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"FORECASTING NATURAL GAS PRODUCTION USING DIFFUSION MODELS: APPLICATION TO ALGERIAN CASE"

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Firma dello studente

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Knowledge is a deadly friend
If no one sets the rules

King Crimson

ABSTRACT

The aim of this thesis is to forecast the production of conventional Algerian natural gas. Algeria is a long-standing gas supplier of Europe, especially Italy and Spain, therefore a close examination of the phenomenon should be carried out. The analysis is divided in two parts and each of them has a peculiar research approach. The first one involves the depiction of the “broad picture”, that is how natural gas market is changing across the world, and then a more detailed description of Algeria and its energy market. The second chapter presents a class of statistical models called “diffusion models”; several specifications are showed with the aim to capture different features of the population, such as latent heterogeneity among the agents and multiple generations. The models yield useful statistics to assess future development of gas production in Algeria. The forecasts stemming from the two approaches are coherent each other, suggesting an incontrovertible declining trend in gas production for Algeria and a shift towards renewables energy resources.

CONTENTS

INTRODUCTION

The aim of this thesis is to depict a landscape for natural gas combining different research approaches. In the first chapter, I will use a “geopolitical” method that considers the evolution of many key variables that define the structure and the potential developments of natural gas market across the world. This task is quite complicated because it entails the evaluation and the analysis of several dynamics and unstable factors, which involve strategic, political, technological and economic considerations and their associated risks. For example, in 2006 the Ukraine gas crisis is an outstanding example of geopolitical risk; geopolitical risk is paramount variable to take into consideration especially for the current structure of natural gas market that ties together different countries via pipelines. Those kinds of issues are studied in the first part of this work, in which a comprehensive analysis will touch the prominent risks associated with the current configuration of the market.

Another crucial point is the development of new technological possibilities such as shale gas and liquefied natural gas (LNG). Especially the latter will be analysed in this thesis because it has the chance to create an upheaval in the gas market as it is known, shaping a more liquid and flexible market, and creating new relationships among market participants. To this day, the agreements between buyers and sellers are based on a long-term horizon, with the typical take-or-pay clause and huge investments for the development of pipelines; due to the increment of the LNG exports, the situation is changing in many places, perhaps not in Europe, at least for the moment.

After the description of the broad picture, the discussion will be focalised on a specific producer and exporter of natural gas: Algeria. Algeria’s export is strongly tied to countries such as Italy and Spain, rising crucial questions concerning energy policy for our country and Europe. Natural gas market in Algeria is facing an extraordinary challenge which stems from the increasing secular trend in domestic consumption while production is slowing down. For a country like Algeria, the export of natural resources, especially natural gas, is crucial for national balance, therefore a close examination of this subject is vital for Algeria’s government.

The second chapter is devoted to a class of statistical models called “diffusion models”. I will describe these models trying to highlight their features both in an intuitive and mathematical manner. The spectrum of applications for these models is huge, ranging from quantitative marketing studies to diffusion of innovations and natural resources.

The third chapter is an application of these models to the production of natural gas in Algeria. Considering the time series of natural gas production, several models will be applied to describe and forecast the evolution of the production in the country. This very application is interesting because it gives the possibility to appreciate the strong fitting that these models can reach, especially in the first part, and the problems that can arise when the process shows unexpected behaviour, as it happens in the final part of the observable time series.

The following part will present a description of the most relevant works, employed in this thesis, related to diffusion models.

BIBLIOGRAPHY REVIEW

All the models used in this thesis are based upon the work developed by (Bass 1969) in its paper "*A New Product Growth for Model Consumer Durables*". With this specification, he tried to manage the evolution and diffusion of a product in the market dividing the population in two categories: innovators and imitators. Bass model is quite easy to implement and the number of parameters is limited, therefore it is a good starting point for an analysis that involves the specification of other and more complicated models. The two categories in the population are handled, within the Bass model, by two easier models called monomolecular (Louis A. Fourt, Joseph W. Woodlock 1960) for the innovative part, and logistic (Verhulst 1838) for the imitative.

The subsequent evolution is an extended model based on Bass which includes the possibility to manage possible shocks that can occur during the development of the process. This model called "generalized Bass model" (GBM) has been proposed in "*Why the Bass model fits without decision variables*" (Bass, Krishnan et al. 1994).

An important modification has been introduced by (Bemmaor 1993) in "*Modelling the diffusion of new durable goods: word-of-mouth effect versus consumer heterogeneity*". In this case, the distinction between imitators and innovators remains but it is possible to assign a value to the heterogeneity in the imitator sub-population. This value accelerates or diminishes the speed at which the imitators buy a new product allowing for different willingness among them in completing the purchase.

Another important class of models is the so-called "Space" in which more than one generation of a single product can exist in the same time series and they are described in "*A diffusion theory model adoption and substitution for successive generations of high technology products*"

(Norton, Bass 1987). The model can distinguish between different waves that occur during the same process, yielding estimates regarding the market potential of each wave and the value of the specific parameters. An important application of this model can be found in (Guseo 2011). The final class of models I will use, are a modification of the standard Bemmaor model that include two heterogeneity parameters, one for the innovative and one for the imitative part. The specification and an application of this model is showed in (Guseo, Mortarino et al. 2015).

CHAPTER ONE

1.1 *Energy consumption and energy mix*

In this section, there will be depicted the “big picture”, that is a sketch of the current broad energy situation. The focus will be on natural gas market but, at the same time, a complete view of the world energy market it is valuable since different energy sources are interconnected and intertwined. Most of this first part is based upon (Verda 2015) which gives a complete framework of the energy market and international relations among different countries.

Considering the whole situation in the market it is possible to better understand how and why different energy actors are operating and draw forecasts about future development.

Some facts are the basic points of the new energy scenario. It is well known that the trend in consumption and production it is clearly in favour of Asiatic countries, particularly China, whose demand of energy is constantly growing, unlike Europe in which the energy demand and consumption are shrinking. Another important issue is the non-conventional hydrocarbons extraction in North America, which are reducing the dependency from the rest of the world of the US energy market.

Moreover, the future energy mix will be still based upon fossil fuels, mainly due to their economic competitiveness with respect to renewables, and the expectations about the energy mix see an increase of natural gas consumption, although renewables sources will grow but their quote in the mix will be limited. In general, there is a correlation among the economic growth of a country and its energy consumption which can be interpreted as an indicator of the development under way. An important condition to have a strong and sustainable industrialization process is the availability of low cost energy sources that, at the moment, means fossil fuels.

According to the forecasts (IEA 2015) in 2030 the 77% of the total energy mix will be still composed by fossil fuels; this consideration emanates from the fact that investments in new machinery need to be amortised and usually this process, for that kind of high capital intensive investments, takes a long-time period. Therefore, even if a new technological development based on new energy resources was realised, it is likely that few firms would be able to change their prior investment and undertake a new highly expensive cash outlay.

As reported by the outlooks, the general mix will remain quite static, but at the same time some elements in the key variables that determine the energy consumption could be highly dynamic.

For oil, natural gas and their derivatives, the real game changer and the main source of uncertainty is the dynamic of the demand.

Oil will be increasingly confined in transportation sector and petrochemical industry, instead for heating and power generation other energy sources will be employed due to their cheapness and lower pollution effect. Moreover, in sectors in which oil will remain the main source, the correlation between oil consumption and economic growth will be dimmed by the increased efficiency of modern machineries. Therefore, in Asiatic countries, whose economies are expected to rise sharply, it is possible that a boost in economic growth could require less energy consumption and thus the uncertainty regarding the future path of energy demand is difficult to foresee (Verda 2015).

The other important fossil fuel for which the demand is uncertain is coal. Nowadays, the bulk of power production derives from coal-fired plants, and they produce about 40% of the total power production. The main problem regarding coal is the high emission of carbon dioxide.
The largest amount of demand currently is, and will be, from Asiatic countries, therefore coal’s future is related to the choices of the Asiatic decision-maker and their attitude towards coal’s drawbacks such as pollution.
Anyway, the forecasts suggest that the amount of coal used will increase during the next decade, corroborating the fact that economic growth is closely related to cheap and competitive energy sources such as coal (Verda 2015).

The most important alternative to coal, especially in power generation, is natural gas. Even if its cost is higher than coal, the main advantage is the lower emission of polluting substances during the burning phase. The possibility to use it in industrial applications and heating processes means that natural gas could be an interesting alternative to highly polluting energy sources in developing economies such as Asiatic countries.

Related to diversification in electricity production, there is the possibility of new investments in atomic energy, specifically in Asiatic countries. The advantage of this source is the reduction almost to zero of the emissions of carbon dioxide and, also, to move towards zero the dependence on external nations. Investments in atomic energy require notable financial supports by public authority in the developing phase and regulated prices in order to repay the efforts in a foreseeable manner and, last but not least, the evolution of this sector could be hampered by strong opposition by public opinion (Verda 2015).

Renewable resources will increase in the next decade for several reasons such as incentives by public authorities, in particular in Europe, advantages related to balance of trade and, in the long run, costs. At the moment, the economy of renewables is closely tied to state benefit. This framework of sizeable public financial help is particularly adopted in Europe while in emerging countries this kind of public financing are still limited. A nation who is on the cutting edge, in Europe, in the transition from atomic energy to renewables is Germany, who has undergone an intense operation of divestment of nuclear energy towards green resources via public subsidies (Guidolin, Guseo 2016). To conclude, until the reliability and the gain in efficiency of this kind of energy sources will be high enough to justify the adoption on an economic base, their exploitation will be tied to public subsidies (Verda 2015).

1.2 Energy demand

In this section, there will be a sketch of the world energy demand situation, in particular for oil, because specific information concerning natural gas will be explained later. In order to better understand the future demand's path of different energy sources, is necessary to state some considerations about the processes that drive that demand. The energy requirement of a nation stems from its population, economic growth and energy efficiency so evaluating these drivers it is possible to predict how and where the demand of energy will go.
Obviously, this exercise is not straightforward since the variables in the game are several and the unpredictability and the interconnections among them are difficult to be taken into account.

An important indicator is the *energy intensity*, that is the ratio between inland consumption of energy and Gross Domestic Product (GDP), so the higher the energy intensity the higher the amount of energy required to produce one unit of GDP (Eurostat 2016).
This index is important because, normally, more advanced countries have lower value of this ratio since they have achieved a higher level of energy efficiency and therefore their demand is lower for the same GDP compared with less efficient ones. As an example, energy intensity for European economies is particularly low, unlike China and India which are largely energetically inefficient. This inefficiency arises from various factors but especially from technological lag. On average, industrial processes in emerging countries are less efficient with respect to developed ones but they have the possibility to exploit less strict working and environmental legislations and so attracting heavy investments from abroad.
Moreover, industrialised countries are facing an expansion of the service industry that means less energy intensive activities. Energy efficiency, and so energy intensity, of emerging

countries is expected to converge towards the level of industrialised nations and the high level of energy intensity can, at least partially, explain why the bulk of energy consumption is in direction of Asiatic countries, lead by China's demand, a clear trend of the last decade.

The forecasts suggest that future energy intensity of the two Asiatic giants, China and India, will steeply decline but, for what concerning China, the biggest energy consumer of the world, an elevated economic growth rate will sustain as well its energy needs notwithstanding the increasing efficiency; the prediction is the opposite for Europe, and of the same sign for US (Verda 2015).

The expectations state that, whatever the country, fossil fuels will remain the major source of energy; in countries like China and India, coal will remain the dominant source in the energy mix, while in Europe the prevalent role will be occupied by natural gas. Despite the raising in natural gas consumption and huge amount of coal used in China and India, oil will remain the main source across the world for energetic consumption; there is no reliable alternative to oil in transport and petrochemical industry so the use of natural gas is still limited.

An important issue is the forthcoming energetic independence of the US, mainly due to non-conventional extractions, so a lower demand of Europe, America and Japan, could create a total change in the energy scenario. In order to cover this depletion, it is supposed to exploit China's demand but this is related to the growth rate of its economy and, if there would be a contraction in the demand of the Asiatic giant, the supply could exceed the demand, creating a scenario similar to oil in the second semester of 2014.

For natural gas the situation is different because producer and consumer are tied together via pipelines and the effect of the slowdown in one market will not have direct effects on suppliers other than the one directly related to the client (Verda 2015). Gas prices have shown a regional behaviour but the appearance of LNG could change this dynamic easing price convergence between different gas trading point, but it will be discussed later.

1.3 Supply's dynamic

Although the evolution of demand is strictly linked to the needs of emerging countries and therefore the variables in place are several and difficult to forecast, the situation is different for what concern the supply side of the market. In fact, traditional producers and exporters are expected to remain on top, even if the introduction of non-conventional extraction in North America is a great element of change in the world equilibrium. US' production has increased sharply in the last years and US economy is expected to be energetically independent from the rest of the world in next years (Verda 2015).

The introduction of non-conventional oil and gas procedures is an interesting technological progress in the extraction industry that has already shown its strength and the impact it can have on the market and on prices. The fact is that a situation like the one in the US is unlikely replicable, in the medium-term, in other countries despite the geological potentialities present in other contexts; US' framework consists in small and medium oil companies with an easy access to credit, a solid legal system and a not particularly strict legislation.

OPEC members will continue to be fundamental actors in future oil's supply even if their market share could decline; this contraction derives from non-conventional extraction both in North America (*tight oil)* and Canada. Anyway, the three biggest current producers will remain the same in 2030, that is Saudi Arabia, Russia and United States, the latter devoted to extraction for their own market and the others devoted to export.

For what concerns natural gas, the main distinction is between producers that work for their own demand, specifically US and China, and others that will increase production especially for export such as Turkmenistan and Qatar. Other nations like Russia and Iran will continue to export but they will see their internal demand increase with a higher inefficient end-user utilization.

According to these estimates, these dynamics will have a local effect rather than global as for the case of oil, especially on a regional base that is consumers directly connected via pipelines to the specific producers.

Also for provisions of natural gas in form of LNG there will remain some elements of rigidity, as is better explained later, due to the presence of long-term contracts and the presence of new infrastructures for the liquefaction and regasification phases.

The new player here is the Australians' LNG that could increase the quantity offered with significant impact on prices.

The rigidity of the market, mainly due to the presence of pipelines, especially outside Asia, is the reason why the evolution of the supply's framework is quite distributed over time (Verda 2015).

Anyway, the key variable that will drive the evolution of the market will be the demand of energy related to economic growth, and the environmental legislation of importing countries.

1.4 Europe's situation

Europe is one of the biggest political and economic entity in the world. Obviously, this measures imply a commensurate energy consumption. Many indicators are useful in this respect such as energy production and consumption and the dependence on foreign countries' supply. The import of different resources is an issue of crucial importance especially for what concern oil and gas. Data analysed herein refer to *gross inland energy consumption*, that is the total energy demand of a country or region. It represents the quantity of energy needed to satisfy inland consumption of the geographical entity under consideration. Inland consumption is composed by the sum of five energy sources: coal, electricity, oil, natural gas and renewable sources. In 2014 more than a half of EU-28 consumption where covered by imports. For what concerns *primary production of energy*, that is any extraction of energy products in a usable form from natural resources, in 2014 it amounted to 771 tonnes of oil equivalent (toe) (Eurostat 2016), for more information see the appendix 1.

1.4.1 European energy production: a look to the decade 2004-2014

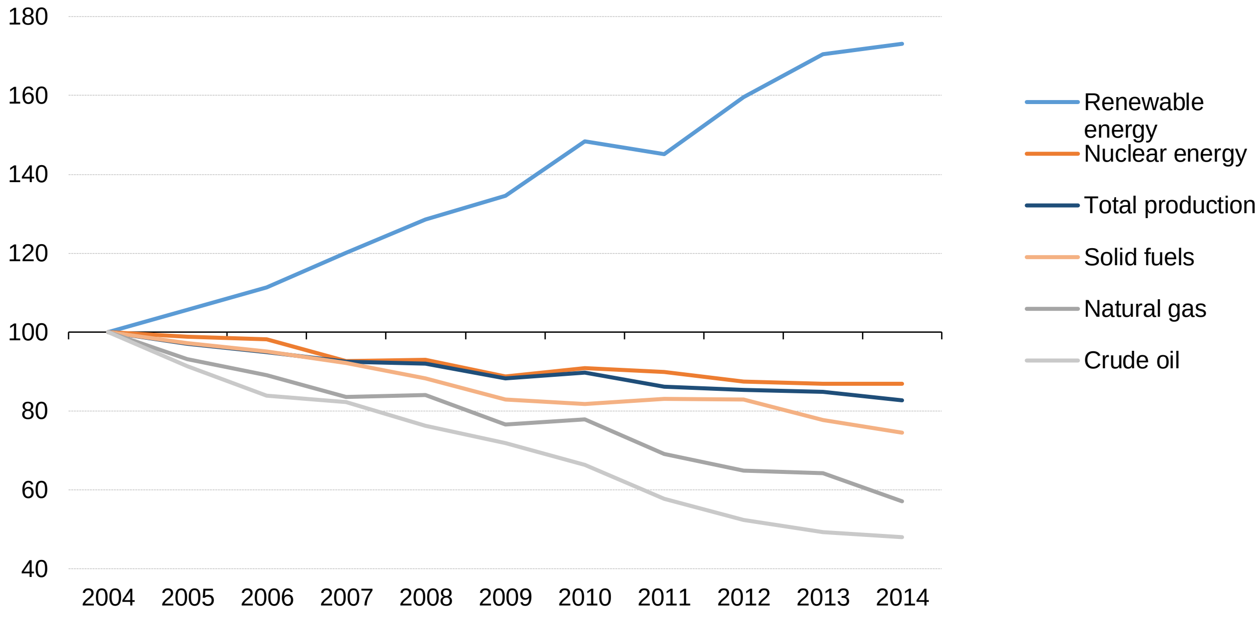
As it is possible to see in Figure 1 below, the energy production inside Europe has collapsed for all energy sources except renewables, with a little exception in 2010. The highest decrease has occurred in 2009 with an important contribution deriving from the financial and economic crisis of those years. Considering the entire decade 2004-2014, there is a clear and probably incontrovertible trend in primary production; total production has dropped by 17,3% in ten years, but the collapse is even more striking if we consider just the production of natural gas and oil: the former decrease by 42,9%, the latter by 52%. According to what reported by (Eurostat 2016), this drop is due to the depletion of the fields or the fact that European producers do not find economically suitable the exploitation and commercialization of primary resources.

France is the main energy producer within Europe with an elevated share, 82.2%, of nuclear energy in its energy production mix, followed by Germany and United Kingdom. In absolute terms, half of EU-28 countries have recorded a production increase in the decade ending in 2014; among them, the highest is in Italy (+7,6 Mtoe), while, on the other side, the highest contraction in energy production is in United Kingdom (-116.7 Mtoe), Germany (-16,9 Mtoe) Denmark (-15,1 Mtoe) and Poland (-11.2 Mtoe). The bulk of production in Europe is nuclear energy, which accounted for 29.4% of total production especially in France, as seen before, Belgium (71,2%) and Slovak (64.1%); Germany has declared the intention to shut down all its nuclear plants within 2022.

As depict in the picture below, renewables are the only energy sources which have shown a steep increase with respect to 2004, all the other have dropped; moreover, as well as in absolute terms, renewables are taking a large share of inland production in fact they are second after nuclear energy (Eurostat 2016).

Starting from the nineties, the depletion of hydrocarbons fields, discovered between the sixties and eighties in the North Sea and other places across Europe, and the increasing marginality of coal mines, have had the effect of boosting the dependence of Europe from other countries: between 1996 and 2012 primary energy production has dropped by 20%, only partially balanced by the increased renewables exploitation (Verda 2015).

