese mathematician Kiyoshi Ito allows us to determine the stochastic process followed by the value of the option, $F(R)$. Defining a function $F(x,t)$, in which x is a GBM process the Ito's Lemma gives us the differential dF as : $dF = \frac{\partial F}{\partial t} dt + \frac{\partial F}{\partial x} dx + \frac{1}{2} \frac{\partial^2 F}{\partial x^2} (dx)^2$.

Substituting, we can write the total return for the portfolio as:

$$\frac{1}{2}\frac{\partial^2 F(R)}{\partial R^2}(dR)^2 - \delta_R R\frac{\partial F(R)}{\partial R}dt \tag{13}$$

Now calculate $(dR)^2$:

$$\begin{aligned}(dR)^2 = [\alpha_R Rdt + (\sigma_{R_p}dZ_{R_p} + \sigma_x dZ_x)R]^2 = \\ (\alpha_R Rdt)^2 + 2\alpha_R Rdt(\sigma_{R_p}dZ_{R_p} + \sigma_x dZ_x)R + (\sigma_x dZ_x + \sigma_{R_p}dZ_{R_p})^2 R^2\end{aligned} \tag{14}$$

Ignoring all terms dt of order higher than 1 we get:

$$(dR)^2 = [(\sigma_x dZ_x)^2 + (\sigma_{R_p}dZ_{R_p})^2 + 2\sigma_x dZ_x \sigma_{R_p}dZ_{R_p})]R^2 \tag{15}$$

Since $(dZ_x) = dt$, $(dZ_{R_p}) = dt$, and $dZ_x dZ_{R_p} = \rho dt$.

$$(dR)^2 = (\sigma_x^2 + \sigma_{R_p}^2 + 2\rho\sigma_x\sigma_{R_p})dtR^2 \tag{16}$$

Substituting:

$$\frac{1}{2}(\sigma_x^2 + \sigma_{R_p}^2 + 2\rho\sigma_x\sigma_{R_p})dtR^2\frac{\partial^2 F(R)}{\partial R^2} - \delta_R R\frac{\partial F(R)}{\partial R}dt \tag{17}$$

Note that this return is risk-free. Thus, to avoid arbitrage opportunities, during short period dt, the return for the portfolio must be:

$$r\Pi dt = r\left(F(R) - \frac{\partial F(R)}{\partial R}R\right)dt \tag{18}$$

Using the equation (17):

$$\frac{1}{2}(\sigma_x^2 + \sigma_{R_p} + 2\rho\sigma_x\sigma_{R_p})dtR^2\frac{\partial^2 F(R)}{\partial R^2} - \delta_R R\frac{\partial F(R)}{\partial R}dt = r\left(F(R) - \frac{\partial F(R)}{\partial R}R\right)dt \tag{19}$$

Dividing both sides of equation by dt and rearranging, we get the following differential equation that $F(R)$ must satisfy:

$$\frac{1}{2}\sigma_R^2 R^2 \frac{\partial^2 F(R)}{\partial R^2} + (r - \delta_R) R \frac{\partial F(R)}{\partial R} - rF(R) = 0 \tag{20}$$

Defining $\sigma_R^2 = \sigma_x^2 + \sigma_{Rp}^2 + 2\rho\sigma_x\sigma_{Rp}$, $\delta_R = k - \alpha_R$ and $\alpha_R = \alpha_x + \alpha_{Rp} + \rho\sigma_x\sigma_{Rp}$, we get:

$$\frac{1}{2}\sigma_R^2 R^2 \frac{\partial^2 F(R)}{\partial R^2} + (r - \delta_R) R \frac{\partial F(R)}{\partial R} - rF(R) = 0 \tag{21}$$

Subject to the following boundary conditions:

$$F(0) = 0 \tag{22}$$

$$F(R^*) = \frac{R^* e^{\alpha_R n}}{k - \alpha_R} e^{-kn} - \frac{C e^{\alpha_C n}}{j - \alpha_C} e^{-jn} - K \tag{23}$$

$$F'(R^*) = \frac{e^{\alpha_R n}}{k - \alpha_R} e^{-kn} \tag{24}$$

Where j represents the discount rate for costs, n the time necessary for the construction of the expansion. The general solution for the equation (21) takes the form:

$$F(R) = CR^{\gamma} \tag{25}$$

Where γ_1 is the positive root of:

$$\frac{1}{2}\sigma_R^2 \gamma(\gamma - 1) + (r - \delta_R)\gamma - r = 0 \tag{26}$$

Using the boundaries 12 and 13, we get the following solution for $F(R)$ and R^*:

$$F(R) = \begin{cases} \frac{K}{\gamma_1 - 1}\left(\frac{R}{R^*}\right)^{\gamma_1} & \text{for } R < R^* \\ \\ \frac{Re^{\alpha_R n}}{k-\alpha_R}e^{-kn} - \frac{Ce^{\alpha_C n}}{j-\alpha_C}e^{-jn} - K & \text{for } R \geq R^* \end{cases}$$

The first equation represents the value of the project considering the opportunity to wait. The second equation represents the value of the project when is opimal to invest. The equation (27) determines the level of revenues for which is optimal to start the investment.

$$R^* = \left(\frac{k - \alpha_R}{e^{n(\alpha_R - k)}}\right)\left[\frac{\gamma_1 K}{\gamma_1 - 1} + \frac{Ce^{n(\alpha_C - j)}}{j - \alpha_C}\right] \tag{27}$$

3.5.2 Incorporating economic shocks

In this section we allow for the possibility that at some random point of time R will take a Poisson jump downward or upward. This variation to the model allows us to describe the effect of exogenous events of moderate magnitude. Shocks of this kind are mainly represented by economic cycles but can be any kind of event which influences the air traffic in the airport. This addition to the model could help to give a more accurate representation of the behaviour of the value of the project during the years.
We change equation (9) to incorporate the presence of shocks, thus obtaining a mixed Brownian motion/ jump process:

$$dR = (\alpha_x + \alpha_{Rp} + \rho\sigma_x\sigma_{Rp})Rdt + (\sigma_x dZ_x + \sigma_{Rp}dZ_{Rp})R + dqR \tag{28}$$

Where:

$$dq = \begin{cases} (1+u) & \text{with probability } \lambda_u dt \\ \\ (1-d) & \text{with probability } \lambda_d dt \\ \\ 0 & \text{with probability } 1 - (\lambda_u + \lambda_d)dt \end{cases}$$

$(1+u)$ and $(1-d)$ represent, respectively, the magnitude of the positive and negative shocks. Thus now the ODE that F(R) must follow is:

$$\frac{1}{2}\sigma_R^2 R^2 \frac{\partial^2 F(R)}{\partial R^2} + (r - \delta_R) R \frac{\partial F(R)}{\partial R} - rF(R) + \lambda_u [F((1+u)R) - F(R)] + \lambda_d [F((1-d)R) - F(R)] = 0 \tag{29}$$

Which can be rearranged as:

$$\frac{1}{2}\sigma_R^2 R^2 \frac{\partial^2 F(R)}{\partial R^2} + (r - \delta_R) R \frac{\partial F(R)}{\partial R} - (r + \lambda_u + \lambda_d) F(R) + \lambda_u F((1+u)R) + \lambda_d F((1-d)R) = 0 \tag{30}$$

We are going to assume that shocks are independent. Thus the probability that a positive and a negative shock happen at the same period of time is: $\lambda_u \lambda_d (dt)^2$. We can ignore this probability because $(dt)^2$ goes to zero faster than dt.
In this case the expected growth of R, to incorporate the effect of the shocks is $\alpha_s = \alpha_R + \lambda_u u - \lambda_d d$.
The boundaries are the same of the previous case, except for the growth rate, which now is α_s:

$$F(0) = 0 \tag{31}$$

$$F(R^*) = \frac{R^* e^{\alpha_s n}}{k - \alpha_s} e^{-kn} - \frac{C e^{\alpha_C n}}{j - \alpha_C} e^{-jn} - K \tag{32}$$

$$F'(R^*) = \frac{e^{\alpha_s n}}{k - \alpha_s} e^{-kn} \tag{33}$$

The general solution is:

$$F(R) = DR^{\phi} \tag{34}$$

Where ϕ_1 is the positive root, which must be solved numerically, of the non-linear equation :

$$\frac{1}{2}\sigma_R^2 \phi(\phi - 1) + (r - \delta_R)\phi - (r + \lambda_u + \lambda_d) + \lambda_u (1+u)^{\phi} + \lambda_d (1-d)^{\phi} = 0 \tag{35}$$

With the boundaries above, again we find the solutions for $F(R)$ and R^* :

$$F(R)=\begin{cases}\frac{K}{\phi_1-1}\left(\frac{R}{R^*}\right)^{\phi_1} & \text{for } R<R^*\\ \\ \frac{Re^{\alpha_s n}}{k-\alpha_s}e^{-kn}-\frac{Ce^{\alpha_C n}}{j-\alpha_C}e^{-jn}-K & \text{for } R\geq R^*\end{cases}$$

$$R^*=\left(\frac{k-\alpha_s}{e^{n(\alpha_s-k)}}\right)\left[\frac{\phi_1 K}{\phi_1-1}+\frac{Ce^{n(\alpha_C-j)}}{j-\alpha_C}\right] \tag{36}$$

3.5.3 Incorporating pandemic shocks

In this section we are going to assume the presence of another random event in addition to the economic shocks, represented by a pandemic. This kind of event, which is unlikely to occur, becomes of interest in this kind of projects because of the important length of the concession contracts of the airports. Indeed the great magnitude of this events could have a great effect on the value of the expansion. Contrarily to the previous case, this kind of shock is only on the negative side. The equation is the same as (15) but now the Poisson component includes three elements:

$$dq=\begin{cases}(1+u) & \text{with probability } \lambda_u dt\\ \\ (1-d) & \text{with probability } \lambda_d dt\\ \\ (1-s) & \text{with probability } \lambda_s dt\\ \\ 0 & \text{with probability } 1-(\lambda_u+\lambda_d+\lambda_s)dt\end{cases}$$

$(1-s)$ represents the magnitude of the pandemic shock.
Thus, now the ODE that $F(R)$ must follow is:

$$\begin{split}\frac{1}{2}\sigma_R^2R^2\frac{\partial^2F(R)}{\partial R^2}+(r-\delta_R)R\frac{\partial F(R)}{\partial R}-rF(R)+\lambda_u[F((1+u)R)-F(R)]+\\ \lambda_d[F((1-d)R)-F(R)]+\lambda_s[F((1-s)R)-F(R)]=0\end{split} \tag{37}$$

Which can be rearranged as:

$$\begin{aligned}\frac{1}{2}\sigma_R^2 R^2\frac{\partial^2 F(R)}{\partial R^2}+(r-\delta_R)R\frac{\partial F(R)}{\partial R}-(r+\lambda_u+\lambda_d+\lambda_s)F(R)\\+\lambda_u F((1+u)R)+\lambda_d F((1-d)R)+\lambda_s F((1-s)R)=0\end{aligned} \tag{38}$$

As in the previous case, we are going to assume that shocks are independent from each other. Thus, we can ignore the probability of more shocks happening at the same time because $(dt)^2$ goes to zero faster than dt .

In this case the expected growth of R, to incorporate also the effect of the pandemic shock, is $\alpha_S = \alpha_R + \lambda_u u - \lambda_d d - \lambda_s s$.

The boundaries are the same of the previous case, except for the growth rate which now is α_S:

$$F(0) = 0 \tag{39}$$

$$F(R^*) = \frac{R^* e^{\alpha_S n}}{k-\alpha_S}e^{-kn} - \frac{Ce^{\alpha_C n}}{j-\alpha_C}e^{-jn} - K \tag{40}$$

$$F'(R^*) = \frac{e^{\alpha_S n}}{k-\alpha_S}e^{-kn} \tag{41}$$

The general solution is:

$$F(R) = DR^{\theta} \tag{42}$$

Where θ_1 is the positive root, which must be solved numerically, of the non-linear equation :

$$\frac{1}{2}\sigma_R^2\theta(\theta-1)+(r-\delta_R)\theta-(r+\lambda_u+\lambda_d+\lambda_s)+\lambda_u(1+u)^{\theta}+\lambda_d(1-d)^{\theta}+\lambda_s(1-s)^{\theta}=0 \tag{43}$$

With the boundaries above, again we find the solutions for $F(R)$ and R^* :

$$F(R) = \begin{cases} \frac{K}{\theta_1-1}\left(\frac{R}{R^*}\right)^{\theta_1} & \text{for } R < R^* \\ \\ \frac{Re^{\alpha_S n}}{k-\alpha_S}e^{-kn} - \frac{Ce^{\alpha_C n}}{j-\alpha_C}e^{-jn} - K & \text{for } R \geq R^* \end{cases}$$

$$R^* = \left(\frac{k-\alpha_S}{e^{n(\alpha_S-k)}}\right)\left[\frac{\theta_1 K}{\theta_1-1}+\frac{Ce^{n(\alpha_C-j)}}{j-\alpha_C}\right] \tag{44}$$

3.6 Abandonment option

In the previous section we assumed that the airports continue to operate forever. It is plausible, however that at a certain level of revenues the firms will prefer to sell the assets and exit the market. In order to take into account this possibility we will consider an abandonment option. This option is constructed as a perpetual american put option, which give to the firm the possibility to sell the the assets at a certain value A when revenues lower to a trigger value R_E.
In the previous case the value of the project after the moment of the decision of expand was constructed as:

$$F(R_*) = \frac{R^* e^{\alpha_R n}}{k-\alpha_R}e^{-kn} - \frac{Ce^{\alpha_C n}}{j-\alpha_C}e^{-jn} \tag{45}$$

To take into account the abandonment option our NPV needs another term, which consider that a certain time, the firm will give up the asset in change of a value A, losing the subsequent cash flows. Thus, the value of the project at the moment of the investment will be:

$$\begin{aligned}
F(R_*) &\equiv E_t\left[\int_t^T e^{-k(s-t)}R_s - e^{-j(s-t)}C_s)ds + e^{-k(T-t)}A\right] \\
&= \frac{R_t e^{n(\alpha_R-k)}}{k-\alpha_R} - \frac{C_t e^{n(\alpha_C-j)}}{j-\alpha_C} - \\
&\quad E_t\left\{e^{-k(T-t)}\left[\int_T^\infty e^{-k(s-T)}R_s ds - A\right] - e^{-j(T-t)}\left[\int_T^\infty e^{-j(s-T)}C_s ds\right]\right\} \\
&= \frac{R_t e^{n(\alpha_R-k)}}{k-\alpha_R} - \frac{C_t e^{n(\alpha_C-j)}}{j-\alpha_C} - E_t\left\{e^{-k(T-t)}\left[\frac{R_T}{k-\alpha_R} - A\right] - e^{-j(T-t)}\left[\frac{C_T}{j-\alpha_C}\right]\right\}
\end{aligned}$$

Where T is the (unknown) future time to which the firm decides to abandon the project and t is the moment when the investment is made. Moreover, we assume that A and R have similar uncertainty and that the expansion is endend at the moment of the exit.
Rewriting $C_T = C_t^{\alpha_c(T-t)}$. Using the law of iterated expectations, Eq. (6) can be expanded as follows:

$$F(R_t, R_T) = \frac{R_t}{k-\alpha_R} - \frac{C_t}{j-\alpha_C} - E_t(e^{-k(T-t)})\left[\frac{R_T}{k-\alpha_R} - A\right] + E_t(e^{-j(T-t)})\left[\frac{C_t e^{\alpha_C(T-t)}}{j-\alpha_C}\right] \tag{46}$$

$E[*]$ represents the expectation operator conditional on the starting revenues R_t, and R_T, the trigger at which the abandonment option is exercised. It is known[34] that:

$$E[e^{rt}] = \left(\frac{R_t}{R_T}\right)^{\gamma_2} \tag{47}$$

Where γ_2 is the negative root of equation (26). Thus, equation (46) can be written as:

$$F(R_t, R_T) = \frac{R_t}{k-\alpha_R} - \frac{C_t}{j-\alpha_C} - \left(\frac{R_t}{R_T}\right)^{\gamma_2}\left[\frac{R_T}{k-\alpha_R} - A\right] + \left(\frac{R_t}{R_T}\right)^{\gamma_2'}\left[\frac{C_t}{j-\alpha_C}\right] \tag{48}$$

We assume that $\gamma_2' = \gamma_2$, hence the equation above becomes:

$$F(R_t, R_T) = \frac{R_t}{k-\alpha_R} - \frac{C_t}{j-\alpha_C} + \left(\frac{R_t}{R_T}\right)^{\gamma_2}\left[A - \frac{R_T}{k-\alpha_R} + \frac{C_t}{j-\alpha_C}\right] \tag{49}$$

Where:

$$EXITOPTION = \left(\frac{R_t}{R_T}\right)^{\gamma_2}\left[A - \frac{R_T}{k-\alpha_R} + \frac{C_t}{j-\alpha_C}\right] > 0$$

In order to obtain the optimal revenues which trigger the exit we maximize the option value w.r.t R_T, obtaining:

$$R_T = \frac{\gamma_2}{(\gamma_2 - 1)}(k-\alpha_R)\left[A + \frac{C_t}{j-\alpha_C}\right] \tag{50}$$

When the revenues arrive to the level R_T the firm exercises the abandonment option, obtaining A. Substituting R_T, the exit option value becomes:

[34] Dixit A. and Pindyck R. (1994), *Investment Under Uncertainty.*, Princeton University Press.

$$EXITOPTION = -(R^{*\gamma_2})\left(\frac{A(j-\alpha_C)+C}{(j-\alpha_C)(\gamma_2-1)}\right)\left(\frac{(A(j-\alpha_C)+C)(\gamma_2(k-\alpha_R))}{(j-\alpha_C)(\gamma_2-1)}\right)^{-\gamma_2} \tag{51}$$

Now we obtain the optimal level of revenues for which is optimal to invest, considering the presence of the option to exit. The ODE remains unchanged:

$$\frac{1}{2}\sigma_R^2 R^2 \frac{\partial^2 F(R)}{\partial R^2} + (r-\delta_R)R\frac{\partial F(R)}{\partial R} - rF(R) = 0 \tag{52}$$

Now the boundary conditions take into account the abandonment option:

$$F(0) = 0 \tag{53}$$

$$\begin{aligned} F(R^*) = {} & \frac{R^* e^{\alpha_R n}}{k-\alpha_R}e^{-kn} - \frac{Ce^{\alpha_C n}}{j-\alpha_C}e^{-jn} \\ & - (R^{*\gamma_2})\left(\frac{A(j-\alpha_C)+C}{(j-\alpha_C)(\gamma_2-1)}\right)\left(\frac{(A(j-\alpha_C)+C)(\gamma_2(k-\alpha_R))}{(j-\alpha_C)(\gamma_2-1)}\right)^{-\gamma_2} - K \end{aligned} \tag{54}$$

$$\begin{aligned} F'(R^*) = {} & \frac{e^{\alpha_R n}}{k-\alpha_R}e^{-kn} \\ & - \gamma_2(R^{*\gamma_2-1})\left(\frac{A(j-\alpha_C)+C}{(j-\alpha_C)(\gamma_2-1)}\right)\left(\frac{(A(j-\alpha_C)+C)(\gamma_2(k-\alpha_R))}{(j-\alpha_C)(\gamma_2-1)}\right)^{-\gamma_2} \end{aligned} \tag{55}$$

Now the solutions for $F(R)$ are:

$$F(R) = \begin{cases} \frac{K}{\gamma_1-1}\left(\frac{R}{R^*}\right)^{\gamma_1} & \text{for } R < R^* \\ \\ \frac{Re^{n(\alpha_R-k)}}{k-\alpha_R} - \frac{Ce^{n(\alpha_C-j)}}{j-\alpha_C} - (R^{*\gamma_2})\frac{\left(\frac{A(j-\alpha_C)+C}{(j-\alpha_C)(\gamma_2-1)}\right)}{\left(\frac{(A(j-\alpha_C)+C)(\gamma_2(k-\alpha_R))}{(j-\alpha_C)(\gamma_2-1)}\right)^{\gamma_2}} - K & \text{for } R > R^* \end{cases}$$

In this case we cannot obtain an explicit solution for the investment trigger R^*, thus we must solve numerically the equation above:

$$\frac{R^* e^{n(\alpha_R - k)}}{k - \alpha_R} - (R^{*\gamma_2}) \left(\frac{A(j-\alpha_C)+C}{(j-\alpha_C)(\gamma_2 - 1)} \right) \left(\frac{(A(j-\alpha_C)+C)(\gamma_2(k-\alpha_R))}{(j-\alpha_C)(\gamma_2-1)} \right)^{-\gamma_2} - \frac{C e^{n(\alpha_C - j)}}{j - \alpha_C} - \frac{K\gamma_1}{\gamma_1 - 1} = 0 \tag{56}$$

The cases in which we incorporate the effect of the shocks are constructed in the same way. Hence, in the presence of economic shocks basically we use the two roots of the non-linear equation(35) ϕ_1 and ϕ_2 instead of γ_1 and γ_2, and α_s instead of α_R.
In case of pandemic shocks again we use the root of equation (43) θ_1 and θ_2 instead of γ_1 and γ_2, and α_S instead of α_R.

4 Model set up

In this chapter we present the main variables necessary to apply the theoretical model presented in the previous chapter. This part is divided in three sections: in the first one we check the Geometric Brownian motion assumptions and estimate the parameters of the processes; in the second one we present the investment phases and the discount rates; in the third one we estimate the magnitude and probability of shocks.

4.1 Parameters estimation

Recently, economic analyses have relied on the assumption that some quantity that changes over time with uncertainty follows a geometric Brownian motion (GBM) process. This kind of process is widely used to represent the growth in the price of stocks over time. With this assumption the pricing of the option is relatively simple through the use of the Black-Scholes formula.
In the real options analysis the GBM assumption is often used to describe the evolution of the value of several assets, which are supposed to move similarly to stock prices.
However, the GBM assumption needs to be tested before relying on that in the analysis. Ryan and Marathe (2005) analysed the GBM assumption on airline passengers, cell-phone revenues and internet hosts. They found out that passengers may follow a GBM process while the other two variables do not.[35] Moreover, they pointed out that the validity of the assumptions could change depending on the data set: hence the need to test a variable before assuming it as a GBM process. Thus, after briefly introducing the geometric Brownian motion process, we check if passengers and revenues per passenger for both airports can be described as a GBM process, then we estimate the parameters of these processes.

4.1.1 Geometric Brownian motion

A Markow process is a type of stochastic process which has a peculiarity: only the present value of the variable is relevant to predict the future value. A particular type of Markow process is the Wiener process in which the mean variation is zero and the variance is equal to the unity. The Wiener process was used to describe the movement of a particle subject to a large number of shocks. A Brownian motion process $z(t)$ follows two properties:

- The change in value δz in a time interval δt is proportional to the square root of Δt, where the multiplier is random : $\Delta z = \varepsilon\sqrt{\Delta t}$. Thus, Δz follows a normal distribution with mean 0 and variance proportional to Δt.

- The changes in $z(t)$ in two non-overlapping intervals of time are independent.

The standard Brownian motion process has a drift rate of zero and a variance of one.

[35] Marathe R.R. and Ryan S.M. (2005). *On the Validity of The Geometric Brownian Motion Assumption.* The Engineering Economist, 50, pp. 159-192.

A generalize Brownian motion process has the form $dx = adt + bdz$ where a and b are constant and z is a Brownian motion process. A further generalization of the Wiener process is the Ito process, where the constants a and b may depend on the values of x and t:

$dx = a(x,t)dt + b(x,t)dz$

In the case of stock prices, the drift rate is no more constant. In this case is the return on investment which is assumed constant. Thus, given y as the stock price and the drift rate as μy, in a time interval Δt the increase in y is $\mu y \Delta t$. The GBM process has a model $dy = \mu y dt + \sigma y dz$. GBM is useful in modelling stock prices over time when one believes that the percentage changeover equal length, non-overlapping intervals are independent and identically distributed.

Hence we can define y_k as a GBM if:

- $\frac{y_{k+1}}{y_k}$ is independent of all variables until time k;
- $ln\left(\frac{y_{k+1}}{y_k}\right)$ has a normal distribution with mean μt and variance $\sigma^2 t$, independent of k.