Figure 1: Development of the production of primary energy (by fuel type), EU-28, 2004–2014



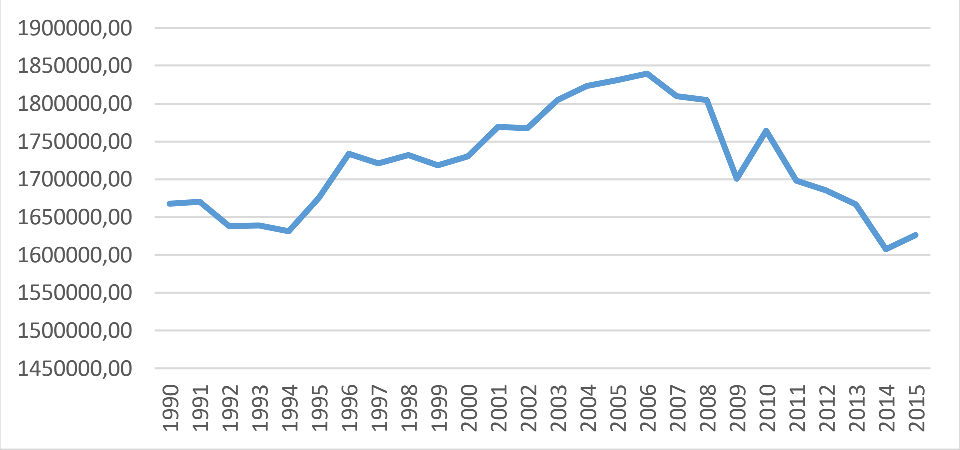
Source: Eurostat (2016)

1.4.2 European energy consumption

The striking fact in the evolution in energy consumption, as well as in energy production, is the considerable shift towards renewable resources like hydropower, solar energy, wind power and biofuels. As described in the subsequent paragraph, several energy initiatives have been proposed by the European Commission and European Council with the aim to increase the efficiency in energy use and reduce energy demand.

In 2015, the EU-28 total amount of energy consumption was 1626 Mtoe, an increase of roughly 1,2% with respect to 2014, probably tied to the expansion phase of European economy. The same pattern with the opposite sign happened in 2009 when a sharp decrease of 5,8% in energy consumption occurred due to a lower level of economic activity and production; again, it is possible to recognise how strong is the bond between economic activity and energy consumption, a link that can create a sudden and sizeable change in the energy demand of a country without entailing a shift in the energy mix (Eurostat 2016).

Figure 2: EU-28 gross inland energy consumption (1000 tonnes of oil equivalent)



Source: Eurostat (2016)

The declining trend in consumption reached its peak in 2014, that is 12,7% lower than the highest peak in 2006 which corresponds to an average reduction in consumption of 1,7% per year. This pattern could have a crucial importance in the future equilibrium in the energy market, because the trend is quite stable and, at the same time, energy efficiency in Europe is into an increasing way. The consequence of that could be the decision of exporting countries to divert the bulk of their investments towards new destinations, especially Asia, that entails uncertainty in future prices and quantity of the provisions (Verda 2015). As reported in appendix 2 the main energy consumer in Europe is Germany which accounted for 19,5% share of the EU-28, followed by France (15,5%) and United Kingdom (11,8%). Moreover, Germany, United Kingdom, Denmark and Italy have a lower current level of energy consumption with respect to the beginning of the time series (1990).

In the last decade, the consumption of solid fuels has diminished consistently and probably this is related to the sharp increase in the share of renewable sources, passed from the 4,3% in the energy mix in 1990 to a quote of 12,5% in 2014. Natural gas had a strong increase at the beginning of the decade but around 2010 the share started to decline, maybe due to the geopolitical problems of supply with Russia.

1.4.3 Energy import in Europe

The reduction in production of almost all kind of energy sources, has the direct consequence to increase the dependency from energy imports. Net energy import is computed as the difference between import and export, considering all the energy entering a country excluding the amount that only pass through that nation, for example via pipelines. In 2014, the amount of import was 881 Mtoe higher than inland production and the main importers were the biggest regions within the continent, except for Poland. Since 2013, there has not been energy exporters in Europe, because also Denmark became an energy importer.

Russia has maintained its prominent role as exporter to Europe, both for oil, natural gas and, recently, for solid fuels. In 2014 its quotes were 29% for oil, 37,5% for natural gas and 29% for solid fuels. The second exporter of oil and natural gas to Europe is Norway, with an export of crude oil that has slipped from 18,7% in 2004 to 13,1% of European imports in 2014 with a little recovery from 2013; for what concerns natural gas, there is stable increasing trend, +30% in the last decade (Eurostat 2016).

The alarming issue is the low level of differentiation among the suppliers of resources. In fact, 69,1% of imports of natural gas in EU-28 derive from Russia and Norway, percentage that has increased since 2010 in which the level was 59,6%. The same situation occurs in oil import (43,5% from Russia and Norway) and in particular for solid fuels (70,7% from Russia, Colombia, US). Something has changed since 2004, since new partners enter in European energy market, both for oil (Nigeria, Kazakhstan, Iraq and Azerbaijan) and natural gas (Qatar and Libya).

Imports are strongly related to energetic dependency, something that could become an issue especially when international relations are unstable. The dependency in EU-28 has increased from less than 40% of gross consumption in the eighties to 53,5% in 2014; the dependence is particularly critical for crude oil and natural gas, 88,2% and 67,4% respectively. Natural gas is the resource that has recorded the highest increasing rate in the decade (+13,8%) followed by crude oil (+7,5%) and solid fuels (+7,4%) (Eurostat 2016).

Having in mind that, it is necessary to consider the context related to energy security for Europe and the consequent policy measures applied by European policy-maker.

As seen before, the bulk of energy supplies derive from Russia, a country that had many controversies with neighbouring countries through which pass oil and gas pipelines and the gas crisis, between Russia and Ukraine in 2009, became the starting point for a revision of the energy policy in Europe, with more focus on energy security (Verda 2015).

In 2005, Moscow accused the national Ukraine's gas company, Naftogaz, of illegally took gas headed towards European countries and asked for the repayment of the previous debt collect by the company. At the peak of the crisis, in January 2006, Russia stopped gas supplies towards Ukraine for three days and in the end, it reached a new deal regarding Ukraine's provisions, obviously more favourable to Russia. In 2008, there were new issues concerning Ukraine's debts towards Russia. In that year, Russia decided to use the suspension of provisions, even more stronger than 2006, as a contractual tool. At the beginning of 2009, the heaviest gas suspension ever halted almost the whole industrial sector in Ukraine and eighteen European nations experienced a complete or partial halt of their supplies. There were two important consequences of this happening: the first is the intent of European policy-makers to catalyse the diversification of energy routes, too much depended on Russia. The second is the South Stream project, through which Russia will be able to bypass Ukraine passing through the Black See up to Bulgaria (Tatò 2014, p.886).

1.4.4 Energy policy in Europe

Herein there is a brief analysis of the most important directives, communications and general principles on which the energy policy in Europe is based. As seen before, geopolitical events are powerful sources of uncertainty and risks that can undermine the stability and the correct functioning of an economy. After Russian crisis in 2009, European Council enacts the directive 2009/119/EC which defines the obligation to maintain a minimum level of provisions of crude oil and petroleum products for the member States, in order to respond as well as possible to energy crisis. In May 2014, there has been the European Energy Security Strategy (COM(2014)/330 final) which "aims to ensure a stable and abundant supply of energy for European citizens and the economy". In 2010, the European Commission issued "*A strategy for competitive, sustainable and secure energy*" (COM(2010) 639 final), outlining a strategy for a ten years period in which the goals are security in the provision of energy at competitive prices, consolidation on technological leadership and effective negotiation procedures with international partners. Long-term strategies are depicted in the "*2030 Energy Strategy*" (COM(2014) 015 final), an energy framework for the period 2020-2030 aimed at reducing greenhouse gas emission, increase the consumption of renewables and energy savings.

These goals can be meet following the related policies for 2030, that is reformation of emission trading schemes, new indicators for competitiveness of energy system and better interconnections between EU countries. The energy targets for 2050 involved mainly the reduction of greenhouse emissions of 80-90% (Gouardères, 2016). In 2014, following the "*Energy security strategy*" (COM(2014) 330), all the European member States underwent "Energy security stress tests", simulating the arise of two different adverse scenarios for a period of one or six months, these events are: a complete halt of Russian gas imports to EU and a disruption of Russian gas imports through the Ukrainian transit route. The results were particularly alarming for Eastern EU and Energy Community countries[1], moreover the results suggest that, if there had been a cooperation among all the involved countries, the final consumers would have remained supplied for all the months of the simulated gas disruption. This simulation belongs to the so called "short-term measures" related to energy security, while there also exists long-term actions related to five key areas:

- Increasing energy efficiency reaching the 2030 energy and climate goals.
- Increasing energy production in the EU and diversifying energy suppliers and routes.
- Reaching the completion of the internal energy market and finishing the infrastructure needed to quickly move the supplies from a country to another if there would be the necessity.
- Acting as a unique community in energy deals with external countries and each member state must inform the European Commission on energy agreements with non-EU countries that could affect the EU's security of supply.
- Improving emergency and solidarity mechanism and protecting critical infrastructures. Therefore, it is crucial to increase the coordination among members, using existing storage facilities, develop reverse flow, do risk assessment and create an emergency plans at regional and EU level.

European Parliament has notified e general principles and targets related to energy security (Stoerring 2017). European energy security is subject to several risks such as the increasing dependency on imports, little diversification, elevated and volatile prices, risks related to security in production and transit countries, renewables energy, still too little interconnections among energy markets.

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[1] Energy Community is an international organisation, created in 2005, composed by European Union and countries from the South-East Europe and Black Sea region. The scope is to enlarge the European internal energy market with other nations without "legally binding framework". For more information www.energy-community.org

The ultimate purpose of the European policy is to create an integrated energy market, to increase the security in the provisioning of energy and the sustainability of the energy sector in general.

1.5 General natural gas situation

In this section, there will be a description of recent data about gas around the world and after that a closer examination of core countries related to natural gas.

Recent data concerning natural gas (IEA 2016) show a record of natural gas production in 2015 which amounted to 3590 Bcm that means an increase of 1,6% with respect to 2014. Data regarding production are dividend, depending on their origin, in three zones: OECD, gas exporting countries (GECF[2]) and rest of the world.

OECD production rose from 1270 Bcm to 1304 Bcm year-on-year in 2015, driven mainly by United States which recorded a +5,5% in production notwithstanding the negative result in Europe (-2,5%). In the Pacific Basin, Australia is the leading producer with an increase of 5,5%. GECF are driven by the production of Islamic Republic of Iran (+5,3%), with an increment of 9,3 Bcm per year, and the total GECF production amount to 1325 Bcm.

The rest of the world has seen an interesting increase in its global gas share, passed from 19.8% in 1990 to the current 26.8% and in the 2015 it has overpassed for the first time 960 Bcm.

In Europe, it is noteworthy to say that Norwegian gas production has increased thanks to new fields start-ups, unlike Netherlands where the Government decided to cap Groningen gas field because of the risk of earthquake, so that the decline in gas production is sizeable (-23,8% in 2015). Remaining in Europe, United Kingdom production rose by 7% thanks to the discover of two new gas fields, Jasmine and Kew.

Outside OECD countries, Iran is become the world’s third gas producer, with an increase of +5,3%, and sizeable as well is the production of Turkmenistan, +20% since 2012 exceeding 83 Bcm.

In Africa, the production has reduced by 2,3% especially because Egypt production fell by 8,9% due to low speed in development of new fields.

Pipelines gas prices declined steeply especially in US (-45,6% in 2015) while in Europe the declined amounted to -27,2%, continuing the reduction of the gap among the two. In 2015 the

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[2] Composed by: Algeria, Bolivia, Egypt, Equatorial Guinea, Iran, Libya, Nigeria, Qatar, Russia, Trinidad and Tobago, United Arab Emirates and Venezuela.

price for United States market was about 2.78 US dollar/MBtu, and the European price was roughly 6.95 US dollar/MBtu.

Imports by pipelines in OECD Europe increase in 2015 by 21 Bcm, therefore this region continue to maintain its primary position across the world. Inside Europe, the highest increases are recorded in Netherlands (+27,1% thanks to the plummeting national production) and Germany (+14,6% because of increasing demand).
On the other side of the Atlantic, Mexican production fell and it obliged to import from United States, increasing import volume by 7 Bcm (+48,6%) (OPEC 2016).
Another ample drop is recorded in Non-OECD Europe: Ukraine's recession implied a reduction in consumption of 4.2 Bcm.

In terms of gross production, the biggest producers in 2015 are the United States with an amount of 768 834 cu m, followed by Russia (637 386 cm) and IR Iran (257623 cm) (OPEC, 2016).
In the United States, the gas export amounted to 49880 cm that corresponds to an increase of almost 17% with respect to 2011, but the share of exported gas over the gross production is low.
The greatest gas exporter is Russia with 196016 cm, in a strong decline since 2011, but it holds its first position, followed by export-oriented gas producer such as Norway which has exported 114221 cm in 2015 and Qatar (129877 cm). Russia is one of the biggest exporter and producer of natural gas and moreover is closely tied to Europe in terms of quantity exported.

As seen in the previous section, Russia is the world's first exporter of natural gas and its exportations are mainly headed towards Europe (BP 2016). The largest importers inside Europe in 2015 are Germany (45 Bcm), Turkey (26,6 Bcm) and Italy (24 Bcm), and only 33 Bcm were exported in 2015 towards CIS countries. Therefore, Europe is the most important market for Russia but the events of 2014 could have important consequences; the annexation of Crimea and the sanctions from the EU have implied a diversification of the Russia's strategy. Asiatic market is expected to be the most important market for the future of Russia's export. The bulk of its reserves are concentrated in Siberia and they cover more than 40% of total national reserves but these reserves have been already exploited so the production is expected to decline, even if the researches of new on-shore and off-shore fields are already started with discoveries in Barents Sea, Yamal peninsula and Sakhalin Island (Verda 2015). As said before, the exportation of Russia's oil and gas follow two main routes, that is occidental (Europe, Turkey and ex-soviet countries) and oriental (China, Japan, South Korea) but the former is prevailing at the moment.

Gas export towards Europe are carried through pipelines that pass across foreign nations, except for the Nord Stream which arrives directly in Europe. The Asiatic route are supplied only with LNG.

The Nord Stream started in 2011 and from that moment on the amount of gas that transit through Ukraine has diminished and in 2013 only the 13% of the whole European needs passed through that pipelines.

The other great project is the South Stream, which could have great importance in terms of diversification of the routes for Russia; the project is expected to be ready in 2020 and it will pass across the Black Sea, Bulgaria, Serbia, Hungary, Slovenia, Austria and Italy.

These new and recent projects should highlight the importance that Russia gives to European market but, in the meanwhile, the geopolitical situation has changed therefore it is difficult to foresee the evolution of future behaviour of European Commission in terms of energy policy and security and so the role that Russia could have in the future (Pirani 2014).

The central position of Europe as a market for Russia’s exports will remain stable in next years. Notwithstanding policy guidelines that push towards the Asiatic market, there are some problems that hamper the development in the short-medium period: the elevated costs needed to extract and commercialize gas from the Artic and Siberia fields and the future of LNG exports towards Asia of United States and Australia (Verda 2015).

Another region which is gaining a consistent share in the production of oil and gas is the Caspian – Sea region, namely Azerbaijan, Kazakhstan, Turkmenistan. After 1991, the region has been isolated from the market both in geographical and in infrastructural sense; the first stems from the lack of access to the sea, the second from the fact that the bulk of infrastructure for gas transportation were directed towards Russia, an infrastructural framework inherited from the Soviet Union. Therefore, the attempt to diversify the export routes of the new independent regions has the twofold effect of gaining economic benefits and underlining the independence from Russia. The problems to face in order to activate the export process were related to the absence of infrastructure and the political instability of that zone.

The Caspian region is composed of three main countries which have a not homogeneous distribution of the resources: in fact, oil reserves are concentrated in Kazakhstan and Azerbaijan while the biggest share of gas fields are mainly in Turkmenistan and secondarily in Azerbaijan and Turkmenistan is the fourth country for proven reserves around the world (OPEC 2016).

From 2011 to 2015 the marketed production of natural gas has increased in each of them: in Azerbaijan, the increase was + 26%, in Kazakhstan + 11% and in Turkmenistan +31,5%, suggesting that these countries have the possibilities to become large and active global actors in the gas market. A factor that helped these regions to elevate their production is the shift towards Asiatic countries instead of European ones. China became the largest partner of Turkmenistan with an import of 27,7 Bcm in 2015 (BP 2016) and in this respect, it has overcome Russia as a leading partner of the region. China's strategy to penetrate in that market is based upon the development of project in collaboration with the local Government. In this way, it has reduced the infrastructural problems with investments which have diminished the isolation of that productive countries, solving the issues related to extraction as well as commercialisation, and at the same time it has gained an important influence with these strategic partners (Verda 2015).

Europe as well will probably become an important partner of the Caspian region with the Southern gas corridor (SGC). The corridor is intended to implement the strategy of energy diversification undergone by European Commission, especially with the aim to reduce the dependency on Russia's provisions. The pipelines will link Europe with Azerbaijan passing through Georgia, Turkey, Greece, Albania and then Italy. The whole pipeline is composed by the South Caucasus Pipeline, which crosses Azerbaijan and Georgia, starting in Sangachal Terminal, a natural gas processing plant. Then it is linked with the Trans Anatolian Pipeline in Turkey and finally with the Trans Adriatic Pipeline which passes across Greece, Albania and then Italy. From that point it is possible to send the gas in other pipelines that transport natural gas all around Europe (TAP 2016).

After all, the distances between the Caspian region and the final market are huge, therefore a considerable amount of investments in infrastructures are needed. Conditions to attract these investments are a sustained level of prices of hydrocarbons and the creation of a favourable and stable environment for foreign investments, in fact foreign capital and technology are crucial for the correct and economically sustainable exploitation of the ample reserves of the region.

1.6 Liquefied natural gas (LNG)

For many years, the structure of natural gas market has remained confined into a regional level. This static situation emanated from the inherent technological constraints imposed to the delivery procedure. Unlike oil market, which is not confined thanks to the possibility to efficiently ship oil all over the world, natural gas is mainly transported via pipelines. Pipelines, obviously, tie together the producer and the customer on a reciprocal commitment usually on a long-term basis given by the considerable costs involved. The introduction of liquefied natural gas has opened new possibilities and geographical innovation to the industry, establishing new routes for the shipment making the framework more global; notwithstanding this innovation, the market remains fairly confined into three wide areas: North America, Europe and Asia.

LNG has almost the same chemical characteristics as gas transported via pipelines composed of methane in the main part, 80-90%, and other hydrocarbon such as ethane and propane. Through a cooling process (–600 Celsius degrees) at atmospheric pressure, it is possible to reduce its volume by 600 times, put it into special tanks and shipping it using the methane tankers. Clearly, the main advantage of this procedure is the possibility to get rid of the geographical obstacles to which are subject normal pipelines method and contributing to create a more flexible and global market. Countries with an unfavourable geographical position have benefited from this: for example, Japan which is an island far away from productive countries has the possibility to obtain natural gas more easily and, nowadays, is the largest LNG consumer. On the opposite side, Qatar, a country poor of oil and rich of gas is subject to an unfavourable geographical position for the implementation of pipelines and it is currently the biggest producer of LNG. Moreover, also Europe has exploited LNG in order to diversify its suppliers, reducing geopolitical risk connected to pipelines and cross-border deliveries. As for the implementation of classical pipelines, investment costs are elevated with high capital intensity in all the phases of the process. The phases are: research and development of gas fields, pipelines transportation towards the coast, construction of liquefying plant and final take on board into the methane taker. Finally, the opposite process happens when the shipment reaches the destination. Just to give an idea about the costs trade-off between the two alternatives, pipelines and LNG, pipelines are less expensive for distances between 2000 – 3000 km, while LNG is more convenient when the distance is between 5500 – 6000 km; the intermediate distance is a field of competition among the two, considering different factors that could hamper the regular course of the process. In recent years, the growth of *spot* transaction, instead of long-term agreement, and the excess on the supply side of the market have created the possibility of arbitrage between different region of the world, exploiting the difference among price (Verda 2015).

The ensemble of these reasons has entailed a surge in the utilization of this resource which is expected to rise in following years.

As mentioned before, the utilization of natural gas is connected to a lower emission of polluting substances, a subject of crucial importance in Europe and probably, in next years, for emerging economies, especially for that highly tied to coal such as China and India. This scenario in favour of natural gas will have a likely positive effect on the future evolution of LNG.

During the period 1980 – 2010, volumes exchanged have grown more than ten times and the number of countries involved in the exchange have risen, mainly fuelled by Asiatic countries. The number of nations and volume of LNG have surged during the economic crisis period, probably suggesting that importing nations prefer to exploit the elasticity of this kind of supply (Verda 2015).