4.1.2 Testing the validity of geometric Brownian motion assumptions and estimating the parameters

In this section we check the validity of the Brownian motion assumption and estimate the parameters (drift term and volatility of GBM). To do so, we use the time series of passengers and revenues of the two airports. The validation concerns both the variables useful for the analysis and both the airports. The procedure is as follow.[36]

Supposing that our process of interest, y , follows a geometric Brownian motion process, it satisfies:

$$\frac{dy}{y} = \mu dt + \sigma \varepsilon_t \sqrt{dt} \tag{57}$$

By Ito's Lemma we have:

$$\ln y_t = \ln y_{t-1} + (\mu - \frac{1}{2}\sigma^2) + \sigma \varepsilon_t \tag{58}$$

Defining $R_t = \ln(\frac{y_t}{y_{t-1}}) = (\mu - \frac{1}{2}\sigma^2) + \sigma\varepsilon_t$, it is possible to obtain σ as : $\hat{\sigma} = \sqrt{Var()R_t)}$

Then we rewrite equation (2) as:

$$\frac{\ln y_t}{\hat{\sigma}} = \frac{\ln y_{t-1}}{\hat{\sigma}} + \frac{(\mu - \frac{1}{2}\sigma^2)}{\hat{\sigma}} + \varepsilon_t \tag{59}$$

Defining $Z_t = \frac{\ln y_t}{\hat{\sigma}}$, $Z_{t-1} = \frac{\ln y_{t-1}}{\hat{\sigma}}$ and $c = \frac{(\mu - \frac{1}{2}\sigma^2)}{\hat{\sigma}}$, equation (3) becomes:

$$Z_t = c + \phi Z_{t-1} + \varepsilon_t \tag{60}$$

[36]Chen, Po-yuan. (2012). *The investment strategies for a dynamic supply chain under stochastic demands.* International Journal of Production Economics, 139, pp. 80–89.

To prove that y is a GBM we regress equation (4) to find out the constant c. Then we perform a Dickey Fuller (DF) test on the series to prove the unit root hypothesis. The DF substantially tests the hypothesis :

$$\begin{cases} H_0 : \phi = 1 \\ H_1 : \phi \neq 1 \end{cases}$$

The second task is to test whether the error ε is a white noise. To do this we perform a randomness test under the hypothesis:

$$\begin{cases} H_0 : \varepsilon_t & \text{is generated by a random process} \\ H_1 : \varepsilon_t & \text{is generated by a persistent process} \end{cases}$$

Once we prove that y_t is a GBM process, it is possible to derive the parameters. The volatility can be retrieved as $\hat{\sigma} = \sqrt{Var(R_t)}$ and the drift term can be derived as $\hat{\mu} = \hat{c}\hat{\sigma} + \frac{1}{2}\hat{\sigma}^2$.

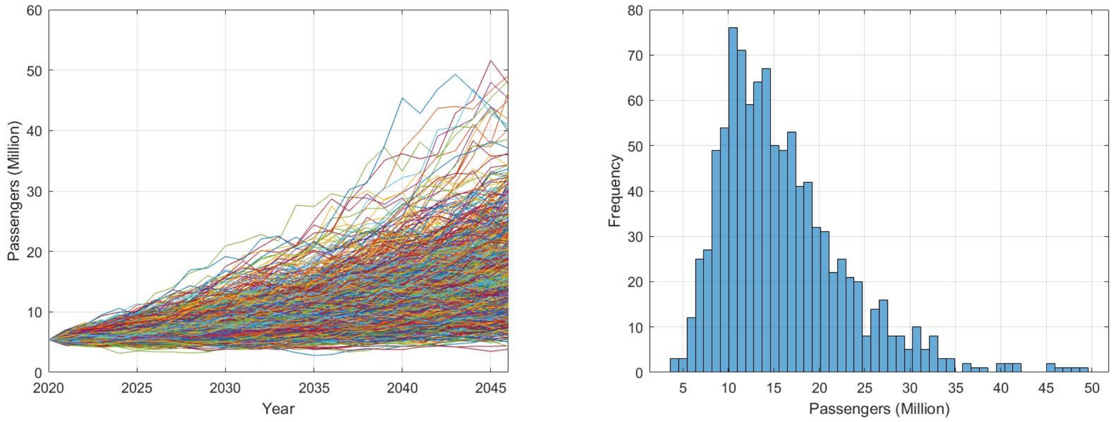
The results are summarized in the table below:

Variable	μ	σ	Unit root test	Randomness test	DW
Pisa passengers	0.0411	0.08	0.9074	0.7044	1.6720
Florence passengers	0.0332	0.0875	0.1632	0.6372	2.0755
Revenues per pax Pisa	-0.0054	0.0343	0.3626	0.8671	1.9658
Revenues per pax Florence	0.0099	0.0544	0.8416	0.4775	2.0090

Table 4.1: Parameter estimation and the tests for the validation of a geometric Brownian motion.

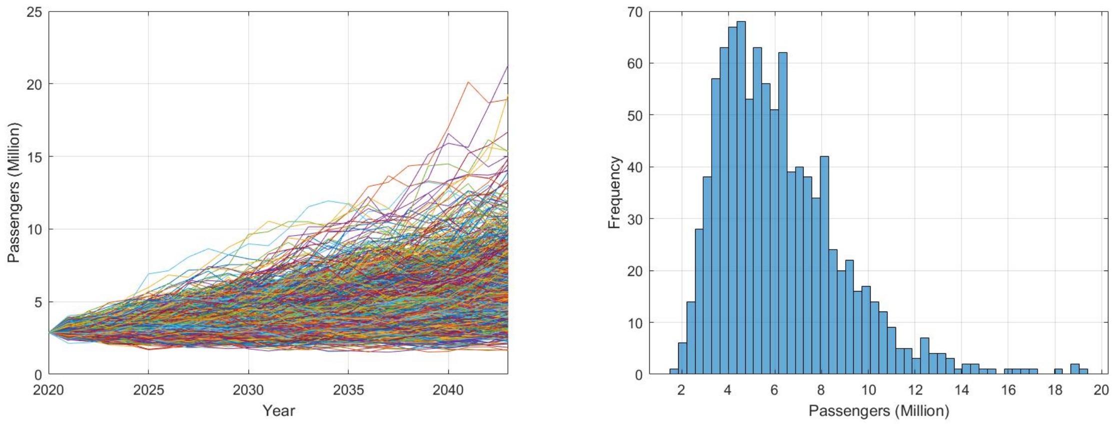
From Table 1, for both passengers and revenues per passenger it is not possible to reject the null hypothesis of unit root. The randomness test, in the same way, fails to reject the null hypothesis of a random process generating the error. In addition, the Durbin Watson test for all the variables gives values close to 2, confirming the independence of errors. These evidences seem to confirm the possibility to use the GBM assumptions on these variables. Moreover, the expected passengers growth of the two airports is very close to the 3.7% growth indicated by ACI for the next twenty years.[37] On the profit side the estimated values reflect the historical pattern and the different nature of the two airports. Especially, regarding Pisa Airport, the estimated value reflects the long term decrease in revenues that derives from the rise of low cost carriers. Below we show the Montecarlo simulations of the processes during the concession life of Pisa and Florence airports (respectively 26 and 23 years). Furthermore, we show the distribution of the results of the Montecarlo simulation at the end of the period.

[37] World Airport Traffic Forecasts 2019–2040



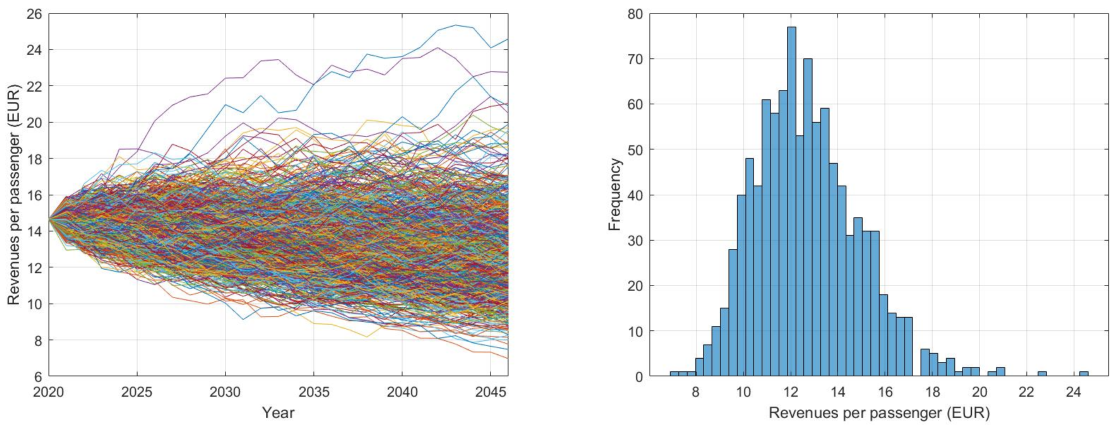
(a) (b)

Figure 4.1



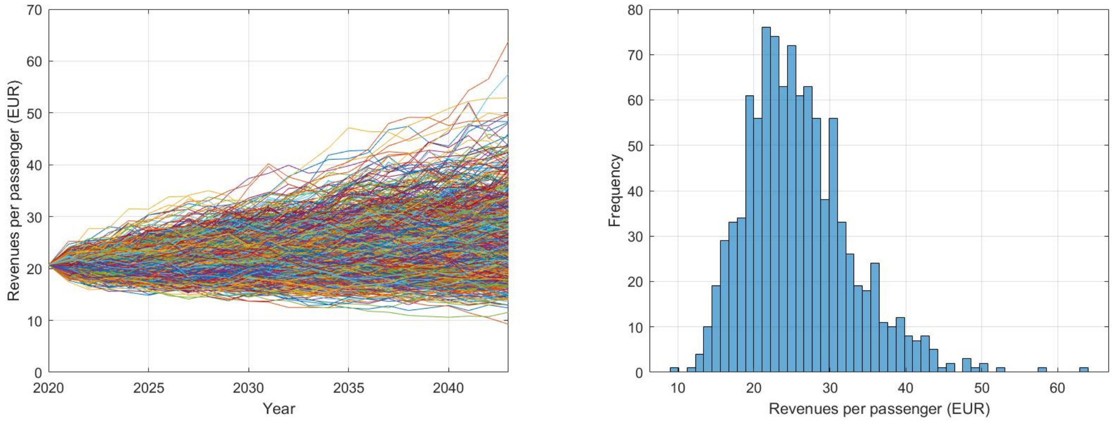
(a) (b)

Figure 4.2



(a) (b)

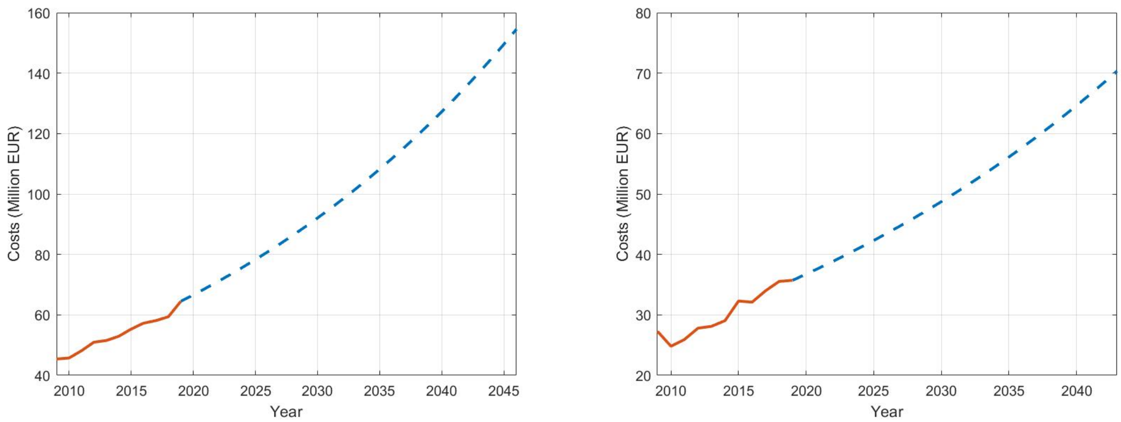
Figure 4.3



(a) (b)

Figure 4.4

Lastly to determine cost parameters we choose the average value between 2009 and 2018 and we use it as an estimate of the future growth. The time interval is chosen in order to avoid the years of greater increase in the number of passengers, thus we consider only the stable growth of the airports. We calculate an expected growth of costs of 3.29 % for Pisa and 2.86% for Florence. They seem reasonable considering the greater growth in the number of passengers of Pisa compared to Florence.



(a) Pisa Airport (b) Florence Airport

Figure 4.5: Forecasts of costs during the concessions' life.

4.2 Investment plan

In order to analyse the convenience of the expansion of the two airports, it is necessary to define two variables: firstly we have to define the discount rates appropriate for the project; then it is necessary to determine the length and the value of the investment. To define a plausible investment plan for the airports we take into account the masterplan projects. A large part of the investments has not being made yet, so we consider the remaining part to define the next investments to be made. Next we look for the present value of the costs of overall expansion, which will be necessary to define the value of the overall project.

4.2.1 Discount rate

Every project valuation method is in some way built on net present value calculations, and every NPV calculation requires a discount rate. Thus, the choice of that rate is one of the crucial variable to take into account. This choice is mainly conditioned by the level of risk that the project has to face. In our case we consider two different kinds of cash flows, which are assumed to have different levels of uncertainties about their future values. Indeed, we assume that revenues move according to a GBM process, which is supposed to have a certain volatility, i.e. a certain level of risk. On the other side the cost component is assumed to move deterministically, hence its future evolution is considered as predetermined, thus riskless. This difference leads to the necessity to consider two different rates in order to take into account the different riskiness. The costs, being riskless, should be discounted using the risk free rate. However, this choice would lead to a disproportion between the present values of costs and revenues, because of the wide difference between the risk free rate and the risky rate. Therefore, we choose to discount costs with the 4% rate suggested by the E.U. commission for infrastructural investments financed through public fund.[38]

For the revenues the appropriate discount rate should be found through the weighted-average cost of capital (WACC) formula, because it represents a project financed through debt and equity. This rate, k, is calculated as :

$$k = k_E \frac{E}{(D+E)} + k_D(1-t)\frac{D}{(D+E)}$$

Where $\frac{E}{(D+E)}$ represents the weight of the equity in the capital structure of the firm. $\frac{D}{(D+E)}$ represents the weight of the debt in the firm. These two variables are estimated as, respectively, 0.7364 and 0.2636. t is the corporate tax rate, that we calculate as 24% . k_D represents the cost of debt, which is calculated as the rate between taxes and taxable income, which results as 3.194%. Finally, k_E is the cost of equity and can be calculated through the capital asset pricing model (CAPM):

$$k_E = r + \beta(r_M - r)$$

[38]European Commission (2014). *Guide to cost-benefit analysis of investment projects. Economic appraisal tool for cohesion policy 2014 – 2020.*

Where r represents the risk free rate, and is calculated as the average of the last year of 10y BTP, which is 1.76%. $(r - r_M)$ is the market risk premium and it is estimated as 5.5% for by the Italian transport authority.[39]. Lastly, the β represents the market beta, and it is estimated as 1.01. The discount rate for revenues calculated through WACC with these parameters results in 6.1%, which seems plausible considering the assumption of a perpetual concession.

4.2.2 Investments

As we already mentioned in Chapter 2 the expansion of Pisa and Florence airports should have started in 2014 and ended respectively in 2028 and in 2029. In reality after six years only a small part of the plan has been made.

Florence Since 2014, several problems slowed down the execution of the masterplan. The first reason is the delay in the technical approval of the masterplan from ENAC. Thereafter the process of environmental impact assessment experienced many interruptions and it was concluded in 2017. The main problem was caused by the proceedings to the Regional Administrative Court, filed by the municipalities around the airport. The main complaint was about the landscape conservation and the pollution deriving from the new runway. In 2016 the Regional Administrative Court sentenced that the maximum length of the runway should have been 2000m instead of 2400m (as established by the plan).
Only recently the Ministry of Infrastructures and Transport has recently approved the expansion plan. In light of this, the first phase, projected by the masterplan, which should have been finished in 2018, has not being completed yet. It was possible to complete only those interventions that do not require a technical approval. Less than 30% of the projected intervention has been completed, with a total expense of 27.6 million euro[40].

Pisa The expansion of Pisa airport has been more straightforward. The large available area attracted less criticism from the municipalities located around the airport and the expansion was delayed only by the technical approval, which has required a total of three years and six months. The environmental impact assessment was completed in 2016. From that moment only half of the projected investments have been made, mainly regarding the terminal and the flight infrastructures. The main intervention completed is the ”Pisa Mover”, a connection between the airport and the train station which helped to improve the airport accessibility. The total expenses until now have been nearly 130 million euro, of which only 57 million financed by the airport company. In addition, recently the company has published a new masterplan, which provides a new plan for the expansion of the terminal and further investments for a total of 43 million euro.

For the purpose of our analysis we consider the original masterplan expenses. Starting from

[39] Autorità regolazione dei trasporti. Resolution n. 62/2017.
[40] ENAC-Report stato degli investimenti infrastrutturali per gli investimenti nazionali 2018

that base we subtract the investments already completed.
Regarding the expansion of Florence starting from the projected value of 268.1 million euro of the initial plan we subtract the interventions mentioned above and further 5.4 million euro indicated by the financial statement of 2019. The residual expenses amount to 245 million euro, of which 120 million euro of public financing. The total length of the construction is supposed to be 8 years. This period is calculated starting from the 15 years planned in the masterplan from which we subtracted the 5 years necessary for the environmental approvals and the further 2 years of intervention which are supposed to be already completed. Overall the expenses for the airport are 125 million euro. Assuming a distribution in the years similar to the one of the masterplan and using the 4% discount rate, we have a present value of the expenses of 115.3 million euro

Regarding Pisa airport the original investment was 258.8 million euro during 14 years. Subtracting the expenses already made it remain a total of 125 million euro to be complete, of which 30.5 million euro of public financing. For the expansion we supposed a period of 7 years that account for the concluded authorisation period. Here, contrarily to Florence, a significant part of the investment has been completed. To this expenses we added the 43 million euro of the further investment decided in 2018, which we supposed divided in half between SAT and public financing. Overall the expenses for the airport are 116 million euro which corresponds to a present value of 105.5 million euro.

4.3 Calculating shocks

After having defined all the variables of interest we calculate the probability and the magnitude of the shocks. As mentioned in the previous chapter we divide the possible shocks in two types: the first one mainly regards the fluctuations in the demand that come from the different phases of the economy; the second one is a particular type of shock, which derive from a particular case of catastrophic event, the pandemic.

4.3.1 Economic shocks

In order to calculate the probability of a shock and its magnitude, we take into account the series of passengers in Italian airports between 1947 and 2014. The choice to use the national series of passengers instead of the one of Pisa and Florence airports has two reasons: firstly, the impossibility to obtain a series longer than twenty years taking into account the passengers of the single airport; secondarily, because the fluctuation of the airport passengers could depend on the natural evolution of the variable, assumed to move as a GBM process. The aggregate Italian series is expected to be less volatile, thus more linear. For this reasons it is expected to be more representative of the cyclical fluctuations caused by economic cycles. Moreover, the choice to calculate the shock on the revenues of the firm through the use of a passengers series is justified by the high correlation between passengers and revenues. The log of the passengers series is represented in figure (4.8). Figure (4.9), instead, shows the detrended series: we can notice that the two more significant negative variations correspond to the 2001 dot-com bubble, which, in its turn, corresponds to the 11 september 2001 terrorist attack, and to the global financial crisis of 2008.

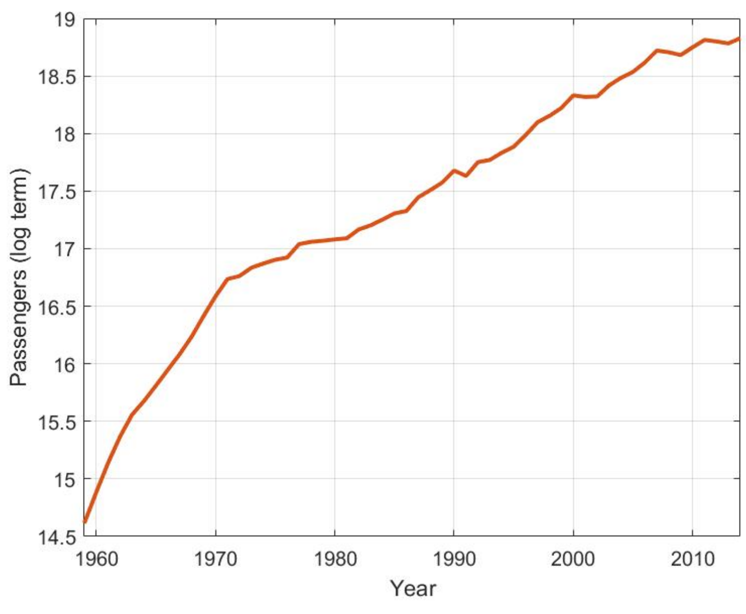


Figure 4.6: The growth of passengers in Italian airports

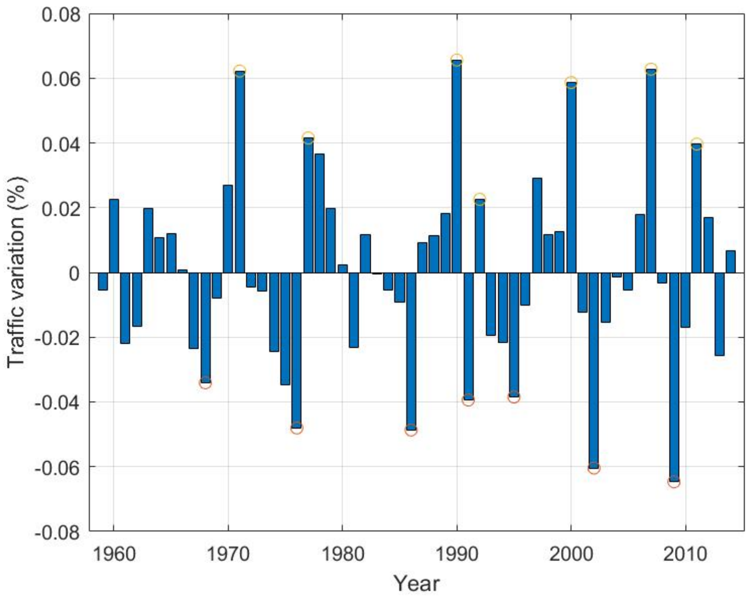


Figure 4.7: Detrended series and its peaks

In order to calculate the probability and magnitude of these shocks we calculate the peaks of the detrended series, excluding those which have a prominence lower than 4%, to avoid to consider events with low effect on the air traffic. To calculate the magnitude of the shocks we take the mean of the variations that correspond to these peaks. In the same way, to determine the probability of the shocks we calculate the average distance between peaks and we derive the probability using the simple rule $\frac{1}{t}$, with t representing the average distance between peaks. The resulting probability are 14.58% annual probability for the positive shocks and 15.09% for the negative shocks, with magnitudes of 5.14% and 4.59% respectively.

4.3.2 Pandemic shocks

In the last part of our analysis we take into consideration the possibility of the spread of a pandemic. These shocks have different characteristics with respect to economic ones: firstly, they are only on the negative side; secondly, they are characterized by a very low probability; lastly, their magnitude is far greater than the one of economic shocks. During the last century there were many epidemics, which hit different countries around the world. The first one was the Spanish flu in 1918, which killed more than 40 million people worldwide. Later in 1957 the Asian flu and the 1968 Honk Kong flu killed more than one million people each and had significant effects on the economies of Asian countries and in some cases on western countries too. More recently the HIV pandemic have spread around the world, causing large damages mainly in Africa. In the 2000s the SARS and the Swine flu have hardly hit Asia. Finally, the recent spread of Covid-19 has caused tragical declines of the global economies.

These recent events highlight the importance of taking into account this kind of shocks. Indeed, the low probability of the pandemics could lead to think that the effects are negligible. In reality, the long term nature of some kind of projects, as in the case of airport concessions, makes it

necessary to include the possibility of a pandemic in the project valuation. In particular, it is of further importance in the air sector because of its global nature.
To represent this shock we use an annual probability of 1.6%, which is the probability of a severe pandemic according to the World Bank.[41] The magnitude of the event is calculated using the Icao data for the effect of Covid-19 pandemic, which assesses an average loss of 59% of the annual revenues of the European airports.

[41] Fan V.Y., Jamison D.T., Summers H.L., (2018). *The Loss from Pandemic Influenza Risk*, Disease Control Priorities, Ch. 18.