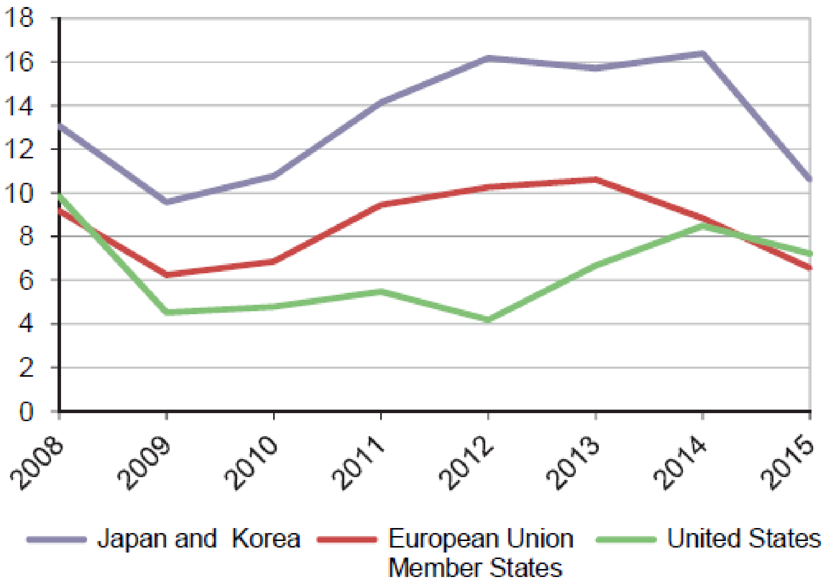
In fact, with the beginning of twenty-first century there were substantial changes in the typology of contracts employed. For decades, the standard contracts in natural gas distribution were long-term contracts, at least twenty years, but nowadays there is an increasing number of *spot* contracts or at least a short-term of about four years. An important consequence of spot and short-term contracts, quoted in the so-called gas *hub*, is that prices need to be adjusted on a more realistic demand and supply dynamic. Yet the volumes exchanged using this possibility remain still lower with respect to the canonical contractual form.

Long-term contracts have the features to share the risks related to natural gas commercialisation between suppliers and consumers, spurring the building up of costly infrastructure. With a long-term contract the importer commit itself to buy and pay a fixed percentage of the contracted volume through the so-called *take or pay clause*, in this way the risk associated to volume is in the hands of the acquirer and the seller has a protection to repay at least partially his investment. On the opposite side, the seller assumes price-risk, because the price of natural gas is pegged to oil and subject to its fluctuations (Verda 2015).

Spot transactions arose for different reasons: more dynamic and global market with an excess of supply and volumes of gas not tied in long-term contracts; technological improvements that reduce the costs of the entire production and selling process; evolution of the structure of natural gas market with a transition from monopolistic to a more competitive environment. Related to the latter characteristic, spot transactions allow to reduce the long-term power and constraints that the supplier exert on the buyer. Moreover, it is easier for new competitors to enter in the market, making it more flexible with the possibility to adapt supply and demand in shorter time (Verda 2015).

After the *shale gas revolution* in North America and the decline in natural gas demand in Europe, the equilibrium in gas market changed and the global demand was mainly sustained by the Asiatic one. This significant shift towards Asia has entailed a regional price behaviour instead of a global one with higher prices for Asiatic countries. This behaviour is reducing in recent years as is possible to see in the picture below.

Figure 3: LNG import prices (US dollars/million British thermal units)



Source: Key Natural Gas Trends (EIA 2016)

For what concern LNG, Asia is the principal consumer of this resource. The historical importers are: Japan, South Korea and Taiwan and in more recent years China and India, from which it is expected the higher future demand of LNG.

Considering the importance of both LNG and Asiatic countries in shaping the future of energy markets, the following section is devoted to a close analysis of important energy consumers and producers

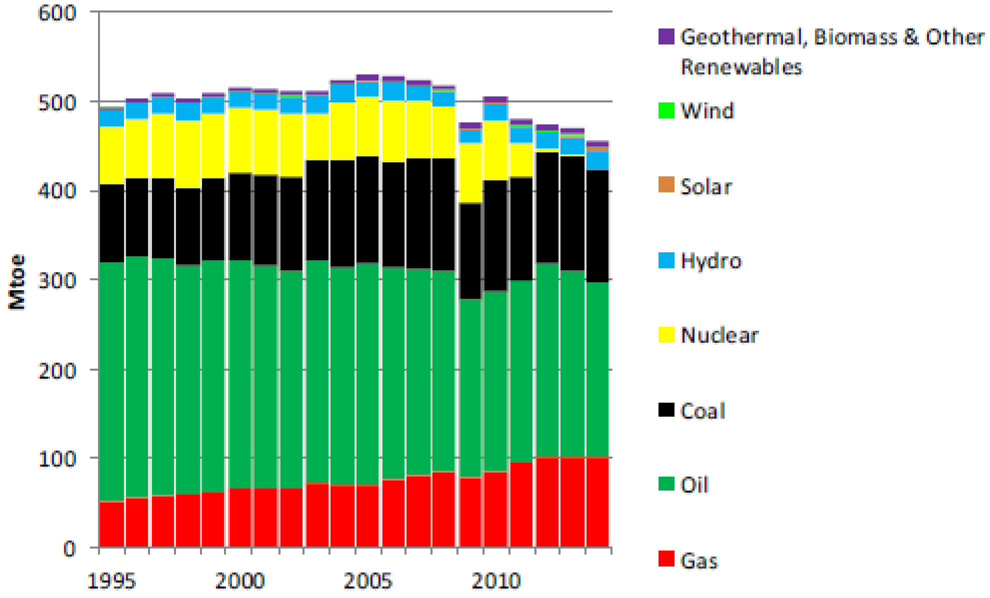
1.6.1 Mature LNG consumers

Hereafter there is a brief overview of the three major LNG consumers of the world considered as "mature", that is, they have already experienced a consolidate and abundant consumption of

LNG. The first is Japan, the largest consumer, followed by South Korea and Taiwan (Rogers 2016).

Japan is facing a peculiar situation, especially concerning economic activity and population aging. Its public debt is the largest of the world, almost 250% of GDP and, since 2012, the government started a public plan of economic stimulus such as monetary easing and structural reforms. Another crucial fact was the disaster of the Fukushima Daiichi Nuclear Power Station in 2011, due to the earthquake and the resulting tsunami, which led policy maker to shut down all the nuclear plant in Japan (Miyamoto 2012). The lack of nuclear power generation obliged Japan to increase the consumption of gas, coal and oil-fired during the subsequent years. As many other countries, Japan had a sudden decrease in energy consumption in 2009, due to the economic crisis, with a little recovery in 2010 but, in 2014, the total amount of energy was well below the 2009 level. The striking fact in the figure below, is the total depletion of nuclear power and this will be the core issue regarding the future of other energy sources.

Figure 4: Japan's Energy Mix 1995-2014



Source: Rogers (2016)

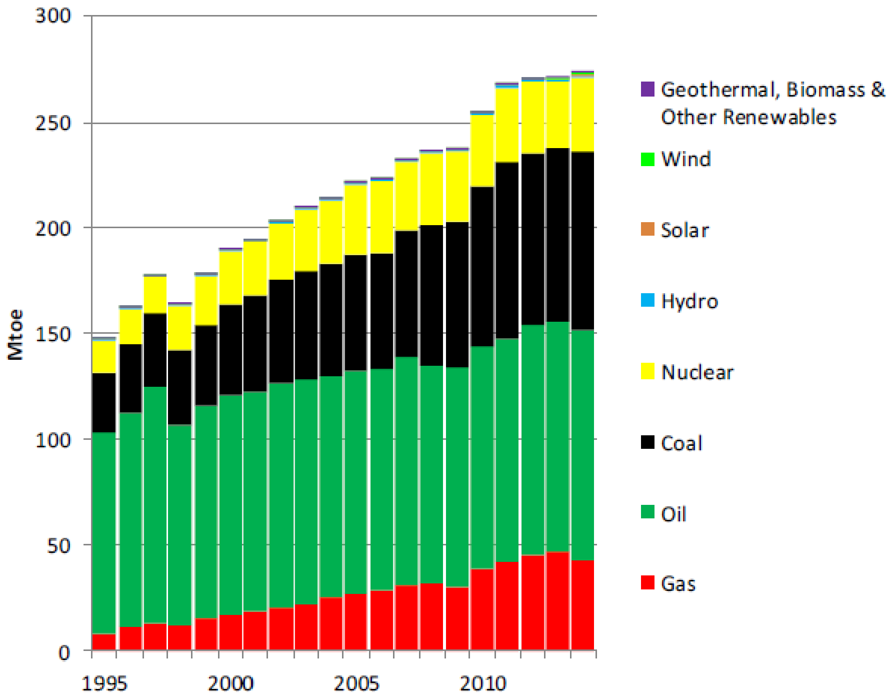
The structure of the demand of gas in Japan has the typical seasonal pattern with the peak during the winter; in order to manage this seasonality storage tanks are deployed and cargo deliveries are exploited during high demand periods. Analysing the sectors of final consumption of gas, it is possible to see that residential usage is remained flat during the decade, unlike the industrial sector which grown at a pace of 10% per year from 2000 to 2007, reducing to 2,6% per year from 2008 to 2013. After the 2007 fiscal year, the total energy consumption in Japan has decrease and even though the gas' share has enlarged, eroding oil's share, coal consumption has grown as well. As reported in (Miyamoto 2012), the key determinants of future expansion and success of gas are tied to infrastructure, that is easy access to the resource and price competitiveness relative to other energy sources; the authors state that industrial and commercial sector will continue to expand their consumption of natural gas until 2020, but residential sector will decline in the near future.

In July 2011, after Fukushima, was established the Energy & Environment Council (Enecan), to sketch future Japan's energy strategy. One of the most important decisions undertaken has been the aim to phase-out nuclear power by 2040. A "green energy policy framework" was stated focusing on LNG, coal and renewables. The decision to phase-out nuclear power was criticized by the industry, which declare that at least a 20-25% share of nuclear energy is necessary to sustain the economy, at least from an economic point of view. The subsequent government abolished Enecam. In June 2015, a new plan for electricity generation to 2030 was approved and in this case the share of nuclear energy accounted for 20-22%, followed by renewables, 22-24%, LNG, 27% and coal, 26% (Rogers 2016).

To conclude this brief overview on Japan, LNG and its flexibility helped Japan to quickly respond to the drop of power generation after Fukushima, in fact more than 50% of the additional power generation was supplied through this source. In 2014, Japan was the largest importer of LNG and it accounted for 22% of its energy mix. However, its future development is closely tied to nuclear energy restart which, at the moment, is absolutely uncertain.

South Korea is an export oriented country who experienced an incredible economic growth. In the 1960s it was a poor country comparable with the poorest countries of Africa and Asia, but in subsequent years became more and more global becoming the twelfth largest economy of the world. In the figure below there is its primary energy consumption across the years. In 2014 natural gas accounted for 15,7% share of the energy mix, consistently lower than the 2013's level. The most important energy sources are oil (39,5%) and coal (31%) with a lower share of nuclear energy (13%). Total energy consumption has become almost flat from 2010 on, after having experienced a constant growth since 1995. The key elements to take into account for future energy consumption and therefore gas consumption are: the general slowdown in energy consumption since 2010, perhaps due to the reduction in consumption of South Korea's manufactured export market; the slowdown in domestic non-power sector is tied to population growth which is expected to be negative or flat in the future; the conflicting messages sent by the Government concerning the future of gas share in power generation, especially in substitution of coal and oil, do not give precise information on the interest in reducing greenhouse gas and on the attitude towards nuclear power.

Figure 5: South Korea Primary Energy Mix 1995-2014



Source: Rogers (2016)

These two countries plus Taiwan have accounted for around 60% of global LNG demand since 1980 (Rogers 2016). Each country has peculiar characteristics related to gas consumption and import, but there are some common issues that will likely impact future demand of LNG. The most important among them are:

- Future development of nuclear power, especially after Fukushima. In Japan, future LNG demand is highly tied to the pace and the extent at which the nuclear restarting program will be implemented. South Korea has restarted nuclear plant after a temporary shut down and Taiwan has declared a phase-out of nuclear plant by 2015.
- The principal competitor of gas in these regions is coal, especially in price term. Nowadays, the plans to meet the COP21 obligations in term of greenhouse emissions are based on the assumptions of a great increase in energy efficiency and a rapid development and deployment of renewable sources.
- Other issues arise from economic and social factors such as low birth rate, aging population and general population decline; given these problems the countries need to rely on export oriented strategy instead of domestic consumption to spur economic growth .
- Economic growth is perhaps the key factor in energy consumption and demand. For all the three countries, the expectations are not brilliant. Japan has suffered low growth since the nineties. South Korea has seen a strong reduction after the economic crisis due

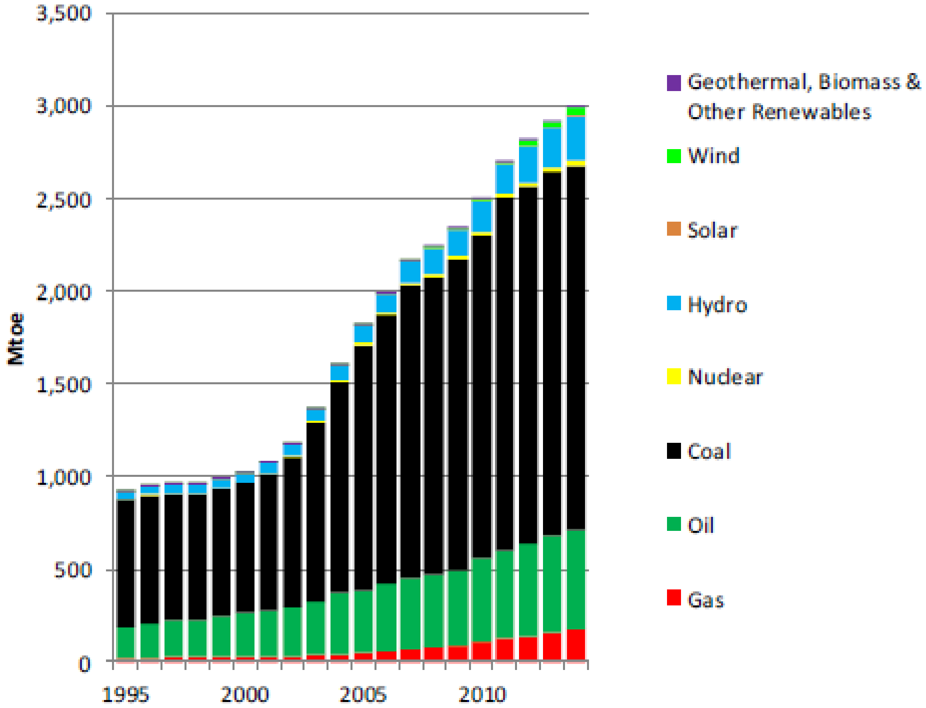
to the slowdown in economic growth in USA, Asia and Eurozone, which are its main market.

- In general, the forecasts of LNG demand for the involved countries are less optimistic than the expectation based on secular trend.

1.6.2 Emerging LNG markets

The Chinese's economic miracle is well known, with an average economic growth of 9,6% in terms of GDP between 1995-2014, it is the second largest economy in the world. As it is possible to see in the figure below, the extent of energy consumption has closely followed the pattern of economic growth, with an extraordinary explosion in the consumption of several primary resources but, above all, coal. The share occupied by gas is widely lower than the share of coal, in 2014 gas amounted to 5,6%, coal to 65,7% and oil 17,9%. The interesting thing related to gas consumption it is not its current share but the fact that, since 2010, its consumption growth has increased at a pace of, on average, 13,2% per year and the total energy consumption has grown at 4,7% per year. In 2014 there were a general slowdown in energy utilization, it increased only by 2,5% over 2013, and the rise in gas utilization was 8,4%. The largest share of gas consumption in China is occupied by manufacturing and the major increase occurred in power generation (+42,5%). Even though, the increase has been intense in many sectors, especially Chemicals, Fuel Processing, Metal Product and Machinery, gas remains widely behind coal and oil in terms of consumption. As well in power generation, the main exploited resource is coal (76%) and hydro (18%).

Figure 6: Primary Energy Mix of China 1995 to 2004



Source: Rogers (2016)

Starting from 2006, domestic gas production has started to be lower than domestic consumption and this imbalance was initially filled by LNG imports. In 2010, it has started the importation through pipelines, initially from Turkmenistan and Central Asia and, since 2014, from Myanmar.

China's gas production plans are directed towards synthetic gas production, that is producing gas from coal, which could be able to reduce the particulate pollution stemming from coal combustion needed in power generation, but the emissions of carbon dioxide are elevated as well as the consumption of water. Anyway, it is likely that the planned volume of production will be scaled down. For what concern the LNG suppliers, the largest, from 2012, has been Qatar but initially the bulk of provision were sent from Malaysia, Indonesia and Australia.

As for many other Asiatic countries, future energy policies are focused on the exit from coal and other polluting resources. The expected share of gas in the future energy mix is 10% and wind and solar capacity are the other two resources that are expected to grow the most. The researchers state that China has accumulated an oversupply 18 billion cubic meter per year (Bcm/y) in contracts signed for the period 2015 – 2017 due to a lower than expected demand growth (Rogers 2016).

Regarding China’s gas supply, the picture is even more complicated because of weak gas demand in 2015 and the fact that many upstream companies are changing their target in terms of production, reducing conventional gas output and increasing shale gas production. Domestic gas supply is composed by conventional gas, shale gas and synthetic gas; based on the opinion of the author, the rest of the analysis of China will be based on a conservative future growth assumption, extracted from the IEA outlook for the production between 2015 and 2020, supported by the “lack of positive news on the progress of unconventional gas development in China” (Rogers 2016).

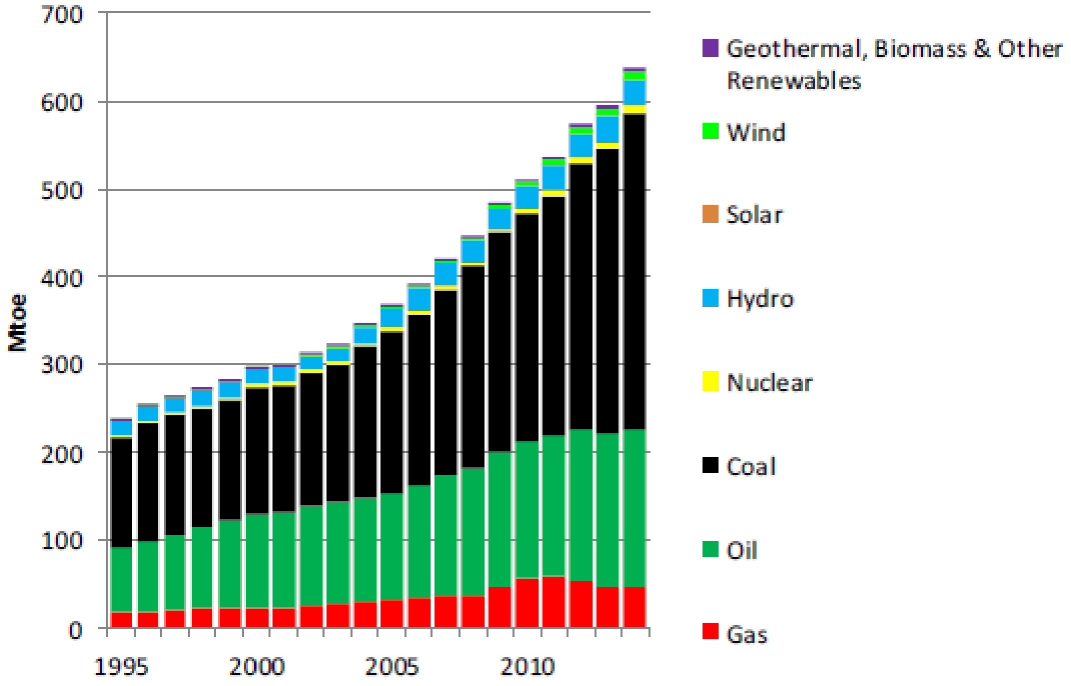
The largest Chines oil and gas company, China National Petroleum Corporation (CNPC), has invested either in upstream field and pipelines; the major countries connected by pipelines are Turkmenistan, Kazakhstan and Uzbekistan entering in the country across the North-West border and then send to the demand centres. The amount of imports via pipelines in 2014 was 28,3 Bcm but there is the possibility to increase the import capacity to 65 Bcm/y. Important actors in the augmentation of supply are Myanmar, which sold 3 Bcm in 2014 with the possibility to raise this amount to 10 or 12 Bcm/y in the future.