5 Results

In this Chapter we examine the results of the application of the model on the expansion of the two airports. We divide the results in four parts: we start from the base model, then we add the economic shocks, then we incorporate pandemic shocks and in the last section we analyse the effects of the abandonment option on the project in the various cases. For each scenario, we examine both the case in which the correlation between the stochastic variables is zero and the one in which we use the historical correlation.
The values of the parameters necessary for the analysis are summarized in the table below.

Parameter	Description	Pisa	Florence
α_x	Expected growth rate of passengers	0.0411	0.0332
σ_x	Standard deviation of passengers	0.08	0.0875
α_{R_p}	Expected growth rate of revenues per passenger	-0.0054	0.009
σ_{R_p}	Standard deviation of revenues per passenger	0.0343	0.0544
σ_C	Expected growth rate of costs	0.0329	0.0286
K	Present value of the investment cost (million EUR)	105.5	115.3
k	Discount rate for revenues	0.061	0.061
j	Discount rate for costs	0.04	0.04
r	Risk-free interest rate	0.0176	0.0176
ρ	Correlation between the two stochastic variables	-0.551	0.0582
X	Current number of passenger per year (million)	5.38	2.87
R_p	Current mean revenues per passenger (EUR)	14.65	20.66
$R = XR_p$	Current total revenues per year (million EUR)	78.93	59.38
C	Current total costs per year (million EUR)	64.48	35.72
n	Number of year for the construction	7	8

Table 5.1: Parameters for the analysis.

5.1 Base-case

We start from the most basic case. The growth rates of the revenues α_R for Pisa and Florence airports are respectively 0.0342 and 0.0434, when we take into account the correlation between the two variables. On the other hand, when there is zero correlation the α_R are respectively 0.0357 and 0.0431. The correlation has a positive effect on the growth rate. Indeed, we see that the growth rate of Pisa Airport experiences a mild increase when we consider $\rho = 0$, while the effect is the opposite for Florence Airport. Regarding the standard deviation σ_R, the effects are similar to the ones of the growth rates. Regarding Pisa Airport, we notice a mild increase from the case with negative correlation ($\sigma_R = 0.0675$) to the one with no correlation ($\sigma_R = 0.087$). Again, the effect for Florence airport is the opposite, moving from 0.1064 to 0.103. Overall the effect of the correlation is very low for Florence Airport, whereas for Pisa is much stronger, considering the strong negative correlation between the two variables. Moreover, the revenues of Pisa Airport are characterized by lower growth and volatility than Florence. While the low growth of Pisa airport is coherent with its low-cost nature, lower volatility could depend on the greater dimensions of the airport.

		Pisa		Florence	
Parameter	Description	$\rho = -0.551$	$\rho = o$	$\rho = 0.058$	$\rho = o$
R^*	Critical total annual revenues that trigger investment	283.60	265.19	62.12	63.13
NPV	Value of the project if implemented today	-6307.20	-6133.90	-48.61	-100.29
$F(R < R^*)$	Value of the investment opportunity	0.006	0.22	77.05	69.80
OD	Value of the option to defer the construction $[OD = F(R) - NPV]$	6307.30	6134.10	125.67	170.09

Table 5.2: Output value for base-case (million EUR).

The wide difference in the growth rate of the two airports leads to significant gaps between the values of their projects. Indeed, Pisa Airport has a strongly negative NPVs of -6.3 and -6.1 billion euro. These values imply a very high level of revenues that triggers the investment and implies a low value of the investment opportunity, that represents the value of the project during the time in which is non-optimal to start the expansion. The overall value of the option to defer is very significant, mainly due to the strongly negative NPV. Thus, in this case the possibility to defer the investment gives significant value to the project. The expansion, however, is substantially delayed. Given the level of optimal revenues, we calculate that the probability to start the construction during the life of the concession (26 years) is 9.5%. The zero-correlation case, on the other side, has a slightly higher NPV and value of investment opportunity, which implies a lower value of the option to defer: indeed, in this case the trigger level of revenues is lower, whereas the probability of expansion increases to 22.3%.

Regarding Florence Airport, the situation is far more positive. The NPV is slightly negative in both cases and the value of the project during the non-expansion phase is worth, respectively, 77 and 69 million euro in the two cases of positive and zero-correlation. In this case, the value of the option to delay is still valuable but has a strongly lower value with respect to the Pisa Airport case. Finally, the trigger revenues are 62 and 63 million euro, which are just few millions more than the actual revenues. These results imply a high probability (99.1% and 99%) of realization during the concession life (23 years).

5.2 Incorporating economic shocks

Parameter	Description	Value
u	Magnitude of positive shocks	0.0514
d	Magnitude of negative shocks	0.0459
λ_u	Probability of positive shocks	0.1458
λ_d	Probability of negative shocks	0.1509

Table 5.3: Economic shocks parameters.

Adding the presence of shocks to the base analysis we see that the overall effect of the shocks is positive. Indeed, the total effect on the growth rates is small but positive: currently, the growth rates of Pisa Airport are 0.0348 and 0.363 in the two cases, whereas the growth rates for Florence Airport are 0.439 and 0.437.

		Pisa		Florence	
Parameter	Description	$\rho = -0.551$	$\rho = o$	$\rho = 0.058$	$\rho = o$
R^*	Critical total annual revenues that trigger investment	276.60	258.33	59.99	61.01
NPV	Value of the project if implemented today	-6244.50	-6063.20	62.60	7.42
$F(R < R^*)$	Value of the investment opportunity	0.024	0.39	91.29	83.19
OD	Value of the option to defer the construction $[OD = F(R) - NPV]$	6244.50	6063.60	28.69	75.76

Table 5.4: Output value including economic shocks (million EUR).

Looking at the table above, it is evident that the shocks cause an improvement in the value of the project: Pisa Airport NPV improves by 200 million euro in both cases, whereas Florence Airport NPV improves by 100 million euro. Also, the latter becomes positive in both cases, but it still remains lower than the value of the investment opportunity, which reaches 91 and 83 million euro in Florence case, whereas in Pisa one there is a slight improvement even though it remains very low. This strong improvement in the value of non-investing is given both by the reduction of the optimal revenues and by the reduction of the parameter ϕ_1. On the other side, the option to defer loses value but it still remains profitable in both cases: for Pisa Airport it is strongly profitable to wait, whereas for Florence the value of the option becomes lower, even if still convenient. Moreover, the critical revenues for the investment are slightly lower in the totality of cases, improving the probability to invest during the life of the concession. Indeed, currently, for Pisa Airport the probability of expansion is 12.9% in the negative correlation case and 23.6% when the correlation is zero. Regarding Florence Airport, the probability remains at the 99% level in both cases.

5.3 Incorporating pandemic shocks

Parameter	Description	Value
s	Magnitude of pandemic shocks	0.59
λ_s	Probability of pandemic shocks	0.016

Table 5.5: Pandemic shocks parameters.

In this section we take into account the presence of a strong negative shocks in the analysis, which has a strong effect on the growth rate of both airports. Thus, considering that we have assumed that the project is perpetual, the value of the project strongly reflects this shock. For Pisa Airport, the shock brings the growth rates to 0.0253 and 0.0268 in the two cases of negative and no correlation. These growth rates are even lower than the growth rate of costs, which seems implausible. Regarding Florence the growth rates now are 0.0345 and 0.342, thus even for this airport the effect of the shock reduces the yearly growth rate by 1 percentage point, which in turns strongly reduces the value of the project.

		Pisa		Florence	
Parameter	Description	$\rho = -0.551$	$\rho = o$	$\rho = 0.058$	$\rho = o$
R^*	Critical total annual revenues that trigger investment	401.62	380.99	99.51	100.68
NPV	Value of the project if implemented today	-7024.3	-6928.9	-1162.1	-1184.9
$F(R < R^*)$	Value of the investment opportunity	0.00069	0.0249	14.61	12.91
OD	Value of the option to defer the construction $[OD = F(R) - NPV]$	7024.3	6928.9	1176.7	1197.8

Table 5.6: Output value including pandemic shocks (million EUR).

From the table above we can notice that in Pisa case the NPV reduces by nearly 1 billion euro in both cases, thus improving the value of the option to defer of the same amount. The value of the investment opportunity now it is worth a few thousand euro and the critical revenues are up to 401.62 and 380.99 million euro. In these hypotheses, the construction of the expansion seems improbable, indeed these levels of revenues imply a probability of expansion during the life of the concession of 0.2% and 1.7%. Regarding Pisa Airport the NPV reduces by 1 billion euro from the base case due to the strong reduction of the growth rates and the value of the investment opportunity arrives to 14.61 and 12.9 million euro. Overall, this cause an improvement of the value of the option to defer the project of more than 1 billion euro. This shows that taking into account also improbable events has strong effects on the project and gives value to the option itself. The level of critical revenues in this case shows the necessity to wait for higher revenues to justify an investment of this kind. Thus, now the probability to expand is 73,5% when taking account the correlation and 72% with zero correlation.

5.4 Abandonment option

Parameter	Description	Pisa	Florence
A	Value recovered at the exit	15.82	17.29

Table 5.7: Abandonment option parameter (Million EUR).

In this section we analyse the effect of the abandonment option on the project. We assume that when the firm decides to exit the project it receives an amount A equal to 15% of K. A can be thought as the value that can be recovered from the sale of the assets obtained through the expansion project. For this reason, it is represented by a share of K. Moreover, the recovery percentage is low because of the nearly total irreversibility of the investment.

		Pisa		Florence	
Parameter	Description	$\rho = -0.551$	$\rho = o$	$\rho = 0.058$	$\rho = o$
R^*	Critical total annual revenues that trigger investment	205.05	183.81	44.95	45.98
R_T	Critical total annual revenues that trigger abandon	134.62	121.56	31.83	32.58
NPV	Value of the project if implemented today	-3879.09	-3422.93	797.16	730.41
OA	Value of the option to abandon the project	2428.14	2710.95	845.78	830.7
$F(R < R^*)$	Value of the investment opportunity	0.0049	1.01	/	/
OD	Value of the option to defer the construction $[OD = F(R) - NPV]$	3879.14	3423.94	0	0

Table 5.8: Output value base-case + abandonment option (million EUR).

We start analysing the effects of the abandonment option on the project in the base-case. Looking at the table above we notice the significant effect of the exit option on the value of the project. The NPV of both airports is significantly higher when it includes the exit option. With respect to the base-case the NPV of Pisa Airport improves by 2428 and 2710 million euro, which is the value of the abandonment option. Moreover, the critical revenues strongly reduce, improving the probabilities to invest, which are,respectively, 36% and 45% in the two cases of negative and zero correlation. Once the firm enters the project, we find that it should exit if its revenues go down to 134 and 121 million euro. Overall, the option to abandon reduces the value of the option to defer of nearly 3 billion euro. Indeed, the option to abandon, given the possibility to exit the project, offers a strong incentive to anticipate the enter, thus reducing the value of the option to defer.

Regarding Florence Airport, the effect of the abandonment option is even more interesting because it improves the NPV of the project to the point that it overcomes the value of waiting. Thus, it leaves the option to defer worthless. Indeed, now the critical revenues for the investments are lower than the actual revenues, which means that the firm should invest now in both cases. On the other side, the critical revenues for the abandonment are lower than the actual revenues.

		Pisa		Florence	
Parameter	Description	$\rho = -0.551$	$\rho = o$	$\rho = 0.058$	$\rho = o$
R^*	Critical total annual revenues that trigger investment	198.49	177.38	43.23	44.21
R_T	Critical total annual revenues that trigger abandon	131.05	118.35	30.64	31.38
NPV	Value of the project if implemented today	-3767.87	-3310.56	920.32	850.91
OA	Value of the option to abandon the project	2476.64	2752.68	857.78	843.48
$F(R < R^*)$	Value of the investment opportunity	0.147	1.67	/	/
OD	Value of the option to defer the construction $[OD = F(R) - NPV]$	3768.02	3312.23	0	0

Table 5.9: Output value including economic shocks + abandonment option (million EUR).

In the case with economic shocks the effect of the abandonment option is stronger than above, mainly because of the slight improvement in the growth rates. The trigger revenues for the investments are the lowest in this case, improving the probability of the investment in the Pisa case to 46% and 58%. For Florence Airport, instead, in the presence of the exit option, the immediate expansion is always convenient.