Other extremely important pending deals are with Russia: the “Power of Siberia” project and the “Altai Pipelines”. The first will send 38 Bcm/y from East Siberia fields and the other 30 bmc/y from West Siberian; these projects are expected to be on stream around 2020. The expectation on volumes, stemming from different sources, are reported in appendix 3 subject to different scenario. In both, LNG imports are assumed as the source that make up the difference between the consumption and the import via pipelines.
In the last annual statistical bulletin (GIIGNL 2017) is reported that the LNG import in 2016 has impressively increased (+39,9%) after a moderate performance in 2015.

To conclude, an important fact to consider is the current low-growth phase in which China is entered in 2014 and the consequent lower energy demand. Moreover, the high reliance on coal has made complicated the switch from coal to other sources; as reported in (Rogers 2016), the timescale of investment programmes to change energy source is often underestimated, but the increase in nuclear, hydro, wind and solar is a good news in this respect. The future role of gas depends on the capability of China to maximise the domestic production, and acceptable contracted prices that do not hamper market-related prices in the future.

India is the other big actor in the energy market. The evolution in consumption is a stable and regular increasing trend mainly supported by two resources, coal and oil. Just to give a couple of information about India's economy, it is worth to say that its population is 1,2 billion and since 2001 its GDP was higher than the world average. The main sectors in the economy are agriculture (18%), industry (31%) and services (51%) but strong obstacles in its development are corruption, infrastructure and fiscal deficits (Rogers 2016).

Figure 7: Primary Energy Mix of India 1994 - 2014



Source: Rogers (2016)

As said before, the bulk of the energy mix is occupied by coal (56,5%) and oil (28,3%) with a modest percentage of gas (7,1%) that has declined after 2011 following a general decline in the wake of a reduction in domestic production. Between 2010 and 2014, the average annual growth in coal consumption (8,5%) was higher than the average increase in energy consumption in the same years (5,8%), a compelling argument to stress the point that the exit from coal and polluting substances it is not near.

As it is possible to see in the figure above, the gas share has even more contracted after 2011. As reported by the author (Rogers 2016), the overall demand of energy has dropped after 2011 because of the fall in domestic production with different consequences in sectors which utilize natural gas. In the decade 2004 – 2014 the level of industrial consumption and fertilizers have remained quite stable whereas power generation has contracted, in 2012 and subsequent years, after having experienced a boom between 2009 and 2011. As for China, LNG imports have ramped up in 2016 (GIIGNL 2017) reaching 19 MT and so India is the fourth LNG buyer worldwide.

Gas utilization in India is managed by the "Gas Utilization Policy" which divides the market in two sectors: Tier 1, "Priority Sector", that is City Gas for households and transportation, fertilizers, LPG extraction plants, and Tier 2 which includes industrial users, commercial users and merchant power plant, they are labelled as "lower priority users".
Domestic gas producers receive a state-regulated price depending on the starting licencing terms. In April 2015, there was a price reforms which would have doubled the prices, instead on average the prices rose from 4,20$/MMBtu to 4,66$/MMBtu, perhaps driven by general low prices in other markets and hub, such as US Henry Hub, Canadian hub prices and Russian domestic price.

Gas demand is not supported by power generation which relies heavily on coal; just 10% of the total installed capacity derives by gas-fired generation, and moreover it suffers because of geographical constraints and the capacity of distribution grids.
Positive gas demand is expected in city gas consumption which has a growth potential either in domestic, commercial and transportation, always subject to poor infrastructure and supply availability.

For what concerns domestic production, onshore has remained almost stable between 2004 and 2014, whereas offshore production peaked in 2011, after a sharp boom started in 2009, but it has begun to decline immediately after perhaps due to bad wells performance and water influx into the reservoirs (Oil&GasJournal 2013).

The forecasts for domestic production are not optimistic. There could be a significant amount of resources but the exploration phase and the subsequent developments are expensive and they could be profitable only if the price would remain above 8$/MMBtu (Sen 2015).
According to IEA World Energy Outlook 2015 (IEA 2015), any further increase in gas demand will be meet by LNG imports, because of the difficulty in maintaining regulated price at a level that can incentivize new explorations. The greatest share of LNG's import emanates from Qatar, about 80%, followed by Egypt and Nigeria.

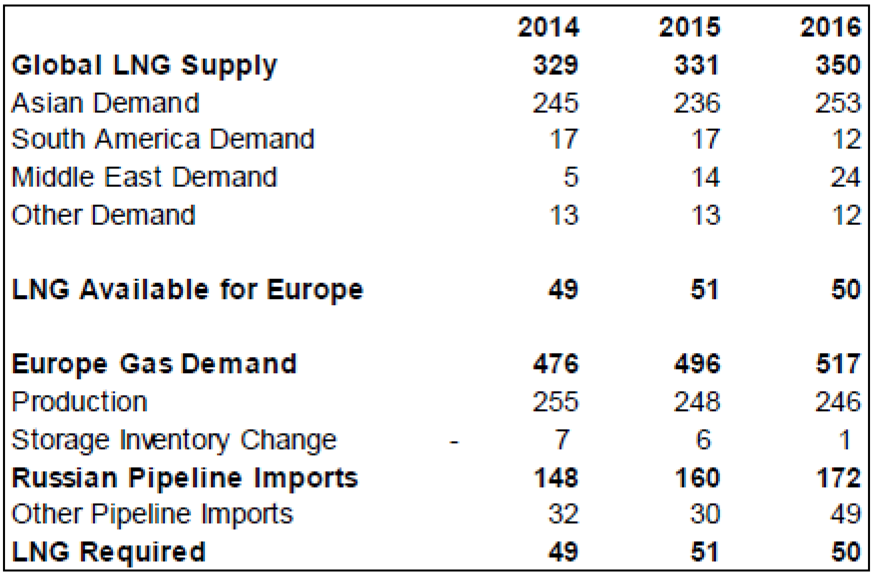
The outlook for gas demand is difficult to state especially in quantitative terms. It seems almost sure that coal will remain the main source in power generation, corroborate by the fact that does not exist a specific policy or target for gas. Many factors are likely to hamper future development of natural gas in India; on the supply side the main problem is the pricing process managed by the state for internal production, therefore not liberalised at all and not linked to whatever international index.

There are no likely plans for pipelines, too much expensive and binding for a country with a lot of uncertainties regarding the demand level, infrastructure and prices (Rogers 2016).

1.6.3 Europe and productive countries

Europe, historically, is the second gas regional market after the Asiatic one, but in recent years the trend is negative (Rogers 2017). This trend was against the most part of the forecasts of the decade before, which foreseen a strong growth in the consumption of LNG, instead its share has halved. Probably, the consumption of natural gas and consequently LNG has reduced because of the general crisis and the public sustain to renewable energy resources. The LNG was the first that has been cut, since is more expensive than the natural gas transported via pipelines, moreover the LNG exporters were more interested in Asiatic partners because of higher prices, especially in the past, at which it was possible to sell the cargoes using spot prices (Verda 2015). Despite the expectations, the exports from Gulf of Mexico (Sabine Pass Train 1 and 2) are headed towards Latin America (58%), Asia (19%) and Middle East (14%) and only a residual part goes to Europe (9%) (GIIGNL 2017).

Table 1: Global LNG and European Balance 2014 – 2016 (Bcm)



	2014	**2015**	**2016**
Global LNG Supply	**329**	**331**	**350**
Asian Demand	245	236	253
South America Demand	17	17	12
Middle East Demand	5	14	24
Other Demand	13	13	12
LNG Available for Europe	**49**	**51**	**50**
Europe Gas Demand	**476**	**496**	**517**
Production	255	248	246
Storage Inventory Change	- 7	6	1
Russian Pipeline Imports	**148**	**160**	**172**
Other Pipeline Imports	32	30	49
LNG Required	**49**	**51**	**50**

Source: Rogers (2017)

As it is possible to see in the table above, there has been an increase of 6% in global LNG supply (+19 Bcm) and the main part of the growth has been consumed in Asia (+17 Bcm) and Middle East (+10 Bcm). Moreover, the cold winter in Europe and the switch in power generation from coal to gas has speeded up the demand of natural gas in Europe, mainly supported by pipelines from Russia and Algeria. Therefore, the conclusion from the data is that the foreseen rise in LNG production has happened but Europe is just a residual consumer after Asia and Middle East, in fact its gas demand has risen but the consumption of LNG has decreased. Europe LNG market can be considered as a “market of last resort”, tied to the ample influence and power exerted by Russia. Therefore, the development of LNG market will depend upon the behaviour of the “primary market”, that is Asiatic and Middle East (Rogers 2017). In a low Asian LNG demand scenario, the competition between Russian pipelines and LNG in Europe could become more tight, in a period from 2018 to 2021, because of the overflow from the Eastern market towards the European one.

Otherwise, in the Asiatic high demand scenario, the possibility of oversupply will be curtailed and, obviously, this will play in favour of Russian pipelines exports that could be maintained above 150 Bcm/year until 2019-2020. As seen in the previous section, the Asiatic low or high demand scenario will depend upon different drivers such as policy support to the switch from coal to gas, especially in China and India, and slow pace in nuclear restart in Japan.

Unlike the demand, the supply side is more concentred around three areas: the Atlantic basin, which covers the 22% of the demand, the Pacific basin, 37%, and the Middle East which is the biggest with a share of 41% of the global demand exploiting the favourable geographical position with respect the three areas of consumption. The production is concentrated around three nations that supply more than a half of the global demand: Qatar, Malesia and Australia.

Qatar, unlike the other Gulf States, has plenty of natural gas and limited amount of oil, and in 2013 it was the second exporter of natural gas after Russia, notwithstanding the moderate amount of gas exported via pipelines. It started the exportation of LNG in 1997 and it became the greater LNG exporter in 2006 (Verda 2015). In 2016 it has seen a contraction in its exports and its share fell from 30% in 2015 to 27% in 2016 (GIIGNL 2017).

The forecasts suggest that in the future the relative weight of Qatar in the global competition will be reduced for the political decision to contain the expansion of new gasification plants in order to preserve the methane fields of the country (Oil&Money 2014).

The bulk of the future increment in supply is expected to be in Australia, which has been the third exported of LNG in 2013 and it is possible that it will overcome Qatar in next years. The key factors in future Australian's global success are the huge amount of gas resources, the little dimension of internal market, a stable political environment and the geographical proximity to Asiatic market (Verda 2015).

1.6.4 Recent reports about LNG market

LNG trade has experienced a robust growth in 2016 (+7,5%) comparable to the level occurred before 2011. Australia has played a central role, as expected, in fostering the supply although not higher than foresee. The import side see the interest of Asiatic region in 2016, China and India, growing more than 2015 which confirms the willingness of these countries for competitive LNG prices. Moreover, an excessive supply and low prices of oil has implied a slowdown in investments (GIIGNL 2017).

The trade framework remains regional, but the expansion of Panama Canal could create a great opportunity for American exports, which are currently confined in the Atlantic Basin, to reach the Pacific Basin,. Regionality of trades stems from the large amount of LNG regulated by long-term contracts with fixed destination and the low-price differential among different basins. The biggest share of exchanges is in the Pacific Basins, driven by China and India in the demand side, and from Australia on the supply side.

There is also the possibility of an oversupply LNG market in next years, mainly due to the completion of Australian projects, but low prices could rebalance the supply/demand dynamic. As said before, the recent agreements in Paris and the looming need to reduce polluting emissions, are favourable elements for natural gas and the flexibility of LNG could be pivotal to this end (GIIGNL 2017).

1.7 Algeria

This section of the thesis is focalised on Algeria. There will be an analysis that will depict the geopolitical framework of the country and the energy policies transformation underway. As stated in some precedent paragraphs, this country has an important role in European energy market, hence a clear analysis should be undertaken.

Algeria is a North African country that belongs to the so-called MENA region, the area that include Middle East and North African countries.

The MENA region has a dominant role in terms of hydrocarbons reserves but the forecasts related to future natural gas demand within the region see an increasing need of gas for domestic use and there exists the possibility that, despite the sizeable reserves available, future inland demand could be higher than the disposable supply. This future energy need stems from the huge rise in gas demand that is expected in the region, rising from 480 Bcm in 2015 to 738 Bcm in 2040, together with a domestic production unable to adapt to the secular increasing trend in demand and the lack of pipelines devoted to import. Therefore, LNG is an interesting option to offset this rise in demand, although it is also likely that many countries will adopt a more cautious behaviour before embark themselves in highly capital-intensive investments in LNG-import terminals.

In 2015, consumer countries in the region have imported just 10,5 Bcm of LNG, roughly 40% of which from Qatar, but the possible future overhang of LNG and the consequent flexion in prices could increase the expediency to exploit this resource (APICORP 2016).

Gas demand in the MENA region has increased more quickly than oil in the last thirty years due to different reasons. For example, power generation sector in the MENA region relies heavily on natural gas which, in turn depends upon population magnitude and, given the fact that population has abundantly increased, the need of natural gas has surged as well. Moreover, MENA governments have pushed towards gas-intensive industrialization with the aim to exploit low prices and, especially for oil-producing countries, diversify their energy mix (APICORP 2016).

1.7.1 Energy issues in Algeria

In the International Monetary Fund Country Report (IMF 2016) it is stated that from 2002 until 2014, hydrocarbons exports have had the most important impact on the country for many reasons: on average, they accounted for 98% of export earnings, 69% of fiscal revenues and 36% of national's gross domestic product (GDP). Since gas contracts are largely indexed to oil price, in 2014 the slump has caused a fall in revenues of 41%, highlighting the critical role of hydrocarbons in national economy and the risks associated to the lack of diversification in national assets.

The high level of state revenues generated by hydrocarbon exports during the period of elevated oil prices could be the reason why Algeria has maintained its generous social welfare and energy subsidies even after that drop. It could be also the case that, during Arab Spring, Algeria remained politically stable because of this welfare state and energy subsidies (Grigorjeva 2016).

Energy subsidies in Algeria are the highest in the MENA region after Iran and Iraq and they amounted to roughly 11% of total country's GDP (IMF 2014).

Algeria exports natural gas both via pipelines and LNG, especially towards Europe. In 2015, pipeline's exports are mainly headed to Europe, especially Italy (6,6 Bcm) and Spain (12 Bcm) with a lower share to other European countries (2 Bcm). The share of LNG exported is also relevant in fact, in 2015, Algeria has exported 13,1 Bcm in Europe, especially in France (4,3 Bcm) and Turkey (3,8 Bcm), and 2,6 Bcm in Asia Pacific region (BP 2016).

Based upon the opinion of Ali Aissaoui, (Aissaoui 2016) many analysts have missed the core issue related to Algerian gas production. They have recognised the downward trend in gas production without deepening the underlying causes of the problem; these causes stem from several factors of different nature, ranging from demographic to economic and political environment. The author talks about the "Egypt syndrome" that is "a condition whereby, after a long period of denial, a government suddenly wakes up to the stark reality that production can no longer keep up with fast-growing domestic demand fuelled by massive and unaffordable subsidies, ultimately leading to stranded export assets" (Aissaoui 2016, p.1).
Another author (Darbouche 2011) warned about the problematic situation for Algerian export deriving from the combined effect of low development in upstream facilities and the surging domestic demand of natural gas; as will be show later, this prediction was accurate.
Besides growing domestic demand and upstream problems, the depletion of natural gas reserves seems to be another serious problem to tackle, especially in a country in which a large part of energy production derives from natural gas.
In addition to reserves depletion and shrinking export volumes, the situation has even worsened because of low hydrocarbon prices in energy market, thereby the state rent deriving from export of natural gas and other hydrocarbons has been affected, endangering welfare spending and economic development (Aissaoui 2016).

1.7.2 Declining trend in production and domestic demand

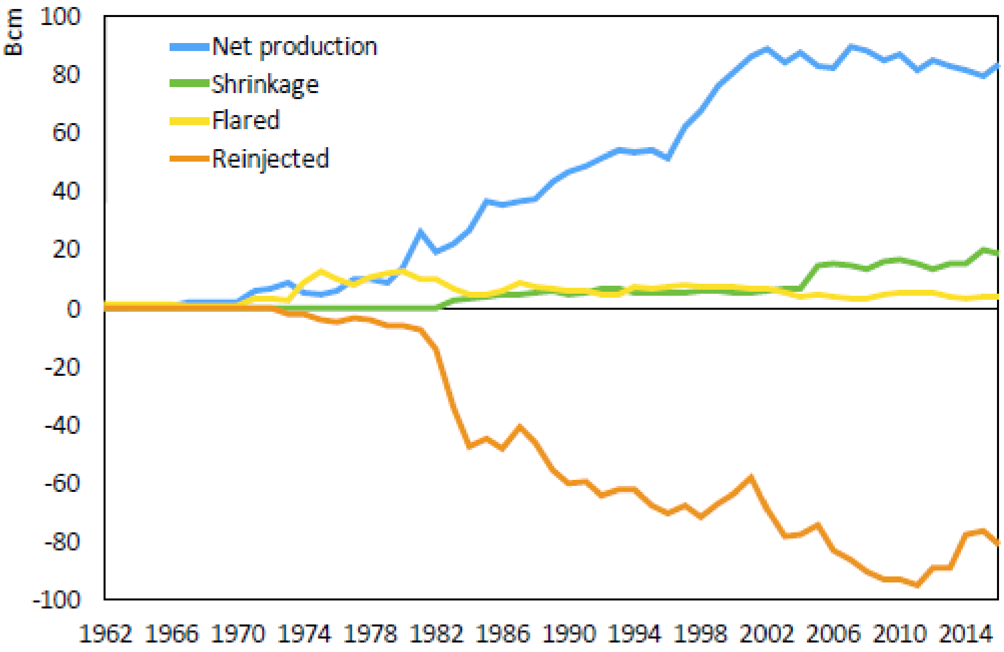
Since 2004, primary energy demand has risen at an average pace of 4,1% per year, together with a decrease in domestic supply that has contracted at an average pace of -0,8% per year, therefore the joint movement of the two has implied a reduction in total hydrocarbon export of – 2,6% per year (Aissaoui 2016). To have a clear idea about the path that gas production is following, the optimal starting-point is the gross production. In 2008, gross production was

201,2 Bcm then it dropped to 179,5 Bcm in 2013 and it recovers a bit in 2014 touching 186,7 Bcm but in 2015 there has been another reduction of -1,6% year-on-year reaching 183,8 Bcm (OPEC 2016).

A more precise insight can be retrieved examining the single elements of gross production. The procedure of extraction and commercialisation is composed by a first stage of extraction, which requires the stripping of natural gas liquids (NGLs) and then the partial reinjection of gas in the reservoir in order to maintain a stable pressure level. The dry gas resulting in excess from the reinjection is supplied to the market, both domestic and foreign.

Looking at the data it is easy to see the at least plateaued trend of net production in the last ten years or so.

Figure 8: Evolution of Natural Gas Production Components



Source: Aissaoui (2016)

It is interesting for the analysis to figure out the relations that occurs between the different measures involved. Net production has steadily increased since the eighties, especially in the second half of the nineties probably due to policy actions aimed to foster gas production in Algeria (Aissaoui 2001). In 2005, net production reached the peak of 89,2 Bcm and then it felt (79.9 Bcm) in 2013 recovery a bit the year later, thanks to the new production of Gassi Touil and El Merk (83,3 Bcm), and touching 83,0 Bcm in 2015 (OPEC 2016).

On the opposite side, there is the clear increment in reinjected gas, plotted in the negative part for visual sake, which can be the keystone to understand what is going on in Algeria. As reported in (Aissaoui 2016) many analysists suggest that the reduction in marketed production was driven by economic reasons, that is accommodate volumes of marketed gas to the demand. It seems logic since the export volumes accounted by Sonatrach have contracted more quickly than the enlargement of domestic consumption; to be clear, the export volumes between 2000 and 2015 have reduced by 25,8 Bcm while domestic consumption increased by 19,7 Bcm. Looking at the data from this perspective, it is easy to draw the conclusion of a simple economic move, but the idea supported by the author is different and relies on the evaluation of reinjected gas. In fact, the declining behaviour of gross production and the huge increase of reinjected gas could mean that "there may not have been enough raw gas to maintain the cycling process at its optimum level" (Aissaoui 2016, p.3). Although the start-up of new plants (Ohanet, In Salah, In Amenas, Gassi Touil, El Merk, Menzel Lejmat) during the last decade, production from new fields have at best offset the downturn from mature plants.

The most important field in Algeria is Hassi R'Mel, operated by Sonatrach. During the nineties, it reached its production peak of 92 Bcm per year of gross production, of which 60 Bcm employed for reinjection to maintain the correct pressure level. The delay in activation of Gassi Touil's output, scheduled in 2007 and started in 2014, implied an over-production of marketable gas from Hassi R'Mel which worked outside its optimal level sacrificing the reinjection of gas in the reservoirs. Probably, due to this over-production, some wells have started to yield water, compromising the level of gross production.

If Sonatrach will not be able to cope with these problems by itself, for example how to extract gas trapped in the water encroachment, other options must be considered such as giving stakes of the fields to major international company that could employ state-of-the-art technology in sub-surface technology and solving optimization problems stemming from large scale surface of the field. The drawback in this case is the political sensitivity of the subject since the supergiant field has gained a relevant symbolic importance in terms of national control over its natural sources (Aissaoui 2016).

Other fields are slated for completion within 2020 but their output will only maintain production stable around 85 Bcm per year, also because some of them will unlikely be ready by that date especially the ones managed by Sonatrach on its own (Aissaoui 2001).

For what concern the country's conventional reserves, they have been drastically reduced in November 2015 from a previous proven reserve base of 4500 Bcm to 2745 Bcm (Aissaoui 2016). Thankfully, there is a large potential for expansion of conventional reserves. In 2012, the US Geological Survey (USGS 2013) stated that the undiscovered reserves amounted to 1,1 tcm, but the real difference could be made by unconventional reserves. In 2013, a new assessment of world's shale resources (EIA 2013) suggests that Algeria's shale gas reserves could amount to 20,3 tcm and they are exploitable using current technology but there is no indication regarding the economic profitability or environmental impact.

New policy measures have been deployed to cope with the declining trend in production of fields from which the extraction of natural gas is easy and cheap. The aim of the new policies is to spur a revision of the national reserves and expedite the phases related to exploration and development of the fields.

In February 2013, the Government revisited the current hydrocarbon law, providing incentives to foster upstream investments and extraction of unconventional resources. To this end, in September 2014, there was a bidding round to auction 31 licenses and the response of the market to this offer was absolutely clear: there were only five bids in total, of which only four were finally awarded. This disastrous auction can be explained considering that, in general, international oil companies (IOCs) evaluate investment decisions on the basis of several criteria among which reward, control and risk. In the case of Algeria's investment projects, the reward factor is hampered by low expected return on the investment, the control factor it is not so attractive because usually Sonatrach holds the majority stake and the risk of the country is considered elevated (Aissaoui 2016); in this respect it is noteworthy the terroristic attack occurred in January 2013 on Tiguentourine plant, managed by Sonatrach, BP and Statoil, that has even more increased the costs related to security of working in the Saharan provinces, adding further elements of risk to take into account in case of new investment projects. The deployment of the national army to the defence of country's assets after the 2013 attack has not avoided another, even if smaller than the first, terrorist event in March 2016 on Krechba plant. Moreover, the situation in energy market does not help Algeria in attracting foreign investments. In fact, the global situation is expected to remain not favourable to new projects since the prices of hydrocarbons are low and they will likely remain not attractive, thereby the attractiveness of the option to wait for a more favourable environment in the future gains value.

Despite the sizeable dimension of the shale gas reserves, there is no mention of shale gas as a "national priority" in the national energy program, unlike upstream development, demand rationalization and shift towards renewables that seem to be the future driver of energy policy in Algeria.

Although shale gas reserves seem an attractive way to deal with the problem of declining production there are some problems to consider, for example anti-shale protests. The origin of the protests can be found in the alleged lack of information regarding the environmental impact of shale extraction especially on the precious and restricted water resources of the country (Aissaoui 2016). Probably, these protests can explain why none of the 31 shale extraction blocks auctioned in September 2014 attracted the attention of IOCs, therefore the hostility of the public opinion can be a strong potential barrier to shale development in the region (Boersma, Vandendriessche et al. 2015).

For what concern the upstream sector, the idea is to increase the efforts in exploration in places close the already existing plants and producing areas; this decision derives from the fact that other small discoveries have already been made but they were to afar from processing plants to be economically exploited (Aissaoui 2016). This will be a short-term strategy, in fact remote explorations are not excluded but they will probably need cooperation with high risk-taking investors. Opinions are cautious about the possibility that Algeria will become a prominent shale producer mainly due to the remoteness of shale fields and the absence of adequate infrastructures, water availability, lack of pipelines and roads to move the materials. These problems are particularly crucial for shale extractions since shale wells deplete faster than those employed in conventional gas extraction and the huge amount of water requires an adequate level of facilities (EIA 2016).

In the above section, the attention was focused on the production side of the market that, along with domestic demand, constitutes the core of Algerian gas issue.
As discussed in the previous section, the marketed production has at best plateaued in the last decade and the forecast are not optimistic towards a possible recovery of marketed volumes. On the contrary, domestic gas consumption shows a totally different behaviour, growing from 22,6 Bcm in 2004 to 39,5 Bcm in 2015. The consequence is that inland needs are absorbing an increasing share of gas production compromising the share of resources which can be devoted to export (Aissaoui 2016).

Gas and electricity consumption are growing at high pace and electricity utilization is increasing on average at 6,6% per year over the last decade. The reasons of this upward trends are rooted into a rapid population growth, in the last 15 years it surged by one third reaching 40 million in 2015, urbanization, low energy efficiency and fossil fuels subsidies (Grigorjeva 2016).

1.7.3 Gas export

The global financial crisis has worsened the already difficult situation, of Sonatrach's gas export. The reduction in export towards European market, the largest destination of Algerian natural gas, has begun in 2004 and then it has declined steadily; the result of this shrinkage is that, in 2014, the utilization rate of existing facilities is around 50%. One reason for the contraction can be the fact that the economic crisis hit more severely the Southern countries of Europe, which are in turn the main customers of Algeria, that is Spain, Italy and Portugal. Another possible explanation can be found in the poor management that is leading oil and gas production in the country: corruption is a plague that causes a loss of competitive edge and it can explain why Sonatrach has lost a considerable share of European customers favouring other competitors such as Gazprom, Statoil and GasTerra (Grigorjeva 2016).

The loss in market share has been particularly severe in Italy, with whom Sonatrach have a long-standing relation. In Italy, the major competitor of Sonatrach is Gazprom, the Russian hydrocarbons giant. Until 2012, Sonatrach and Gazprom accounted for one third respectively of total gas consumption in Italy, roughly 23 Bcm per year over a five-year period up to 2012. Then Algeria's export plummeted to 12,5 Bcm in 2013, 6,8 Bcm in 2014 with a little recovery in 2015 reaching 7,2 Bcm. In the same period, Italian gas imports managed by Gazprom increased until 29,9 Bcm in 2015, passing through Tarvisio and Gorizia entry points, and settled with long-term contracts (Aissaoui 2016).

1.7.4 Energy policy for the future

An important meeting, held on 22 February 2016, has designed a strategy in order to cope with the falling export volumes. The strategy tries to deal with the declining export from different perspectives. The first is a supply-side response, aimed to foster the exploration and implementation of new fields, the second involves the demand-side, rationalizing consumption, and the third is a shift towards renewables (Aissaoui 2017).

For what concern the first point we have already talked about the plans of research of new fields, both in the short and medium run.

The demand side is tied to adjustment both in prices and subsidies. Notwithstanding this aim, there is no evidence of a clear and articulate energy pricing policy. The issue is related to a lack in coordination among different energy authorities, which set respectively the primary and wholesale prices (Hydrocarbon Regulating Authority), end-user tariffs of natural gas and electricity (Regulatory Commission for Electricity and Gas), and political power. To give an example, the rise in electricity and gas tariffs has already created popular discontent in Saharan provinces, therefore the Government has deferred any other adjustment (Aissaoui 2017).

The third factor which could help Algeria in solving the conundrum of export and internal demand can be the implementation of renewable resources.
Algeria has one of the highest level of renewable resources of the world, especially solar and wind power. The 86% of its territory is covered by the Sahara Desert, and the solar radiation exploitable "is approximately at least two time higher than what can be generated on the European continent" (Grigorjeva 2016, p.6) Thus, this untapped potential could represent an interesting solution for Algeria. Nowadays, natural gas is the first source of power generation while the amount of renewable energy account for the 3,4%, dominated by hydropower.

European community can play a prominent role in this transition, helping Algeria in the switching from hydrocarbons sources to renewables and, above all, this collaboration has the potential to create a win-win situation, both for Algeria and Europe. As discussed in the previous chapter, energy security and differentiation of the suppliers are a crucial aspect of European's policy but, if Algeria will not be able to respect its agreements because of its internal energy problems, the consequent weaknesses and urgent needs of energy provisions can be exploited by suppliers that already have a considerable bargaining power. So, building a tight and timely relationship with Algeria in order to develop and implement its huge renewables supply, should be propped by European Commission. Given the fact that natural gas seems to be the hydrocarbon source of the future, the chance to create an internal market largely fuelled by domestic-produced renewable energy and divert the bulk of natural gas production towards the export market should be an interesting option (Grigorjeva 2016).

CHAPTER TWO

2.1 Introduction to diffusion models

In this chapter of the thesis there will be a discussion regarding a specific class of statistical models, namely the diffusion models. At the beginning, the analysis will be focalised on a short introduction of this useful methodology which can be employed in a very wide range of fields. Then, a mathematical formalisation is necessary in order to appreciate how and why the models work. This part will follow the structure of *"Strategic interventions and competitive aspects in innovation life cycle"* (Guseo 2004), which covers, almost in chronological order, the developments of the subject. The mathematical aspects of the models will be reduced as much as possible for sake of simplicity.

The utilization of this kind of models become useful in circumstances in which the application of polynomial regression methods, such as ARIMA, is unfeasible. In fact, ARIMA models are designed for stationary time series but the typical pattern of diffusion is totally different from those series that can be handled using, among others, the ARIMA techniques. One of the assumption required for the stationarity is a constant mean over time (after finite differencing) but, as we will see later, diffusion patterns are clearly not mean invariant.

Moreover, the life cycle of a product or an innovation is characterized by mechanisms such as the *initialization process* and the *saturation* that drive the behaviour and the development through time; using different classes of diffusion models the analyst can manage and recognize the intrinsic features of the process and evaluate, for example, the effectiveness of a certain economic policy, marketing campaign or the residual market of a product and many other important characteristics useful to gain an insight regarding the event under analysis.

In general, to analyse whatever kind of process the rationale behind all the mathematical formalisations is trying to describe, in a simplified manner, the evolution of the input variables that drive the development of the process and lead to the final output.

If the process has a deterministic part, it can be mathematically handled by the concept of "*mathematical function*" describing the stable causal relations between the input variables. On the opposite side, there is the concept of *noise*, which can be useful in describing relations among variables which are subject to a certain degree of uncertainty. These two concepts can be mixed in order to describe processes characterized by stable mean relations and also uncertainty among the input variables.

The first important distinction among this family of models is the typology of the life cycle involved: a life cycle can be *open* or *closed* and assign this feature to the time series is crucial in terms of statistical model employed. Of course, the longer the data already available the simpler will be the recognition of the typology of life cycle. It seems quite easy to assign this feature to the series but, according to the subject under consideration, the evolution process can take a considerable amount of time. For example, in the Algeria's natural gas production the increasing part before reaching the peak, from which it could be supposed that it will start the descending part of the process, have taken more than twenty years; notwithstanding the data available for the analysis include more than forty years of annual gas production, many uncertainties remain about the nature of the life cycle especially if we consider the behaviour of the last five or six years.
Therefore, a careful evaluation of the data and the inherent characteristics of the phenomenon under consideration should be made. The models employed in this thesis are all suited for closed life cycle processes, therefore the *a priori* hypothesis regarding the evolution of the Algeria's production is that, sooner or later, national production will end up.

Diffusion models can be univariate or multivariate. In this work, models are univariate so the only relevant explanatory variable is time. In this framework, the assumption regarding the evolution process is that the behaviour is driven by the inherent parameters of the process, regardless of the interaction with other variables (that are implicitly included) in the environment. As for every typology of statistical models, the trade-off that the researcher must face is the choice between the complexity of the models and their explanatory power. More complexity, for example a higher number of parameters, implies higher uncertainty in parameters' estimate, therefore the analyst can make use of several statistical indicators helpful in this respect, because they give a quantitative indication that take into account the complexity of the model and its explanatory power, helping the researcher in judging if it is worth to add parameters to the model.

Multivariate models can handle complex relations among variables, starting from easier frameworks, in which a positive or negative shocks in the evolution of a resource's production can be explained by the effect of price, for example in (Guseo, Valle et al. 2007), but also complex relations that require advanced knowledge in mathematical and statistical modelling such as substitutive effect, competitive or predatory interactions between different products or technology. Just to give an example, in (Guidolin, Guseo 2016) advanced multivariate models are exploited to describe and predict the phase-out of nuclear plants in Germany and the contemporaneous consolidation of alternative technology like renewables.

The models used in this work have two main features: closed life cycle and non-stationarity. The latter implies the utilization of a special regression techniques, namely the non-linear least squares (NLS). In the dedicated section, there will be a closer look to the relevant characteristics of this procedure which is crucial in this kind of applications.

The research's steps applied in the analysis will follow a sequential procedure of refinement. Having in mind the concept of *function*, that is the mathematical formalisation of the interactions among variables or agents, it is possible to describe the stable and deterministic causal interactions among the input variables. In real applications, randomness of the events is the only thing that happens for sure. Uncertainty of events, outside the control of the transfer function, alters the predicted behaviour of the phenomenon under consideration in a partially unpredictable manner. It is possible to imagine the transfer function as a sort of highway around which the realisations of the data generating process move with a certain degree of uncertainty, whose uncertainty is inversely related to the explanatory power of the selected model.

This short time randomness can be managed with appropriate statistical techniques. In this work, along with the main transfer function, there will be an ARMAX model to recognize predictable and repeated behaviour in the residual component of the model. Considering the time series of the residual component, that is the difference between the predicted value and the actual realisation for each point in time, it is possible to obtain a stationary process, or at least retrieve it adopting an appropriate number of differentiations (usually zero). The latent structures of the residual components can be identified through polynomial regression for stationary time series; in this kind of analysis, the ARMAX models are employed with short time purposes, that is refining the main model, which describes the overall trajectory, capturing the transitory but predictable movements which can also be exploited in forecasting.

Forecasting is a crucial aspect of this methodology of research. As said before, the forecast of the single, in this case, variable of interest relies upon the joint predictive power of the main model, for the "deterministic part", and the ARMAX refinement for the stochastic behaviour of the residual process.

Relying only upon forecasts stemming from a single family of models, although comparing the estimates of different classes and nested models of the same class, could be a drawback for a more comprehensive insight about the phenomenon under consideration. Every strategy of analysis has some *a priori* hypothesis upon which all the procedures employed are based on. Each procedure has positive aspects, which can give important information regarding an event, but it is crucial to be aware that the limitations imposed by the initial conditions can also hamper the correct description, and therefore the predictions, of an event. So, a comprehensive analysis should compare estimates and forecasts from different sources to benefit from the positive contributions that each approach can supply; the aim of this work is to explain and apply diffusion models to a specific situation, that is Algerian gas production, therefore the outlooks will be based only on the output of these models.

In (Aissaoui 2016), the author makes some forecast concerning the future path of gas exports. These estimates are based on other predictions about the future of gas production and national gas demand. Gas production is expected to maintain the actual plateaued level for future years, at least until 2030, therefore this prediction relies on the assumption that it is possible to maintain the current level of extractions without any sign of decline. This forecast is derived from a scenario analysis which mixes together several configurations of future production, so the *a priori* assumptions related to the evolution of production are totally different from closed life cycle models.

In the next section, there will be discussion regarding the development of diffusion models employed in this thesis, starting from the Riccati's equation passing through different approaches that have implemented and refined this statistical approach.

The base model for all the subsequent expansions is Bass' model (Bass 1969) that will be extensively described in the dedicated section. It is rooted in the Riccati's equation, explained in the next section, and from the Bass' model other specification and nested models are retrieved. In this work, I will use the GBM model, Bemmaor's models, combinations of these two classes and another category called "Space Models".

2.2 Riccati's equation

Riccati's equation is an ordinary quadratic differential equation developed by Jacopo Riccati (1676-1754). In this case, we consider the equation with constant coefficients in the following form

$$y' + ay^2 + by + c = 0 \tag{1}$$

Where $a, b, c \in \mathrm{R}$.
Assuming a different from 0 and r_1 and r_2 the solutions of the characteristic equation, $ap^2 + bp + c = 0$, it is possible to represent (1) as function of its roots

$$y' + a\,(y - r_1)(y - r_2) = 0 \tag{2}$$

For sake of simplicity we assume $r_1 < r_2$ and, in case both the roots are real and distinct, it is possible to obtain another form that is

$$a\,(r_2 - r_1) = (\mathrm{b}^2 - 4\mathrm{ac})^{1/2} \tag{3}$$

imposing the existence condition $y \neq r_1$ equation (3) can be rewritten as

$$-\frac{y'}{(y - r_2)^2} = \frac{a(y - r_1)}{(y - r_2)} \tag{4}$$

deriving the right-hand side of (4) and with some algebra we obtain

$$\left(\frac{a(y - r_1)}{(y - r_2)}\right)' = \frac{-y'a(r_2 - r_1)}{(y - r_2)^2} \tag{5}$$

So, equation (5) is equal to the left-hand side of (4) except for the multiplicative constant $a(r_2 - r_1)$. In order to solve this kind of differential equation we have to find the function *y(x)* whose derivative correspond to the left-hand side of (4); in this case the class of function is $\mathrm{z} = \alpha e^{\beta x}$ whose derivative is $z' = \alpha\beta e^{\beta x} = \beta\mathrm{z}$.

In our case, if we compound the parameter a into the constant C_0 we can write the general solution for equation (2) obtaining

$$\frac{(y - r_1)}{(y - r_2)} = C_0 e^{a(r_2 - r_1)t} \tag{6}$$

that becomes

$$y = \frac{r_1 - r_2 C_0 e^{a(r_2 - r_1)t}}{1 - C_0 e^{a(r_2 - r_1)t}} \tag{7}$$

whose first derivative with respect to t is

$$y' = \frac{-aC_0 e^{a(r_2 - r_1)t}(r_2^2 - 2r_1 r_2 + r_1^2)}{(C_0 e^{a(r_2 - r_1)t} - 1)^2} \tag{8}$$

In order to describe and understand the asymptotic aspects of this model, it is better to make a practical exemplification, for example thinking that y is the cumulated series of sales of a product, and y' the instantaneous amount.

The limit of $y'(t)$ for plus and minus infinity yields always zero ($\lim_{t \to +\infty} y' = 0$ and $\lim_{t \to -\infty} y' = 0$) which is coherent with the idea of a closed life cycle.

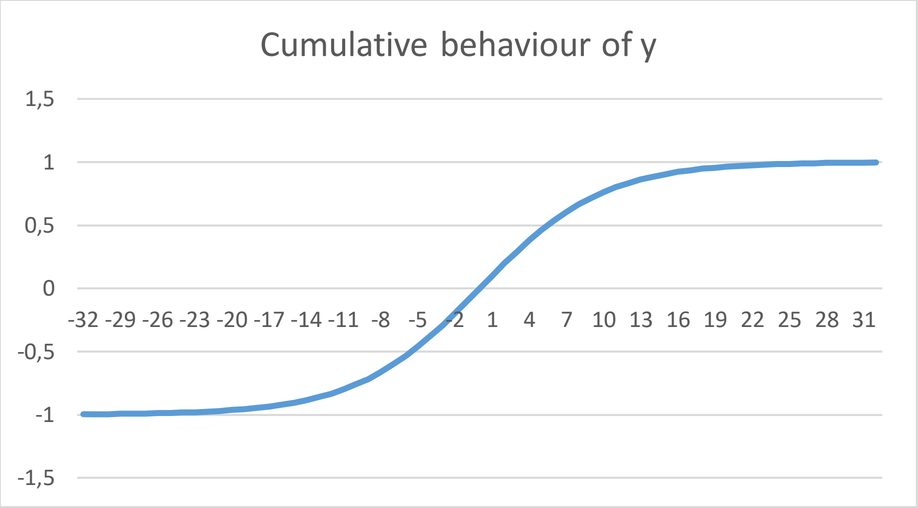
Moreover, if $a > 0$ the solution (7) has two asymptotes, that is $\lim_{t \to -\infty} y(t) = r_1$ and $\lim_{t \to +\infty} y(t) = r_2$.