Parameter	Description	Pisa $\rho = -0.551$	Pisa $\rho = o$	Florence $\rho = 0.058$	Florence $\rho = o$
R^*	Critical total annual revenues that trigger investment	209.62	194.58	53.17	53.94
R_T	Critical total annual revenues that trigger abandon	116.91	110.39	32.09	32.52
NPV	Value of the project if implemented today	-2833.05	-2634.39	252.79	224.57
OA	Value of the option to abandon the project	4191.24	4294.51	1414.93	1409.45
$F(R < R^*)$	Value of the investment opportunity	0.042	0.516	/	/
OD	Value of the option to defer the construction $[OD = F(R) - NPV]$	2833.1	2634.91	0	0

Table 5.10: Output value including pandemic shocks+ abandonment option (million EUR).

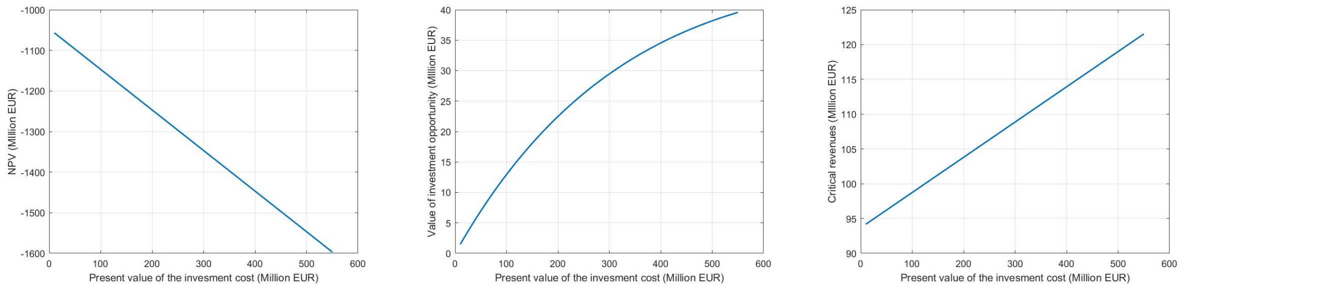
Finally, we analyse the case of the abandonment option in the presence of pandemic shocks. In this case the effect of the shock is completely offsets by the presence of the abandonment option. Indeed, in the case of Florence Airport the NPV remains strongly positive. This is due to the strong value of the option to abandon, which is worth 1.4 billion euro in both cases. Again, it causes the option to defer to be worthless, because the optimal revenues for the investment are lower than the actual revenues, thus causing the immediate investment. Regarding Pisa Airport, the effect of the abandonment option is even more interesting. The critical revenues for the investment are significantly lower than the case without the option and they are very similar to the two cases above. Moreover, the NPV is the highest for Pisa. This fact depends on the strong incentive given by the abandonment option. Indeed, the growth rate of revenues is lower than the one of costs. This means that if the firm invests today, the exit option avoids the strongly negative payout that would occur in the future. For this reason, the option to abandon is valued more than 4 billion euro, while the option to defer is still worth nearly 3 billion euro. Thus, in case of great uncertainty of cash flows, the co-existence of the two options gives significant value to the project.

Overall we notice that if the investment is implemented today Pisa Airport has strongly negative NPV. Florence Airport expansion, instead, seems more reasonable except when we take into account the pandemic shocks that significantly reduce the project NPV. Thus, in both cases, the option to defer the investment is very valuable, in particular in the presence of pandemic shocks (up to 7 billion euro in Pisa case and 1.2 billion euro in Florence one). In the Pisa expansion the level of revenues necessary for the investment is so high that is improbable an investment during the concession life, whereas the Florence Airport investment seems more plausible in the short term.When we take into account the abandonment option the project gains a lot of value. Indeed the NPV improves by a value between 3.5 and 4 billion euro in

Pisa project, due to the high value of the exit option. In Florence expansion the value of the abandonment option ranges between 0.8 and 1.4 billion euro, leading to positive NPV in all cases. Moreover this option has a strong effect on the critical revenues, which strongly reduce, significantly improving the possibility of expansion in Pisa Airport case. This effect in Florence Airport makes the immediate investment convenient, thus leaving the option to defer worthless. Overall the combined effect of the two options strongly improves the value of the expansion projects, in particular in presence of uncertainty deriving from exogenous event.

5.5 Sensitivity analysis

In this section we analyse how changing some parameters affects the NPV, the value of investment opportunity and the optimal level of revenues for the investment, taking as starting points the Florence Airport case. In the figures (5.1) we see that the present value of the investment cost K has a linear negative effect on the NPV of the project. The growth rates of revenues and costs (figures 5.2 and 5.3) have large effects on the value of the project. Indeed, when α_R tends to the value of k the NPV and the value of the investment opportunity go to infinity. The opposite happens with α_C and j. This effects show the importance of the choice of the parameters, which have a big influence on the project value.



(a) (b) (c)

Figure 5.1: Effects of present value of investment cost.

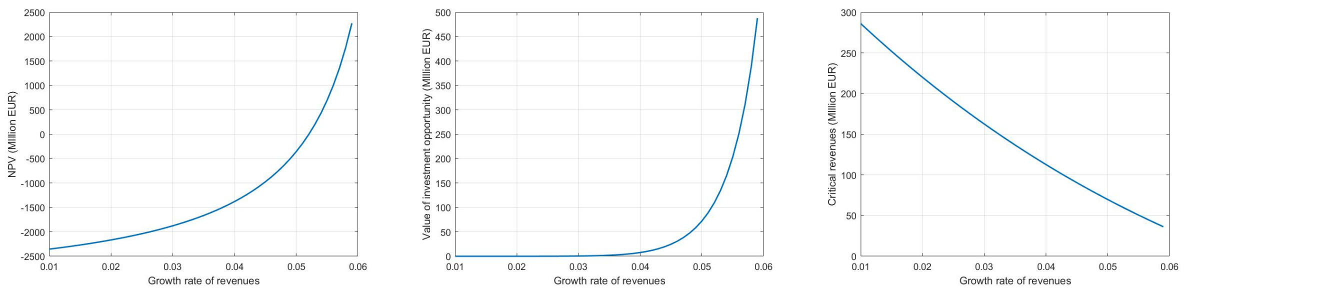


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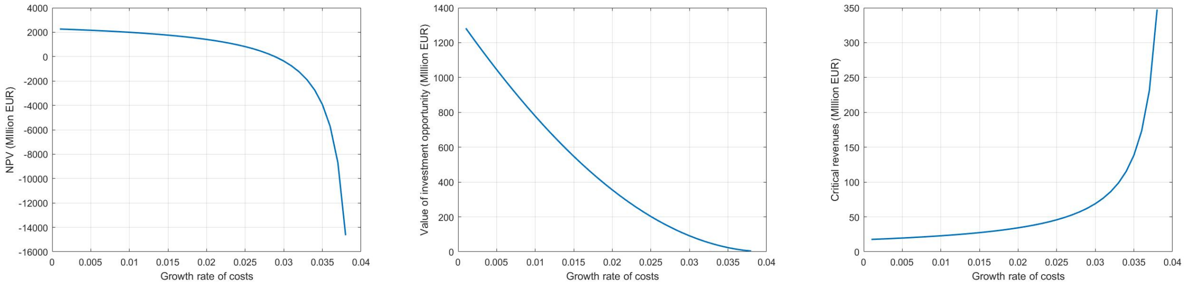
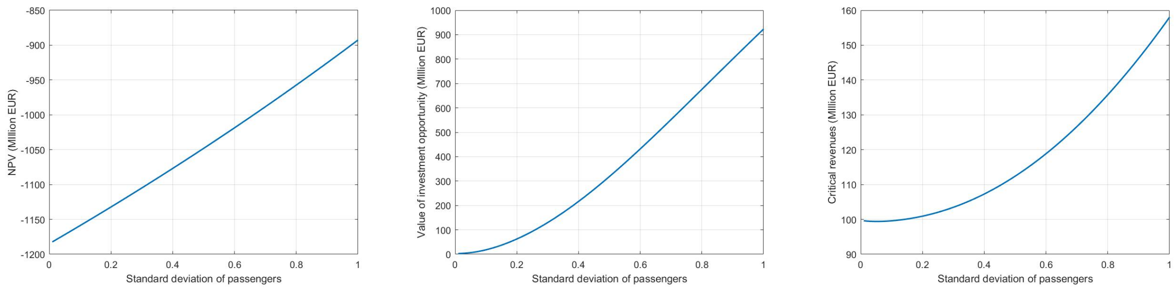
Figure 5.2: Effects of growth rate of revenues.



(a) (b) (c)

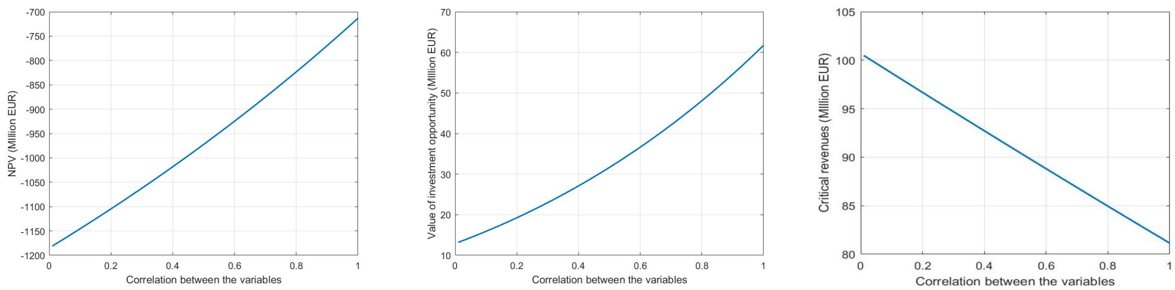
Figure 5.3: Effects of growth rate of costs.

The standard deviation of passengers (or the one of revenues per passenger) have a strong linear effect on the NPV (figure 5.4). In this case this effect is positive because of the positive correlation between the two stochastic variables, which lead the standard deviation to improve the growth rate of revenues. The opposite holds for Pisa Airports, which has a strong negative correlation. The effect of correlation (figure 5.5) is positive both on the growth rate and the standard deviation of revenues, but its magnitude depends on the level of the standard deviations of the stochastic variables.



(a) (b) (c)

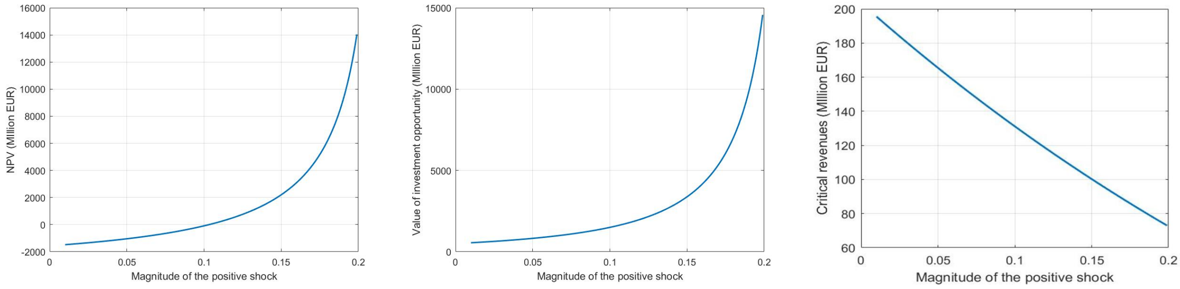
Figure 5.4: Effects of standard deviation of passengers.



(a) (b) (c)

Figure 5.5: Effects of correlation between the two stochastic variables.

Then we see that the magnitude and the probability of the positive shocks (5.6 and 5.7) have significant effects because they directly improve the growth rates. The opposite holds for negative shocks. Finally, taking into account the option to abandon, the value of the project is strongly conditioned by the value recovered at exit, A. Indeed, it is a strong incentive to exit the project when the revenues worsen. Thus, in the analysis of the effects of the abandonment option the attention should be concentrated in the choice of a reasonable exit value.



(a) (b) (c)

Figure 5.6: Effects of the magnitude of positive shocks.