Usually, in the application in which we are interested in, another condition is required, namely that the function passes through the origin; this is coherent with the trivial observation that, if $y(t)$ represents the cumulative sales in a certain time domain, the starting point must be zero. So, the constraint imposed is $y(0) = 0$, which implies that $C_0 = \frac{r_1}{r_2}$, and adding the conditions $r_2, r_1 \neq 0$ and multiplying numerator and denominator of (7) by $-e^{-a(r_2 - r_1)t}$ we obtain another form which will be more handy in future transformations

$$y = \frac{1 - e^{-a(r_2 - r_1)t}}{\frac{1}{r_2} - \frac{1}{r_1} e^{-a(r_2 - r_1)t}} \tag{9}$$

The last function maintains the asymptotic behaviour of (7) and passes through the origin. It is not a monotonic function for $r_1 * r_2 > 0$, with discontinuity where its denominator goes to zero, therefore if the two roots have opposite sign (9) becomes an increasing monotonic function with discontinuity where its denominator goes to zero. In the figure below there is an example of equation (9) with $r_1 = -1,\ r_2 = 1, a = 0.1$

Figure 9: Cumulative Behaviour of *y*



2.3 Bass model (BM)

This model was initially discussed in the famous paper "*A new product growth for model consumer durables"* (Bass 1969). The model tries to deal with the concept of diffusion of new products in a social environment. The important concept behind the adoption process is the *timing* of adoption, that is when a customer decides to buy a specific product; moreover, there are individuals that decide to buy something independently of the decisions already made by others instead some people are more susceptible in this respect. This is an important distinction and it is the core structure upon which the model is built. The first category, the "independent" people, are called *innovators*, and the others are divided as follow: early adopters, early majority, late majority and laggards. The rationale behind this classification is the timing of adoption. The model assumes that, except for the innovators, all the other categories are influenced in timing of adoption by the pressure generate by the social system, that is the network of relations and opinions between the agents, and this pressure becomes more and more tight for late adopters. For mathematical sake, groups from Early Adopters to Laggards are embedded in a single group defined as *imitators.*

The framework adopted by Bass can be well summarized with the statement: “the probability that an initial purchase will be made at T given that no purchase has yet been made is a linear function of the number of previous buyers” (Bass 1969, p.216), therefore the linear function is

$$P(T) = p + \left(\frac{q}{m}\right) Y(T) \tag{10}$$

where $Y(T)$ is the number of previous buyer, and p, q, m are constants. As will be explained later, Bass model is a different specification of Riccati’s equation, and the constraint $Y(0) = 0$ is still valid. For this reason, parameter p is the probability of an initial purchase at time $T = 0$ and its value reflects the importance of innovators in the system. The other parameter $\left(\frac{q}{m}\right)$ times $Y(T)$ is the value that reflects the pressure on imitators taking into account the growing number in adopters, therefore the social pressure increases as time goes by. In the next part a more detailed specification will be made.

It is crucial to distinguish between the twofold form that this model can have and the derived classes based on it. It is possible to deal with it in an instantaneous form, that is y', or in a cumulated way, namely y. The procedure I have followed involves the specification of the model employing cumulated data and then, also for visual sake, data are plotted after differentiation, obtaining the instantaneous series; then, the differentiated series is superimposed on the actual data.

2.3.1 Mathematical features of Bass model

For this part concerning the mathematical formalisation, I will follow more closely (Guseo 2004), for its clearer reference to Riccati’s equation; obviously, the result is the same as the one obtained in (Bass 1969).

The base equation for Bass model is a special form of Riccati’s equation

$$y' = (p + qy)(1 - y) \tag{11}$$

with parameters $p, q > 0$.

As said before, there is the distinction between instantaneous data which are represented through a probability density function (pdf), so in this case y' is a pdf, and cumulative data y which are therefore a cumulative distribution function.

Another useful specification of (11) represents the Bass model as a *hazard rate*, that is the probability of adoption given the fact that the individual does not have adopted the product before.

$$\frac{y'}{1-y} = (p + qy) \tag{12}$$

In fact, the right-hand side of (12) can be view as a sum of conditional probabilities where p represents the probability to be an innovator with the related conditional probability of adoption which is 1. The probability to be an imitator is q and its conditional probability of adoption changes with time because it is the pressure from other adopters that determines the conditional probability of imitators.

It is noteworthy to specify that, in this terms, equation (11) and (12) are expressed in normalised terms, so the range of observations goes from zero to one. It is possible to express these equations in absolute terms but it is necessary to specify the so called *carrying capacity.* This task is done by $z = ym$, where *m* is a positive constant that represents the carrying capacity or asymptotic market. In mathematical terms, it is the cardinality of the events in the domain. If the researcher is working in absolute terms, equation (11) becomes

$$z' = \left(p + q\frac{z}{m}\right)(m - z) \tag{13}$$

Developing the products, we obtain a sum of two elements. The first, $p(m - z)$, drives the innovative effect modulated by the parameter p; as said before, this is the parameter that expresses the power of the innovators in the market but it is possible to interpret this as the influence generated by the institutional communication. This term is directly connected to the residual market, therefore its effect on the instantaneous sales has a time varying power, higher at the beginning, with a complete residual market, and increasingly lower as the cumulated sales increase. This is exactly the rationale of this formula, which wants to isolate the starting effect of the innovators and the subsequent decline.

The other term of the sum is $q\frac{z}{m}(m - z)$, and it describes the imitative effect of the process. Here we have the term q which is modulated by the varying component z/m, that increases through time, so changing the magnitude of the penalizing effect on parameter q. This component describes the so-called *word-of-mouth* effect, namely the pressure exerted, on people that have not already buy the product, by consumer that have already purchased it; clearly the higher the number of adopters the higher the pressure on the remaining non-adopters, thus the pressure is modulated by the varying parameter *z/m* which increases with the level of sales.

Inside the Bass model it is possible to distinguish two different models, one for the innovative and one for the imitative part. The former refers to the monomolecular model (Louis A. Fourt, Joseph W. Woodlock 1960), the latter to the logistic model (Verhulst 1838).

Equation (11) can be expressed in different terms

$$y' + qy^2 + (p - q)y - p = 0 \tag{14}$$

with roots for the characteristic equation equal to $r_1 = -\frac{p}{q}$ and $r_2 = 1$, so $a(r_2 - r_1) = p + q$, and given the fact that in the usual applications of the models the terms $1 - y$ and y' are positive, therefore the terms p and q are positive. In this, case $a = q$ and $r_1 < 0 < r_2$. The solution of interest in this application is the one passing through the origin $y(0) = 0$ which has two asymptotes $-\frac{p}{q}$ and 1.

Replacing these results in (9) we obtain the final model in standardized terms

$$y(t) = \frac{1 - e^{(p+q)t}}{1 + \frac{q}{p}e^{-(p+q)t}} \tag{15}$$

Before we stated that z = ym, so

$$z(t) = m\frac{1 - e^{(p+q)t}}{1 + \frac{q}{p}e^{-(p+q)t}} \tag{16}$$

and the corresponding function for instantaneous normalized data is

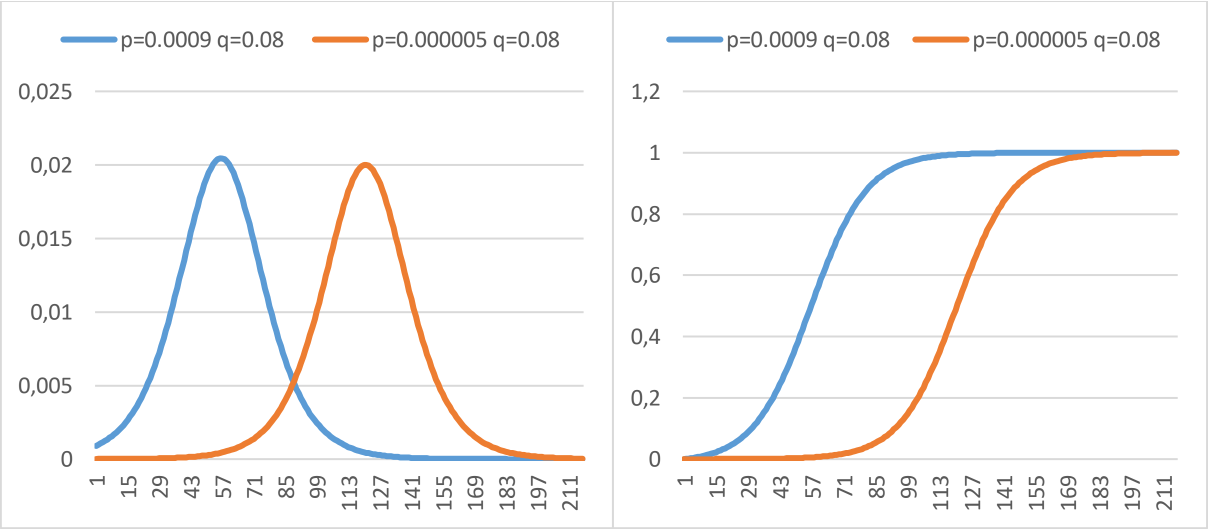
$$y'(t) = \frac{p(p+q)^2 e^{-(p+q)t}}{(p+qe^{-(p+q)t})^2} \tag{17}$$

The model has many features that permit to compute interesting statistics such as the inflection point, which corresponds to the point of the maximum degree of growth before the saturation of the process. This point can be found in

$$t^+ = \frac{ln\left(\frac{q}{p}\right)}{p+q} \tag{18}$$

and it is the centre of symmetry of the Bass curve in instantaneous terms. The function $y'(t)$ is symmetric in the interval $(0; 2t^+)$.

Figure 10: y'(t) and y(t)



In the exemplification above it is highlighted the role of innovators in the evolution process. The second has a lower level of p so the initializing process is slower and it reflects its characteristic both in differentiated and cumulated terms. As it is possible to note, the early part takes off very late compared to the other despite the same value for the imitative part. Both processes share the same carrying capacity, 1 in normalized terms, and start from zero using the cumulated series.

As already said, these two specifications permit to compute the model both in cumulated and instantaneous terms but it is necessary to specify certain constraints and results that could create problems in the analysis. These warnings must be applied to the standard Bass model and to more complicated specifications.

The main statistical indicator exploited in model's evaluation is the coefficient of determination R^2; when we work with cumulated data it usually reaches very high levels. Therefore, we must be aware that a level, let's say $R^2 = 99.87$, it is not as precise as we can expect. In fact, it is crucial to compare the model in differentiated terms with the actual time series and, for level as the one above, the adaptation is quite poor.

The main constraint to which this procedure is subject is the requirement to have the time series from the very beginning. As it possible to see in the graphs above, the series starts exactly from zero so, if starting data are missing, it is difficult for the process to calibrate the launching part and therefore specify the model.

Working with instantaneous data has the advantage that the series can be handle also with missing data at the beginning, but the estimation is less precise than the one carried out with cumulated data.

2.4 Generalized Bass Model (GBM)

The basic Bass model has many interesting features, among which its simplicity, that can help the researcher in the analysis. Obviously, its simplicity implies a lower degree of flexibility in describing the series and unexpected events can lead to inconsistent estimates of the parameters, limiting its explanatory power. Therefore, other specifications have tried to implement the basic model adding more flexibility without loosing its basic features. The result is the "generalized Bass model" (GBM), described in "*Why the Bass model fits without decision variables*" (Bass, Krishnan et al. 1994). The key of this specification is the possibility to insert an "intervention function", possibly dependent upon input variables, that is a special kind of mathematical function that helps to better adapt to the pattern of the process. As already said, shocks in the process could lead to instable parameter estimates because the path followed by the basic Bass model is "rigid" therefore there is no room for transitory shocks. So, the great advantage proposed by the GBM is that it allows to insert different kinds of shocks, according to the type of function chosen, without alter the normal path of the model. In other words, GBM can identify the normal development of the curve but it admits that, in specific points, there could be a transitory deviation from the normal path. In this way, it is possible to preserve the structural parameters of the population, isolating them from sudden but not structural events that may happen during the evolution period. Many kind of shocks can be imagined, for example the launch of a marketing campaign can increase the sales of a product with limited duration, so GBM is able to distinguish between the normal level of sales and the peak after the marketing policy, maintaining the correct value of population's parameters. Or can be the case that an excise tax is transitory demanded on a specific product and then removed. It is likely to expect that, for the duration of the excise, the instantaneous sales level decreases and then it recovers after the removal. We should assume that perhaps the decrease in sales stems only from the external intervention not from the anticipated closure of the life cycle.

The innovation in this model is the introduction of the function $x(t)$ which has the characteristic of modifying the evolution through time of the process. The equation for the GBM is

$$z' = m\left(p + q\frac{z}{m}\right)\left(1 - \frac{z}{m}\right)x(t) \tag{19}$$

where $x(t)$ is an integrable function in the time domain and non-negative and may be dependent upon other time series. In the standard Bass this functions equals to one.

If $0 < x(t) < 1$ the diffusion process slows down instead if $x(t) > 1$ the process speeds up. The general solution of the GBM is

$$z(t) = m\frac{1-e^{-(p+q)\int_0^t x(\tau)d\tau}}{1+\frac{q}{p}e^{-(p+q)\int_0^t x(\tau)d\tau}} \qquad \mathrm{t} > 0, \mathrm{p}, \mathrm{q} > 0 \tag{20}$$

$z(t)$ is a cumulative density function in the time domain $[0, +\infty)$. The intervention function can slow down or speed up the adoption process but, in this configuration, the carrying capacity cannot be modified, therefore m is a constant. In this respect, there exist other models which can deal with this issue, see for example (Guseo, Guidolin 2009), but in this work, I did not use them.

An interesting future of this model, in its several specifications, it is the limited number of additional parameters involved and the sizeable amount of flexibility added. It is worth to note that the main aim of the introduction of this special kind of shock it is not the precise identification and description of the unexpected intervention but rather the isolation of these events from the normal development and evolution of the process, therefore yielding a more precise estimate of the structural parameters of the objective function (m, p, q), with respect to the intervention function $x(t)$.

The range of choices regarding the intervention function is wide, given the not strict constraints, integrability and positivity in the time domain. In this thesis, I have employed two kind of shocks, that is *rectangular* and *exponential shocks.* In the next paragraph, I will show the mathematical formalization of these two intervention functions.

2.4.1 Rectangular shocks

This is the simplest specification of the GBM but it can have a high level of explanatory power despite its simplicity. This intervention has the characteristic to maintain a stable level of "intensity" during the period in which it acts, thus it is called "rectangular". It is constituted by three parameters which module its behaviour. The first two parameters are a and b¸ which define the temporal limits of the intervention space, so conventionally $a < b$, and it is possible to imagine that the shock begins in a and then comes back to its primitive level in b without altering the overall path of the process. The third parameter is c and it represents, if statistically different from zero, the intensity of the local shock; it can be lower or greater than zero according to the kind of shock the analyst can imagine on a visual base.
Before going more into details, it is necessary to write the general formula for $x(t)$

$$x(t) = 1 + c_1 I_{t \geq a_1} I_{t \leq b_1} + c_2 I_{t \geq a_2} I_{t \leq b_2} + c_3 I_{t \geq a_3} I_{t \leq b_3} \tag{21}$$

In this specific case, we have three rectangular shocks, independent each other and each one with its personal level of intensity c. The indicator function has the role to define the closed interval of application, thus defining a transitory and stationary process, and they assume the value of 1 if the events is verified and zero otherwise. In this way, the process is activated in a selective way. For example, if the process is verified in the interval $[a_1, b_1]$, only the first indicator function assumes the value 1 and the others remain at 0; so, the value assumed by the function is: $x(t) = 1 + c_1$.

The define integral, thus the functional form employed in the formula is

$$\begin{aligned} \int_0^t x(\tau) d\tau = t &+ c_1(t - a_1) I_{t \geq a_1} I_{t \leq b_1} + c_1(b_1 - a_1) I_{t > b_1} + \\ &+ c_2(t - a_2) I_{t \geq a_2} I_{t \leq b_2} + c_2(b_2 - a_2) I_{t > b_2} + \\ &+ c_3(t - a_3) I_{t \geq a_3} I_{t \leq b_3} + c_3(b_3 - a_3) I_{t > b_3} \end{aligned} \tag{22}$$

2.4.2 Exponential shocks

The behaviour of this kind of shocks is different from the former because they are characterized by an intense event followed by the reabsorption after the peak, reaching again the normal path. The main difference is that, in the rectangular, the time domain of the shock is well identified and limited and all happens inside that interval, with exponential shock it is possible to identify just the starting point (a) and a constant *(b)* which defines the reversibility of the shock, that is if the shock will be reabsorbed or not. Again, (c) represents the intensity and the indicator functions have the same role as before.

In the case of three exponential shocks the form of $x(t)$ is

$$x(t) = 1 + c_1 e^{b_1(t-a_1)} I_{t\geq a_1} + c_2 e^{b_2(t-a_2)} I_{t\geq a_2} + c_3 e^{b_3(t-a_3)} I_{t\geq a_3} \tag{23}$$

It is important that the parameter b has negative value to guarantee the reabsorption and it represents the speed of this process. As for the rectangular case, the parameter c can have positive or negative value.

The definite integral has the following form

$$\begin{aligned} \int_0^t x(\tau)d\tau = t + c_1 \frac{1}{b_1}\left(e^{b_1(t-a_1)} - 1\right) I_{t\geq a_1} \\ + c_2 \frac{1}{b_2}\left(e^{b_2(t-a_2)} - 1\right) I_{t\geq a_2} \\ + c_3 \frac{1}{b_3}\left(e^{b_3(t-a_3)} - 1\right) I_{t\geq a_3} \end{aligned} \tag{24}$$

So, also with this specification the asymptotic aspects of the model are not modified; it implies that the asymptotic share of imitators and innovators are not altered by the intervention function as well as the asymptotic market.

2.5 Subsequent and independent generations with total absorption

In the models evaluated so far, one of the assumptions was that we were interested in define and analyse a single diffusion process in the time domain. Other specifications have the possibility to insert more than one generation, thus we can imagine that the amount of sales are not totally attributable to a single generation of product but they are summed generation after generation. Several assumptions and thus several models can be supposed; in this work, I have considered a single class of this model, that is model with total absorption, with parametric and non-parametric origin. The idea is that the first generation maintains its normal behaviour if another generation of the same product does not enter in the market, in that case the second will erode the space of the first gaining its autonomous position.

The reference work in this case is "*A diffusion theory model adoption and substitution for successive generations of high technology products*" (Norton, Bass 1987).

The starting point is the normalized Bass model $F(t_i)\ i = 1,2,\dots,k$ with constant parameters, thus the general form is the classical one seen in the previous paragraphs. The only difference is the time index $t_i = t - c_i$ that represents the time passed from the parametric origin c_i. If $t_i < 0$ it implies that $F(t_i) = 0$ because the generation *i* has not yet started.

It is possible to have many subsequent generations, the starting case is the single generation model which corresponds to the standard Bass, but applying the notation of this specific model the cumulated sales are

$$F(t_i) = \frac{1 - e^{-(p_i+q_i)t_i}}{1 + \frac{q_i}{p_i} e^{-(p_i+q_i)t_i}} \tag{25}$$

$$S_{1,t} = F(t_1)m_1 \tag{26}$$

and they reach the stationarity upon the peak m_1 which is the usual carrying capacity. Now, the analyst can suppose the introduction of an updated model of the same product, something that usually happens for example in tech industry, therefore the data concerning the sales refers to the same product but the device is not the same. The migration from one generation to the other can be total or partial.

In the hypothesis of *total migration*, as is the case of the future applications of this thesis, the form of the mathematical problem can be specified as follow

$$S_{1,t} = F(t_1)m_1 - F(t_2)F(t_1)m_1 = F(t_1)m_1\big(1 - F(t_1)\big) \tag{27}$$
$$S_{2,t} = F(t_2)m_2 + F(t_2)F(t_1)m_1 = F(t_2)(m_2 + F(t_1)m_1)$$

This case is limited to two generations but nothing prevents the possibility of many others, with the normal problems linked to the uncertainty of estimation given the possible elevated numbers of parameters.

Asymptotically, for $t \rightarrow +\infty$ we have $S_{1,t} = 0$ instead $S_{2,t} = m_1 + m_2$, so the second generation gains all the market share resulting from the sum of the first and second carrying capacity, so this is the formalisation that specifies the total migration from a generation to the next. In general, if the process assumes n generations, the carrying capacity of the last one is given by $S_{n,t} = \sum_{i=1}^{n} m_i$. In equation (26) it is possible to isolate the quote that the second process progressively takes away from the first, that is $F(t_2)F(t_1)m_1$.

Employing the usual notation for the cumulative sales we can write

$$y(t) = S_{1,t} + S_{2,t} = F(t_1)m_1 + F(t_2)m_2 \tag{28}$$

which can be useful for estimation purposes. Sometimes, to lighten the numbers of parameters to be estimated, it is useful to impose some constraints, for example assuming the equivalence among some parameters of the equation.

2.5.1 Heterogenous diffusion models: Bemmaor Model

The models described in the previous paragraphs have the common features of "homogeneity" among the agents. With that kind of models, it is possible to retrieve the asymptotic shares of innovators and imitators in the market but the assumption is that, at individual level, the propensity towards the adoption is the same inside the reference group, thus each innovator shares the same probability to buy and the same is true for imitators. In fact, a drawback of the standard Bass model is that it has only an aggregate view: it describes the overall market without deepening the micro-structures of the market, so neglecting important features that can help in having a better comprehension of the market both at macro and micro level.

Many studies have been conducted to deal with heterogeneity and, in this work, I have chosen the approach proposed by (Bemmaor 1993). The final solution of the model proposed is quite easy to implement and it can be easily adapted to different specifications of the reference base model.

The model can capture the latent heterogeneity of the population and it is based on the standard Bass model. The latent heterogeneity refers to the individual level, therefore this specification can be considered a sort of micro-structure model nested on a more macro-structure model such as the standard Bass.

As for the standard Bass, the approach to describe the heterogeneity is based upon two different probability distributions: the first is the shifted-Gompertz density function the second is a Gamma distribution. The first is related to the action of first purchase instead individual propensity of the consumers is described by the gamma distribution. Mixing these distributions, it is possible to describe the overall diffusion process and its inherent heterogeneity, from this moment on we refer to this model as the “Gamma-shifted Gompertz”.

The ratio $\frac{q}{p}$, which refers to the asymptotic share of innovators in the standard Bass, varies according to a “scale parameter” $\frac{1}{\beta}$. The latter ratio is the parameter of the Gamma distribution that describes the heterogeneity among the individuals; the heterogeneity is explained by ή, the Gamma distribution, whose structural parameters are $(\frac{1}{\beta}, \alpha)$. At the same time the behaviour for the individual level, that is the first adoption process, is modelled through the shifted-Gompertz distribution. Its function in cumulated terms is defined as follow

$$F(t) = \left(1 - e^{-bt}\right) e^{-ή e^{-bt}} \tag{29}$$

and the associated density function is

$$f(t|ή, b) = b e^{\left(-bt - ή e^{-bt}\right)} [1 + ή(1 - e^{-bt})] \tag{30}$$

with $t > 0$; $\quad ή, b > 0$.

These formulas can describe the first adoption process and, for fixed value of b, lower values of ή imply a lower average time of adoption, thus a higher propensity to buy.

Knowing that ή moves according to a Gamma distribution with the parameter α as a shape parameter and $\frac{1}{\beta}$ as scale parameter, the formulation of the model for the aggregate diffusion process can be described with another distribution function

$$F(t) = \frac{(1-e^{-bt})}{(1+\beta e^{-bt})^{\alpha}} \tag{31}$$

with corresponding density function

$$f(t) = be^{-bt}(1+\beta e^{-bt})^{-(\alpha+1)}[1+\alpha\beta+\beta e^{-bt}(1-\alpha)] \tag{32}$$

Reparametrizing equation (31) in order to obtain a formulation more similar to Bass, we can impose $b = p + q$ and $\beta = \frac{q}{p}$ obtaining the final formula for the aggregate process, that is

$$F(t) = \frac{(1-e^{-(p+q)t})}{\left(1+\frac{q}{p}e^{-(p+q)t}\right)^{\alpha}}, \qquad t \geq 0, \quad \alpha,\ p,\ q > 0. \tag{33}$$

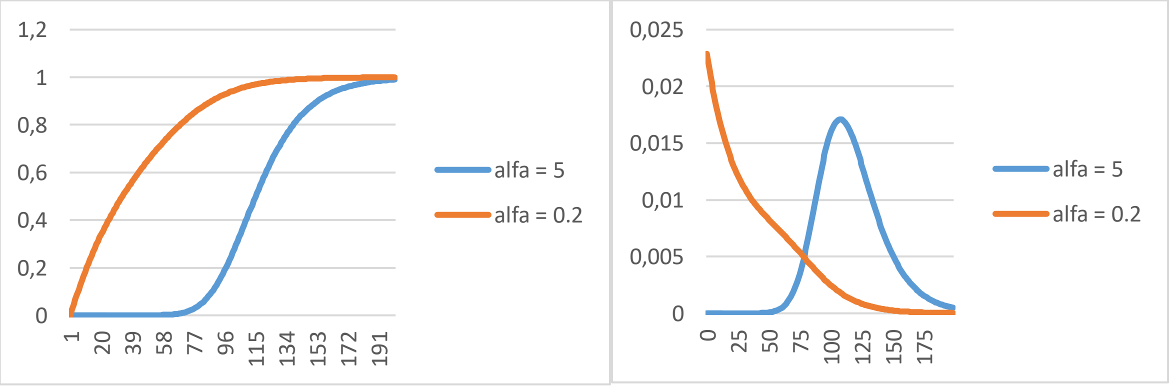
Now, the interesting feature of the estimation process is that the analyst can set different level of α in order to better adapt to the data.

There are three reference values for α which reconduct the model (33) to other distributions.

If $\alpha = 1$ the distribution function is equivalent to the standard Bass model, so there is no evidence for heterogeneity in the population.

When α = 0 the function reduces to an exponential model and so to an exponential diffusion curve. The last interesting value is α = ∞ which implies that the curve is like a logistic curve.

Figure 11: Cumulative and Instantaneous patterns



As it is possible to see with intermediate values of α, its effect is already clear. Lower values imply the tendency towards the exponential model and the effect is that the individuals are eager to make the purchase and therefore the life cycle closes quicker. On the opposite side, if the value of α is higher than one, innovators delay the purchase and the cycle closes later.

2.5.2 Modified Bemmaor model

In the paper "*Homogeneous and heterogeneous diffusion models: Algerian natural gas production*" (Guseo, Mortarino et al. 2015), other specifications based on the standard Bemmaor model are implemented. The logic behind these modifications is the same as in the GBM model discussed above, thus implementing an intervention function $x(t)$ able to manage exogenous shocks.

The first model is indicated with the notation GBMBM, that is a GBM model nested on a Bemmaor (BM) specification. The formula below follows the notation employed in (Guseo, Mortarino et al. 2015) and it is written as a piecewise function

$$F(t) = \frac{\left(1-e^{-(p+q)t}\right)}{\left(1+\frac{q}{p}e^{-(p+q)t}\right)^{\alpha}} \qquad \text{if} \qquad t < a \tag{34}$$

$$F(t) = \frac{\left(1-e^{-(p+q)\left[t+\frac{c}{b}e^{[b(t-a)-1]}\right]}\right)}{\left(1+\frac{q}{p}e^{-(p+q)\left[t+\frac{c}{b}e^{[b(t-a)-1]}\right]}\right)^{\alpha}} \qquad \text{if} \qquad t \geq a$$

the notation is the same used in the previous models, so a is the starting point of the shock, b is its persistency and c its intensity.

A step further in the description of the population can be attained allowing for a double source of heterogeneity. Equation (33) is composed by a ratio in which the numerator can be thought as an independent sub-model, that corresponds to the monomolecular model and explains the effect of the external influence and therefore the innovative part of the population. The denominator is the logistic component of the process that is the imitative part of the population; in that specification heterogeneity is considered only on the imitative share of consumers. Thus, a simple modification is done adding a non-negative exponent in the innovation part of the model. In this way, they obtained the “modified Bemmaor model” (BMM), whose cumulative distribution function is

$$F(t) = \frac{\left(1-e^{-(p+q)t}\right)^{\delta}}{\left(1+\frac{q}{p}e^{-(p+q)t}\right)^{\alpha}}, \qquad t \geq 0, \quad \alpha, \delta, p, q > 0 \tag{35}$$

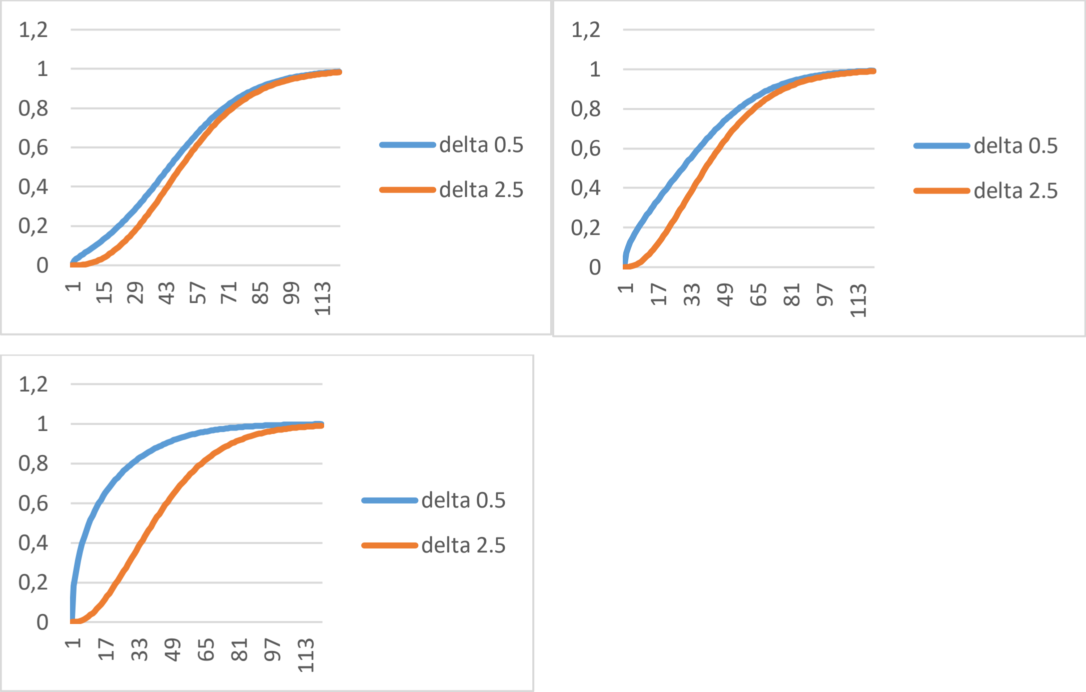
Equation (35) maintains the same characteristics as before, so the numerator is a special form of the monomolecular model and any power of a distribution function remains a distribution function.

The task of the new exponent is the same as the denominator’s one, thus it has the possibility to increase or decrease the propensity of adoption of the innovators. Looking from another perspective, the propensity of the innovators corresponds to the starting behaviour of the market, so the exponent can modify the slope of the initial part of the cumulative distribution function, and thus the instantaneous one, making it more or less steep. In this way, it is possible to describe in a more sophisticated manner the behaviour of innovators and their entrance in the market.

Assuming a fixed value of α, the variations of δ have a precise meaning. For $\delta = 1$ this is the case of the standard Bemmaor model. If delta is greater than 1, the starting behaviour of the process will be delayed because the innovators prefer to be more cautious in the adoption, therefore the starting part of the diffusion process will lay longer on the horizontal axe. On the contrary, value lower than 1 imply an acceleration at the beginning with a higher penetration rate. The influence exerted by the parameter δ on the process is strongly connected with the magnitude of α. As it is possible to note in the figure below, the final shape of the curve is strongly connected with the value of α and the variations in its value have ample consequences: the higher the value of α the lower the impact of δ on the final shape.

For this exemplification, I have used equation (35) in normalized terms, with common level of p and q for all the curves ($p = 0.005, q = 0.05$), varying the value of α (1; 0,5; 0,1) and delta (2,5; 0,5). The cumulated functions show very different behaviours and give and insight about the influence of α in defining the shape of the curves.

Figure 12: Alpha 1; Alpha 0.5; Alpha 0.1



The last modification on BMM regards the plug in of an intervention function in the same manner seen before. This exemplification is made with an exponential shock but the same is valid in the case of a rectangular or whatever kind of $x(t)$. This last model is called GBMBMM and again it is represented as a piecewise function of time.

$$F(t) = \frac{\left(1-e^{-(p+q)t}\right)^{\delta}}{\left(1+\frac{q}{p}e^{-(p+q)t}\right)^{\alpha}} \qquad \text{if } \ t < a \qquad (36)$$

$$F(t) = \frac{\left(1-e^{-(p+q)\left[t+\frac{c}{b}e^{[b(t-a)-1]}\right]}\right)^{\delta}}{\left(1+\frac{q}{p}e^{-(p+q)\left[t+\frac{c}{b}e^{[b(t-a)-1]}\right]}\right)^{\alpha}} \qquad \text{if } \ t \geq a$$

Equations (34), (35) and (36) have been applied for the first time in (Guseo, Mortarino et al. 2015).

2.6 Estimation procedure

As specified in the brief introduction above, these time series do not show the stationary behaviour of the typical economic time series, except for the last part of the cumulative process in which the series stabilize around their asymptotic carrying capacity *m*. In the remaining part of the life cycle, the exploitation of an alternative way of estimation is required. In this paragraph, there will be a brief introduction about the "*non-linear least squares"* estimation method (NLS), useful in retrieving the estimates of the parameters of the models. This brief description has not claims to encompass all the aspects of the subject, but the aim is just to give an insight about how it operates and which are the positive aspects and drawbacks of this technology.

All the models specified in the previous sections can be estimated using the following procedure:

$$Z(t) = f(\beta, t) + \varepsilon(t) \tag{37}$$

$Z(t)$ represents the actual cumulative data, $f(\beta, t)$ is the deterministic function which can assume one of the specifications above with the unknown multiple parameter $\beta \in R^k$ and also it is function of time. The second addend is $\varepsilon(t)$ a stochastic process that represents the residual component of the series; many assumptions can be made about the structure of the residual component, also in hierarchical manner.

Some assumption should be made in order to obtain the identifiability of the model. The first is that the expected value of the erratic component $\varepsilon(t)$ is zero. The practical condition to have this result is that the deterministic function is "correct" so it describes in a properly manner the average behaviour of the process. Having satisfied this requirement, the estimation process can be applied. As for the classic linear models, other assumptions can be tested on the residuals, such as homoscedasticity and non-correlation. If all these three assumptions are satisfied, we obtain a *white noise* process and no additional information can be drawn from these data because the process in totally unpredictable and the future is totally independent from the past. If it is not the case, it is possible to apply some specific structure to the residual component gaining additional information to refine the process. In this case I have employed the ARMAX model that I will briefly describe afterwards.

2.6.1 Non-linear least squares

The general idea with this technique is essentially the same as for ordinary least squares. In this case, the function to be estimated is not a linear combination of parameters, therefore it creates

a surface on the space and not a hyperplane. As for OLS procedure, we must find that combination of estimated parameters that minimize the deviance of the error component.
The objective function to minimize the deviance is equation (39), assuming a general form for the model as in equation (38):

$$y = f(x, \theta) + \varepsilon \tag{38}$$

$$S(\theta) = \varepsilon'\varepsilon = \sum_{i=1}^{n} \varepsilon_i^2 = [y - f(\theta)]'[y - f(\theta)] \tag{39}$$

where (39) must be minimized changing the choice of the parameters θ. To obtain this, we take the derivative of (39) with respect to θ. Now, it is necessary to introduce the Jacobian, that is the matrix whose elements are the first derivative of the function. The advantage of this matrix is that it gives the best linear approximation of the function in a specific point. Therefore, we employ this matrix to compute the first derivative with respect to θ and the function is

$$F.'\left(y - f(\theta)\right) = 0 \tag{40}$$

The objective is to find the parameter θ that gives the orthogonality between the vector difference $y - f(\theta)$ and the surface $f(\theta)$, approximated by the "tangent variety" which is computed as

$$\tau = f(\hat{\theta}) + \hat{F}.(\theta - \hat{\theta}) \tag{41}$$

Here we have the first drawback of the procedure: in fact, given the non-linearity of $f(\theta)$ there can be several local minimum points, unlike the linear regression in which the linearity guarantees the existence of a single global minimum point. This methodology strongly depends on the choice of the initial conditions, that is the input parameters that the analyst must insert at the beginning of the computation, which are the starting point of the recursive estimation algorithm that I will briefly explain.

The estimation procedure is carried out using the Levenberg-Marquard algorithm. The general idea is that, given some starting parameters, the algorithm changes these values in a recursive manner until it finds the combinations of parameters that reduce the most the deviance of the

error component. The magnitude of the recursive variations is given by a parameter β and it stops when equation (40) reaches zero.
For further information see (Seber, Wild 1986).

2.6.2 ARIMA and ARMAX processes

In this paragraph, I will quickly describe a class of models for stationary time series. As said, the stationary series under analysis in this work is the series of residuals. The models employed are largely exploited in economic analysis to describe the mean and the systematic stochastic behaviour of an economic time series. The first class is the autoregressive integrated moving average (ARIMA) model, the second is a different specification of the ARIMA including an exogenous variable (ARMAX); in this analysis, I will exploit the latter.

The conditions to be met in order to obtain a stationary process are:

1) $E[x_i]$ constant for all $i = 1, 2, \dots T$,
2) $V[x_i] = E[(x_i - E[x_i])^2]$, constant for all $i = 1, 2, \dots T$
3) $Cov[x_i x_j] = E[(x_i - E[x_i])(x_j - E[x_j])], \quad i < j$

That is mean and variance of the process are constant for all the time domain and the autocovariance depends only on the lag between the observations and not from the point time. A process is called *weakly stationary* when it is mean and covariance stationary.

The first kind of model is the autoregressive process (AR). The characteristic is that the value in time t of the variable depends on a contemporaneous random component u_t and the value of the same variable in previous lags. The number of lags involved defines the order of the stochastic difference equation that describes the model. For example, if the process has two lags it is a *second order autoregressive process* AR(2) and its equation is

$$x_t = \alpha_1 x_{t-1} + \alpha_2 x_{t-2} + u_t \tag{42}$$

if the model has a sufficient explanatory power the residuals should behave as a white noise process and it possible to investigate this aspect using some statistical tests or looking at the autocorrelogram which shows the autocorrelation at different lags and the confidence interval for assuming the uncorrelation among residuals.

The other kind of process is the *moving average process* (MA). This process represents the current value of x_t as the sum of one or more lags of a pure random process and the equation of an MA(1) process is

$$x_t = u_t - \beta u_{t-1} \tag{43}$$

where u_t is a pure random process. In order to obtain a unique parametrisation of the MA, the *invertibility condition* must be satisfy, that is $|\beta| < 1$.

Mixing these two, we obtain the so-called ARMA process which is composed by an autoregressive and a moving average part. It can be written as

$$x = \alpha x_{t-1} + u_t - \beta u_{t-1} \tag{44}$$

Using the statistical significance of the estimates for the parameters at different lags it is possible to identify the model, choosing the correct number of lags. For further information regarding these models see (Kirchgässner, Wolters 2008).

The estimation procedure adopted in this work starts with the estimation of the deterministic part of the process and then retrieving the residuals. Therefore, the kind of time series model employed is the ARMAX, because it has the AR and MA part plus an exogenous variable that is our deterministic process. The mathematical representation is the following

$$\Phi(\mathrm{B})\left[z(t) - \xi g\left(\hat{\theta}, t\right)\right] = \varphi(B) a_t. \tag{45}$$

The term $g\left(\hat{\theta}, t\right)$ is the predicted value stemming from the non-linear estimation procedure and, if the model is well estimated, the point estimate of ξ is zero. $\Phi(\mathrm{B})$ and $\varphi(B)$ are the usual autoregressive and moving average lag polynomials, B is the backward operator and a_t the white noise process.