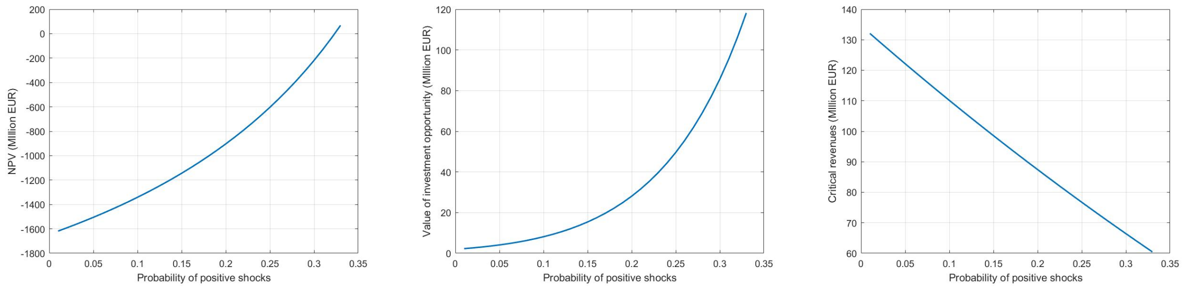


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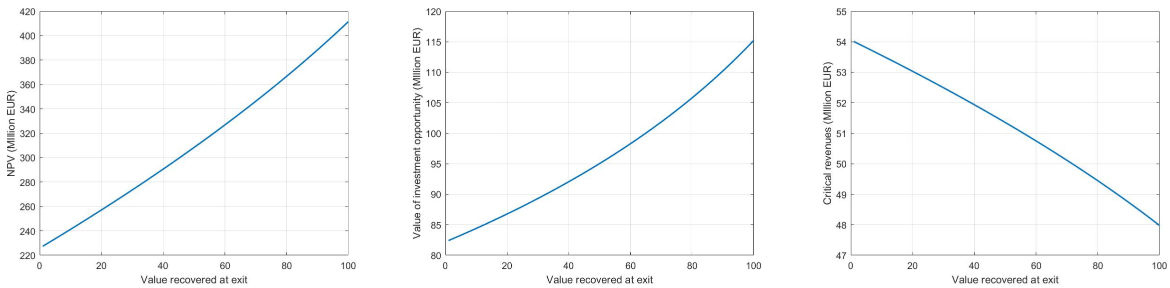
Figure 5.7: Effects of probability of positive shocks.



(a) (b) (c)

Figure 5.8: Effects of the value recovered at exit.

Conclusion

This thesis presents a real option model to evaluate an expansion of an operating airport. In order to have a closer representation of the variables of interest we use two stochastic variables, passengers and revenues per passenger. Together they produce the variable of interest, which is the total revenues. Costs, instead, are treated as deterministically.
We divide the analysis in two cases: in the first one we use the historical correlation between the two stochastic variables, whereas in the other one we assume zero correlation. We incorporate the presence of two different kinds of shocks, one which represents the economic fluctuations and the other one representing the effects of a pandemic, to have a more realistic representation of the evolution of the project value. We study the effect of the presence of an abandonment option on the optimal enter timing and the value of the project. We also assume that the concessions is long enough to be considered as perpetual. Thus, the value of the project is very sensible to changes in growth rates and discount rates.
Our case-study concerns two Italian airports, Pisa and Florence, which are operating almost at full capacity and are planning an expansion. Our aim is to evaluate the optimal timing and the value of the expansion project during the concession life. We find out that the option to defer the investment is valuable in all the cases taken into account. Regarding Pisa Airport the value of the option to defer is between 6 and 7 billion euro, which means that during the concession life it is never efficient to start the capacity expansion. Florence Airport, instead, seems to have less benefits from the postponement of the investment, except when we take into account pandemic shocks. In this case, it increases the value of the option up to 1.2 billion euro. When we add to the analysis the option to abandon, things change significantly. The option gives important incentives to enter the investment. In both cases it strongly reduces critical revenues, thus improving the probability of investing during the concession life. Moreover, the option to exit has a value between 2.5 and 4 billion euro for Pisa Airport and a value between 0.8 and 1.4 billion euro for Florence Airport. This suggests that the exit option strongly improves the NPV of the project. On the other side, the possibility to abandon nearly halves the value of the option to defer in the Pisa Airport case. In Florence case the option to defer becomes completely worthless when the option to abandon is in place, thus making the immediate expansion efficient, even when we consider the presence of pandemic shocks.
Overall, the two options together significantly improve the concession value in the case of an irreversible investment. Indeed, it gives value to projects with strongly negative NPV. On the other side, the finite life of concessions can lead to non-investments, if not compulsory, thus loosing the social benefits deriving from airport infrastructures. In this respect, the option to abandon, making early investments more valuable, could be even more interesting from the point of view of the government. Indeed, it has the double effect of making the immediate investment more valuable and improving the value of the project.

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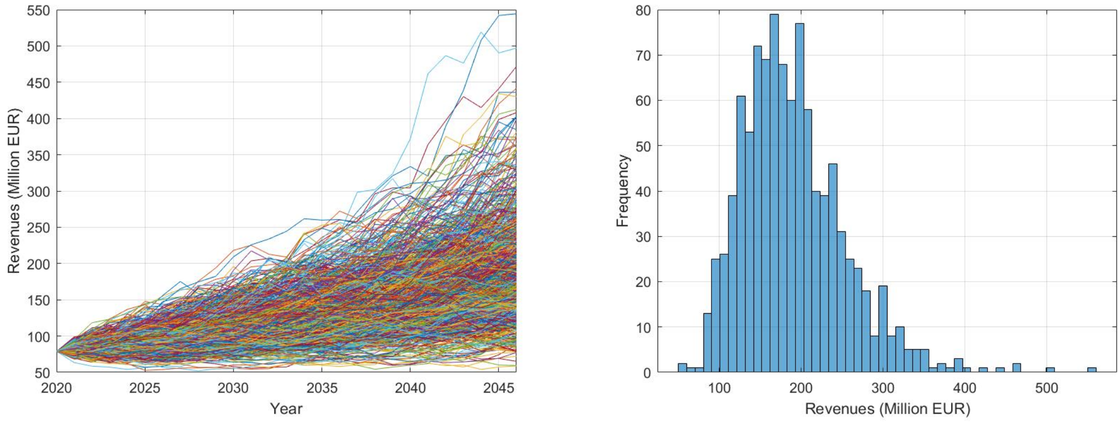
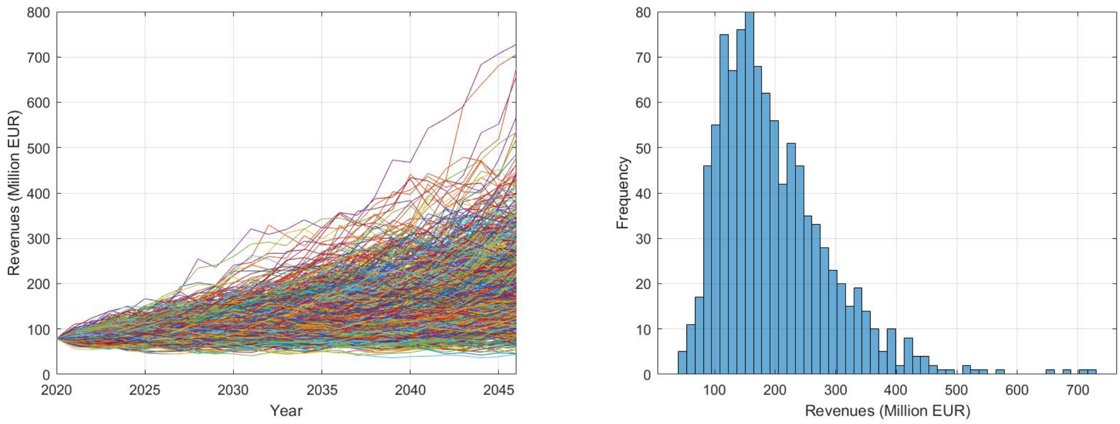
Appendix

Montercarlo simulations of revenues evolution in the various cases and resulting distributions at the end of the concession life.



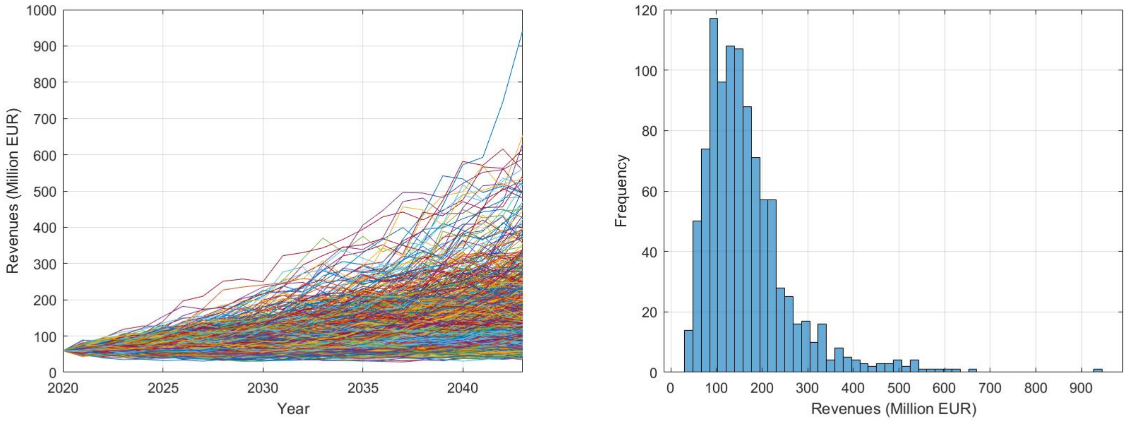
(a) (b)

Figure 5.9: Base-case /Pisa -$\rho = -0.551$



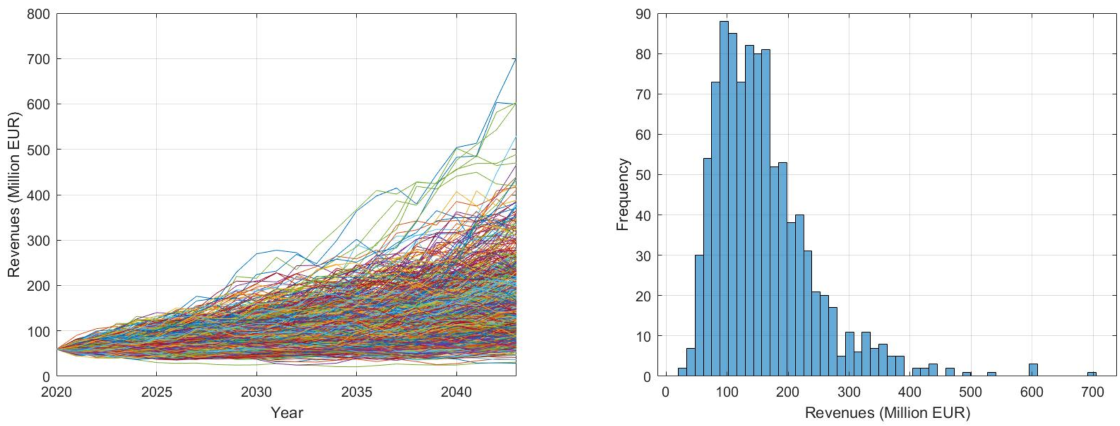
(a) (b)

Figure 5.10: Base-case/ Pisa - $\rho = 0$



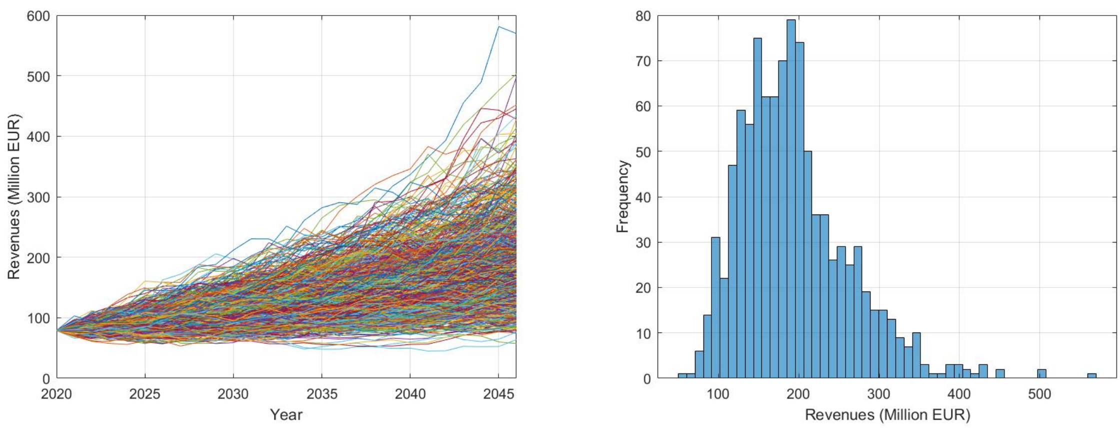
(a) (b)

Figure 5.11: Base-case /Florence-$\rho = 0.058$



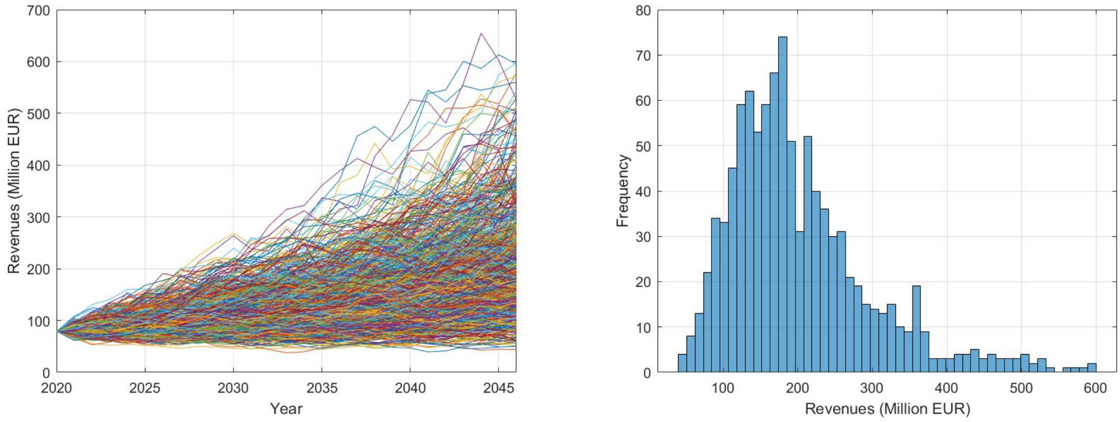
(a) (b)

Figure 5.12: Base-case /Florence- $\rho = 0$



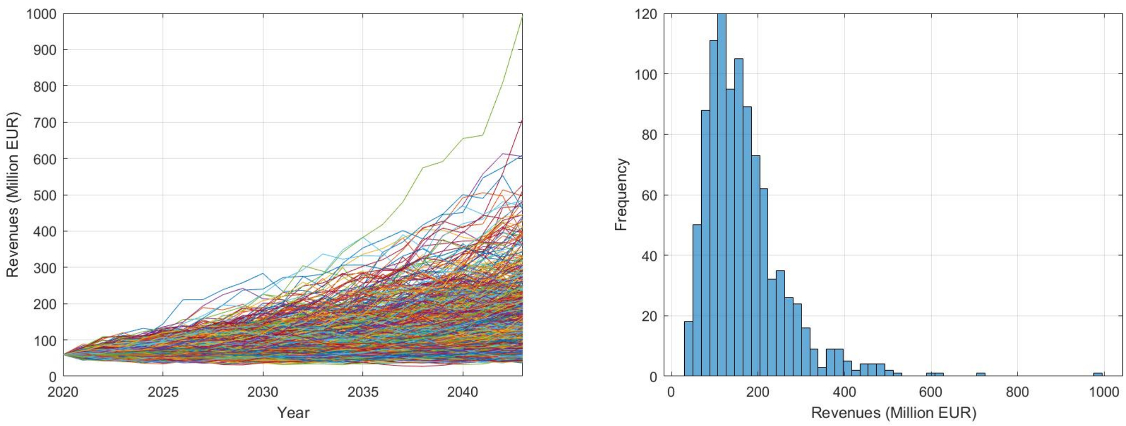
(a) (b)

Figure 5.13: Economic shocks/ Pisa-$\rho = -0.551$



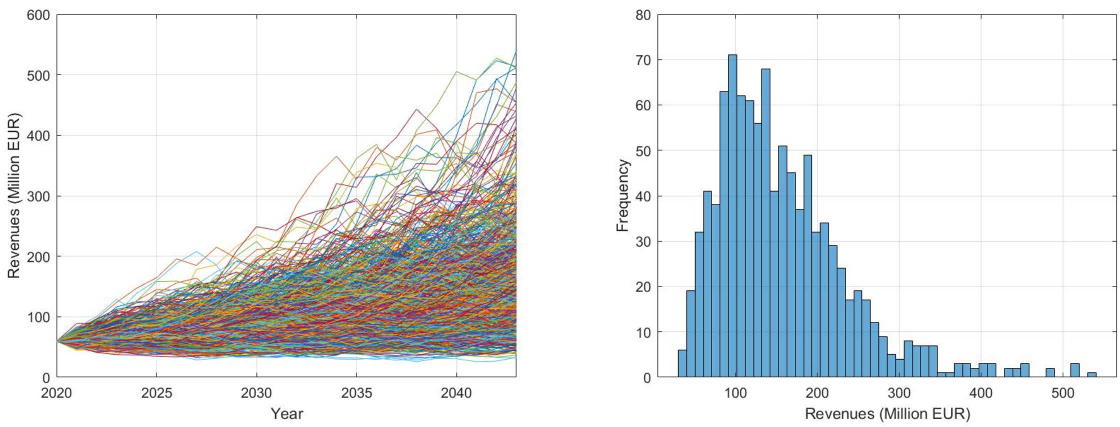
(a) (b)

Figure 5.14: Economic shocks /Pisa-$\rho = 0$



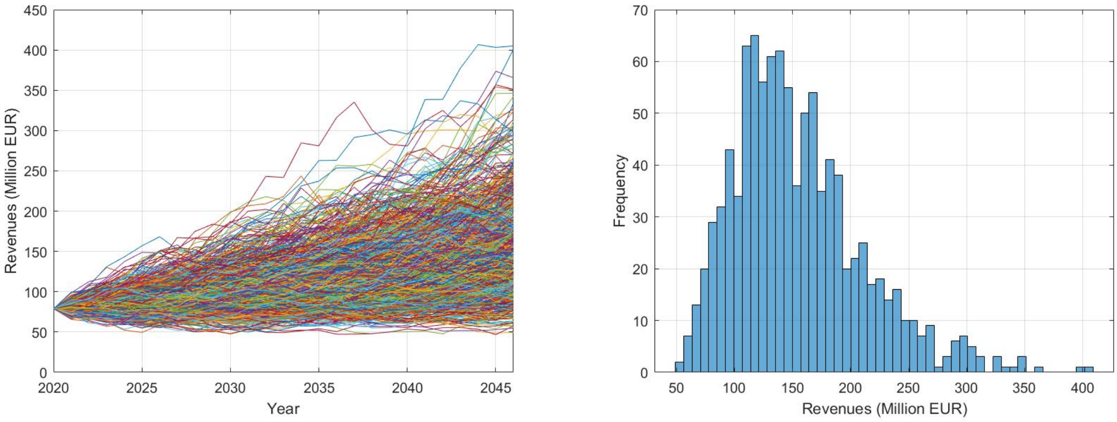
(a) (b)

Figure 5.15: Economic shocks /Florence-$\rho = 0.058$



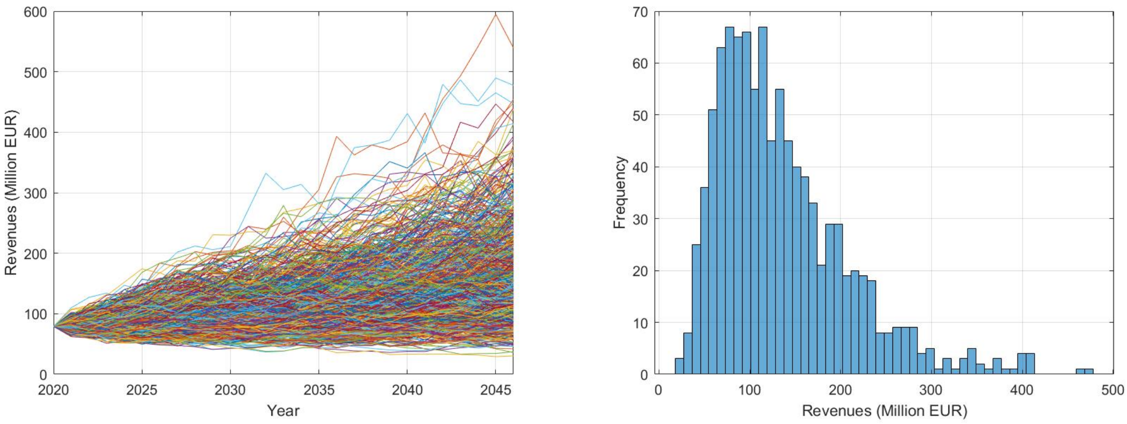
(a) (b)

Figure 5.16: Economic shocks /Florence- $\rho = 0$



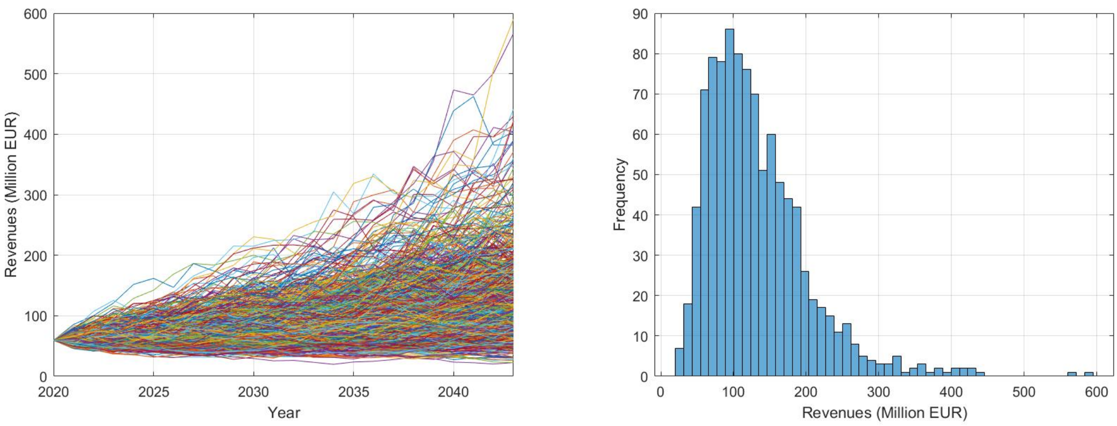
(a) (b)

Figure 5.17: Pandemic shocks/Pisa-$\rho = -0.551$



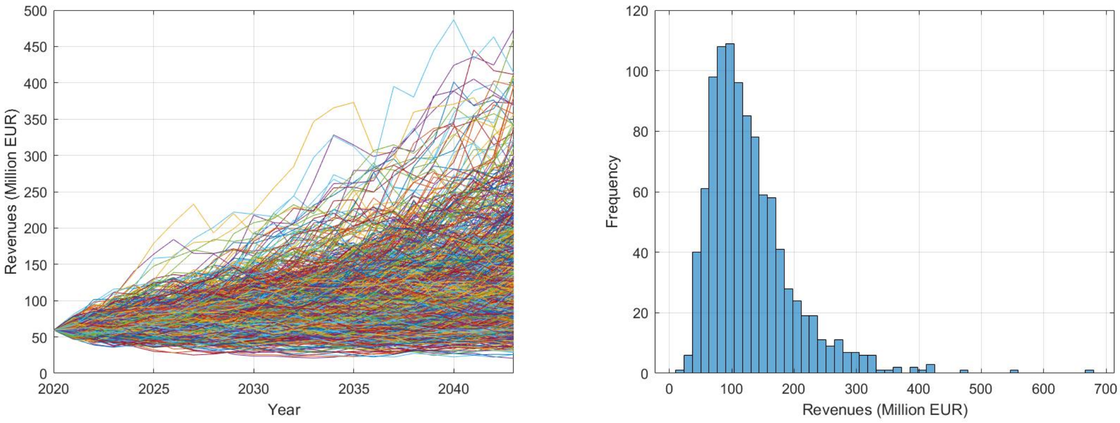
(a) (b)

Figure 5.18: Pandemic shocks/Pisa-$\rho = 0$



(a) (b)

Figure 5.19: Pandemic shocks/Florence-$\rho = 0.058$



(a)

(b)

Figure 5.20: Pandemic shocks/Florence-$\rho = 0$