CHAPTER THREE

3.1 Statistical application to natural gas production of Algeria

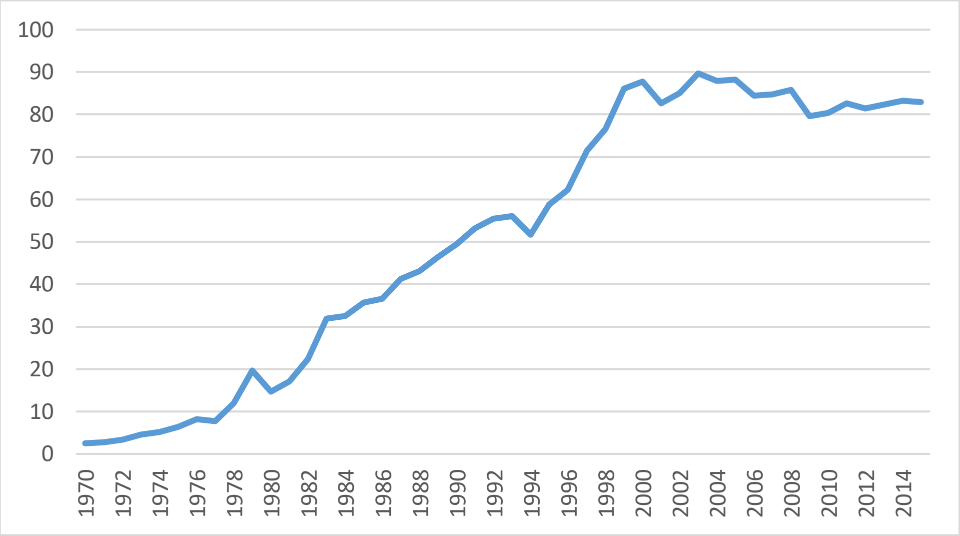
In this final chapter, there will be the application of the models described before to a specific time series that is the production of natural gas in Algeria. The approach followed is close to that used in (Guseo, Mortarino et al. 2015). It could be that data available in both current and past editions of the data source (BP 2016) would been revisited in most recent editions. Obviously, this is a great obstacle if the aim is to compare estimates made on the same time series in different years, therefore the models studied here should be considered independent from the previous carried out in previous works.

Other premises should be made in order to be aware of the possible drawbacks implied in the models. As already said, all the specifications rely on the assumption of closed life cycle. Watching the graph of the instantaneous production, it will be immediately clear that the behaviour of recent years is quite unexpected if the idea is to manage these data with such kind of constraint. In fact, all the models fail, some more some less, in recognising this roughly horizontal path. In this situation it is crucial to formulate additional hypothesis about the process that go beyond the simple application of statistics. The mathematics alone cannot explains all possible outcomes of the process because it relies on *a priori* assumptions that are supposed to remain unchanged for all the life cycle: this is the reason why I consider essential the comparative analysis of different research methods to have a broader insight regarding the events. A discussion about this will be made in the conclusion of the thesis. Hereafter, I will discuss the results obtained from the application of the diffusion models.

3.2 Models confrontation

First, watching the graph of the phenomenon under consideration gives a first idea about what is the general behaviour of the data. In this case, I have employed annual production data starting in 1970 until 2015, drawn from (BP 2016). In the figure below, I have plotted the instantaneous production data. The process shows a quite stable increasing trend for the years ranging from the beginning of the series until 2003, point in which it is possible to assume that the process has reached its peak. From that point on, we should expect the usual decreasing trend that characterizes the closed life cycle diffusion models, instead, the production shows a plateaued level that seems to persist.

Figure 13: Instantaneous Production (Bcm)



In this situation, only the availability of new data can give accurate answers concerning the real nature of the process.

Knowing the limits we are facing, I will describe the results of the analysis. The procedure starts with the simpler model of a certain family and then uses more articulated configurations. If a model is an extension of a simpler specification, it is a good practice to use the estimates of the simpler one as initial conditions for the more complicated. This is tied to the recursive procedure applied that depends on the initial parameters; in this way, we can be quite sure that the starting point is coherent with the other models.

Two basic specifications are the base line for subsequent and more complicated models, namely the standard Bass model and the standard Bemmaor model. In order to have a better and clearer vision of the overall results, I start with the description of Bass and related models, then Bemmaor and related, concluding with the Space specification.

The table below shows the estimates retrieved using Bass. The first statistics to take into consideration to evaluate the model is the coefficient of determination. In this case, the R^2 is substantially higher for the GBM's with respect to the standard Bass but, to have a quantitative confirmation of the additional explanatory power, we need other statistics that I will explain later.

Table 2: Bass Estimation

Model Parameters		Bass		GBM rectangular		GBM exponentials	
General penetration paramenters	m	3006,58	(2916,64; 3096,51)	3121,7	(3068,63; 3174,76)	3202,43	(3106,76; 3298,1)
	p	0,00177808	(0,00168758; 0,00186859)	0,00102116	(0,0006965; 0,00134582)	0,00115074	(0,0010208; 0,00128069)
	q	0,116403	(0,112516; 0,120291)	0,112627	(0,110319; 0,114935)	0,108198	(0,103528; 0,112868)
Exponential shock parameters	a					11,1979	(10,0044; 12,3915)
	b					-0,232004	(-0,329329; -0,134678)
	c					1,13857	(0,772449; 1,50469)
Rectangular shock parameters	a			6,97734	(1,95858; 11,9961)		
	b			19,4831	(18,6752; 20,291)		
	c			0,413237	(0,323045; 0,503429)		
Asymmetry parameters	α						
	δ						
R^2		99,9514		99,9914		99,9914	
Model standard error		17,2622		5,6221		7,51045	

The standard model has only three parameters to estimate and the confidence intervals of each of them are quite stable, especially if compared with more heavy models. The first parameter is the asymptotic market which corresponds to 3006.58 Bcm. Therefore, the straightforward action to do is to compare the actual cumulated production with the carrying capacity estimated with Bass. In 2015, the cumulated production amounted to 2363,4 Bcm, thus Algeria has already exploited about the 79% of the total gas resources. This ratio remains fairly stable comparing other specifications: it amounted to 75% (GBM with rectangular shock), and 73,8% (GBM with exponential shock). Therefore, it is possible to say that all the derivations of Bass are coherent, with respect to the carrying capacity, with the starting model. Then, the other important statistics that is possible to compute from this data is the asymptotic share of innovators and imitators. As reported in (Guseo 2004), the asymptotic share of innovators depends on the ratio *q/p*. In this case, the ratio equals to 65 for the standard Bass so the percentage of innovators is between 8% and 5%, defining the process as essentially imitative. The magnitude of this ratio, for the other two models, is much higher, reaching 110 for the GBM rectangular and 94 for the GBM exponential. The estimates of the nested specifications are very different in value from the standard Bass but the crucial thing is that they are coherent with the base model and confirm even more the imitative nature of the process.

For what concerns the shocks, the results are again coherent among the models.
The first is the rectangular GBM but it is necessary to note the great uncertainty in the estimate of the parameter a which is the starting point of the shock. Probably, this ample confidence interval is due to the sudden peak in $t = 11$; the starting hypothesis I have made regarding the rectangular shock is that it started around $t = 12$ ending in $t = 25$, thus I have imagined a shock with low intensity and long duration. It could be the case that unexpected and irregular peaks, such as in $t = 11$, and near to other movements, $t = 12; 13$, prevent the correct estimation process leading to very ample confidence intervals. The uncertainty related to the starting point of the rectangular shock probably has negative effect on the estimation of the final point, in fact it easy to note, in the figures at the end of the chapter, that the predicted process shows a behaviour not exactly equal to the observed data. Anyway, the coefficient of determination is the same both for the exponential and rectangular shock, with even lower value of model standard error for the latter.

The GBM exponential identifies the starting point of the shock in $t = 11$ and it is coherent also in graphical terms, in fact it follows well the starting part of the shock and very accurately the subsequent part of the series. The negative confidence interval for the parameter b gives statistical significance to the reabsorption of the shock and parameter c confirms the positive sign of the event. In (Guseo, Mortarino et al. 2015, p.375), it is reported that in 1981/1982, near to the point where the model recognises the shock, Algeria signed a 20-years contract with France for the supply of natural gas, thus it is possible to assign an economic interpretation to that event.

However, none of the three models is able to manage the final behaviour of the series. It is clear, looking at the predicted series superimposed to the actual one, that the horizontal behaviour it is missed by every model notwithstanding the increased complexity.

The GBM’s give a better prediction in the final part, in fact the predicted lines close little bit more on the right with respect to the standard Bass but, anyway, the behaviour of the final part is totally missed.

The second class of models is the Bemmaor models. I have divided the models in this way: in the following table, there are the standard Bemmaor and the GBM’s related to it, instead the “modified Bemmaor model” (BMM) and the GBM’s nested on the BMM, will be presented into another table.

The first model to evaluate is the standard Bemmaor, which differs from the standard Bass because of the exponent at the denominator; as said, this exponent can accelerate or decelerate the adoption process giving an interesting additional feature to the model.
The GBM’s give a sizeable increase in terms of determination coefficient gaining interesting level of R^2.
As for the Bass models, the first parameter is the *carrying capacity*. Again, we should compare the level already reached by the cumulated series with the estimated carrying capacity. For the Bemmaor standard (BM), this level amounts to 57,4%, for the GBM rectangular it is 68.9% and for the exponential it is 68%. Given the fact that the two nested models have a pretty higher R^2, we should rely more on them also because the percentage just described are closer to those retrieved with the GBM’s of Bass, giving more strength to these results.
The most important contribution of BM is the asymmetry parameter α. Looking at the table, we can see that for the standard BM the estimate is very high but with an ample confidence interval, however, the lower limit is strongly greater than one, suggesting a marked asymmetry in the behaviour of the process. Nested models increase the fitting but the estimates for the parameter α reduce, maintaining anyway level greater than one.

Table 3: Bemmaor Estimation

Model Parameters		BM		GBMBM rectangular		GBMBM exponential	
General penetration paramenters	m	4111,63	(3783,22; 4440,05)	3428,8	(3219,94; 3637,66)	3472,56	(3182,72; 3762,39)
	p	0,0185076	(0,0102185; 0,0267967)	0,00347743	(0,00098626; 0,00596859)	0,00414489	(-0,00018786; 0,00847763)
	q	0,043801	(0,0278496; 0,0597524)	0,0870953	(0,072282; 0,101909)	0,084307	(0,0623223; 0,106292)
Exponential shock parameters	a					11,7256	(10,4835; 12,9678)
	b					-0,391297	(-0,74357; -0,0390251)
	c					0,96713	(0,460345; 1,47391)
Rectangular shock parameters	a			6,14428	(-0,169897; 12,4585)		
	b			18,3208	(17,2581; 19,3834)		
	c			0,300911	(0,191716; 0,410105)		
Asymmetry parameters	α	3,92765	(1,86173; 5,99356)	1,49019	(1,06534; 1,91503)	1,52527	(0,853532; 2,19701)
	δ						
R^2		99,9873		99,9937		99,9927	
Model standard error		8,9183		6,52141		7,01379	

The two kinds of shocks investigated are the same as in Bass and the estimates confirm almost perfectly the starting and ending points for the rectangular shock and the starting point for the exponential one. This is obviously an important fact in term of significance of the estimates. The other important value in this respect is the negative confidence interval for the parameter *b* that implies the reabsorption of the shock.

Then the analysis involves the innovative specification called “modified Bemmaor model” which has an asymmetry exponent both for the innovative and imitative part. Again, the structure involves the base specification and the nested models with the usual rectangular and exponential shocks.

In this case, the base model for this specification gives an interesting level of fitting, reaching $R^2 = 99.9909$. The GBM’s increase this level but it should be better to use some statistical indicator that gives a more precise indication in terms of significance of the additional parameters involved.

Looking at the asymmetry parameters, the results stemming from the three models should be carefully evaluated. The estimates deriving from the GBM’s suggest a level of α slightly higher than one but the confidence intervals, in both cases, contain values with higher and lower magnitude with respect to one. The base BMM gives an α lower than one with a confidence interval that encompasses values lower and greater than that. So, it is difficult to be sure in assigning the correct value of asymmetry because the estimates are not totally coherent.

The same happens also for δ. Only the base BMM gives a precise indication of the asymmetry at the numerator, which is quite strong, but the nested models do not suggest strong evidence in that respect.

For what concerns the shock parameters, the estimates are confirmed also by these models. The starting point of the rectangular shock suffers the same problem as in the previous models but the punctual estimate is coherent with the others already retrieved. Probably for the heavy parameterization of the GMB’s, the confidence interval of b is ample with limits of different sign, but the shock has been identified in the same location as for the others exponential shocks, therefore we can assume that the reabsorption can work also in this case.

Table 4: Modified Bemmaor Model Estimation

Model Parameters		BMM		GBMBMM rectangular		GBMBMM exponentials	
General penetration paramenters	m	3326,63	(3055,48; 3597,78)	3430,08	(3196,88; 3663,28)	3385,31	(3102,74; 3667,88)
	p	0,00201886	(0,0000925163; 0,0039452)	0,00345464	(0,000726096; 0,00618318)	0,00303347	(-0,000133485; 0,00620042)
	q	0,100931	(0,076932; 0,12493)	0,0870061	(0,0695219; 0,10449)	0,0919163	(0,0683653; 0,115467)
Exponential shock parameters	a					12,7505	(11,4415; 14,0594)
	b					-0,473817	(-0,993846; 0,0462133)
	c					0,768301	(0,0964376; 1,44016)
Rectangular shock parameters	a			5,67909	(-3,37397; 14,7321)		
	b			18,3199	(17,1736; 19,4663)		
	c			0,303326	(0,128963; 0,477689)		
Asymmetry parameters	α	0,886362	(0,590266; 1,18246)	1,49815	(0,83595; 2,16036)	1,21989	(0,657508; 1,78227)
	δ	2,79751	(1,96867; 3,62635)	0,992947	(0,0577948; 1,9281)	1,59941	(0,724511; 2,47432)
R^2		99,9909		99,9937		99,9932	
Model standard error		7,6541		6,60639		6,84386	

The final class of models involved is that with subsequent generations, two in this case, with total absorption by the second. As for the other diffusion models, it is possible to give an interpretation to the parameters of the specification. For example, in (Guseo 2011) this class of models was used in order to evaluate the behaviour in the extraction process for “heavy” and “cheap” oil. In that specific case, the phenomenon of shale oil extraction was well known, therefore the hypothesis of a second surging wave of oil extractions was theoretically correct.

In this case, there is no evidence of different extraction processes, at least for the moment. As already written in the introductive part of Algeria, recent assessments of shale oil and gas reserves suggest that the country has one of the largest shale resources of the world. So, we can imagine that this typology of models could be applied in the future giving precious insights regarding the joint behaviour of different methodologies of extractions. But it could be also the case that subsequent generations do not only depend on different extractions procedures but on some regime changes in the production. The hydrocarbon industry in Algeria changes after the nationalization of natural gas reserves in the Sahara Desert in 1971 (*Algérie énergie * 2016). Therefore, it is possible to imagine that, an event like that, could have some strong consequences in terms of organizational procedure and production output. That is the reason why I have tried to implement this model that can give important quantitative information coherent with the geopolitical situation that the country has experienced. The need to reconcile results that derive from different approaches should give more strength to possible evidences stemming from the quantitative method.

The table below shows the estimates for the Space model with parametric origin of the second wave. The determination coefficient is interesting because it is similar to the level attained with heavier models.

In this specification, there are two carrying capacities: the first, *mg*, represents the asymptotic market for the first wave that starts in $t = 0$ while *mb* is the carrying capacity of the second wave. The second generation starts in *ta*, that in this case has been estimated about nine years after the beginning of the series. The estimates for the two asymptotic markets are very different, in fact the first corresponds to 717,5 Bcm and the second to 2562,7 Bcm. The interesting thing is that the cumulative sum of the two waves yields a result comparable to the estimates retrieved with the other models. In this case, the ratio between the actual cumulative production and the asymptotic market gives 72% which is very close to the estimates made with the other models. Considering the output of the regression, we can see that the estimated second wave starts very early in the time series; knowing that in 1971 the nationalization happened, the hypothesis I have made is that the first wave, the one with limited carrying capacity, is a sort of residual output of the previous production process, that is before the nationalization, and, after a brief period, the real production managed by Algeria has begun. Obviously, this is just a hypothesis that ties together two evidences, one historical and one stemming from the data, thus a more precise analysis should be done in order to gain more precise results in this respect, but this goes beyond the aim of this work.

Table 5: Space Trasled Estimation

Model Parameters		Space Trasl	
Parameters	mg	717,543	(494,06; 941,026)
	p	0,00436361	(0,00393784; 0,00478938)
	q	0,102787	(0,058397; 0,147177)
	mb	2562,72	(2292,59; 2832,85)
	b	0,997168	(0,613711; 1,38063)
	ta	8,83594	(7,66421; 10,0077)
R^2		99,9916	
Model standard error		7,44444	

3.2 ARMAX refinement

In this section of the analysis, I will show the models developed before with the ARMAX refinement. For every diffusion process estimated, the residuals are treated in order to find manageable regularities in their behaviours. As reported in the table below, the determination coefficients increase substantially. The interesting thing is that the final part of the actual series is better interpreted by the model with the ARMAX structure. The diffusion models alone cannot capture the unexpected horizontal move, for the reasons explained before, but introducing the ARMAX the predicted series manages in a more precise way the final period, obviously considering that as transitory; in fact, the forecasts made for future years follow the same path of the diffusion process.

As already said in previous parts, more complicated models nested on the basic specification involve additional parameters, therefore it is necessary to evaluate their effectiveness in terms of explanatory power. More parameters imply more uncertainty in the estimation procedure, thus the trade-off is between the additional explanatory power and the estimation uncertainty, thus this trade-off must be carefully analysed. To this aim, I will use the approach suggested in (Guseo, Mortarino et al. 2015) which involves two steps. The first part computes the square multiple partial correlation coefficient considering the value R^2 for the simpler model M_1 and the same index for the nested model M_2. The formula used is the following

$$\widetilde{R^2} = \frac{R_{M_2}^2 - R_{M_1}^2}{1 - R_{M_2}^2}. \tag{46}$$

The next step uses the square multiple partial correlation coefficient retrieved before to compute the F statistic. In this case, if N is the number of observations in the dataset, λ the number of parameters of the more complicated model and k the difference between the number of parameters in M_2 and the number of parameters in M_1, with this procedure it is possible to have statistical evidence on the significance of the addition k parameters in M_2. The null hypothesis is that the k extra parameters are zero, therefore if the F statistic is higher than the threshold 4, we can assume that the additional parameters are jointly significant. The F-ratio is defined as follow

$$F = \frac{\left[\widetilde{R^2}(N - \lambda)\right]}{\left[\left(1 - \widetilde{R^2}\right)k\right]} \tag{47}$$

and it is distributed as a Snedecor distribution $F \sim F_{k,(N-\lambda)}$ if the residual $\varepsilon(t)$ are i.i.d normal.

All the models have been treated with the ARMAX procedure and the rational in this respect to fit the model is the joint evaluation of the significance of the AR and MA terms involved in the specification and the analysis of the residuals of this further refinement trying to find the best configuration to obtain white noise residuals.

All the treated models have well responded in terms of the constant ξ (see equation 45), that represents the multiplicative terms in front of the estimated diffusion model; all the specifications have a value of ξ close to 1,00 or even lower. It means that the diffusion models fit well the data in their average behaviour.

Table 6: Output After ARMAX

	N Param	R^2	$\widetilde{R^2}$	F w.r.t. Bass	$\widetilde{R^2}$	F w.r.t. BM	$\widetilde{R^2}$	F w.r.t BMM
Bass + ARMA (4,4)	3	99,9932	NA	NA	NA	NA	NA	NA
BM + ARMA (3,3)	4	99,9954	0,324	20,087	NA	NA	NA	NA
BassR + ARMA (4,3)	6	99,9994	0,912	137,778	0,870	133,333	NA	NA
BassE + ARMA (4,3)	6	99,999	0,853	77,333	0,783	72,000	NA	NA
BM_R + ARMA (4,2)	7	99,99922	0,885	75,250	0,830	63,667	NA	NA
BM_E + ARMA (4,3)	7	99,9996	0,941	156,000	0,913	136,500	NA	NA
BMM + ARMA (3,3)	5	99,9991	0,868	134,389	0,804	168,556	NA	NA
BMM_R + ARMA (4,3)	8	99,99924	0,888	60,400	0,835	48,000	0,156	2,333
BMM_E + ARMA (4,3)	8	99,99912	0,871	51,127	0,809	40,159	0,022	0,288
Space + ARMA (3,4)	6	99,9997	0,956	288,998	0,935	286,667	NA	NA

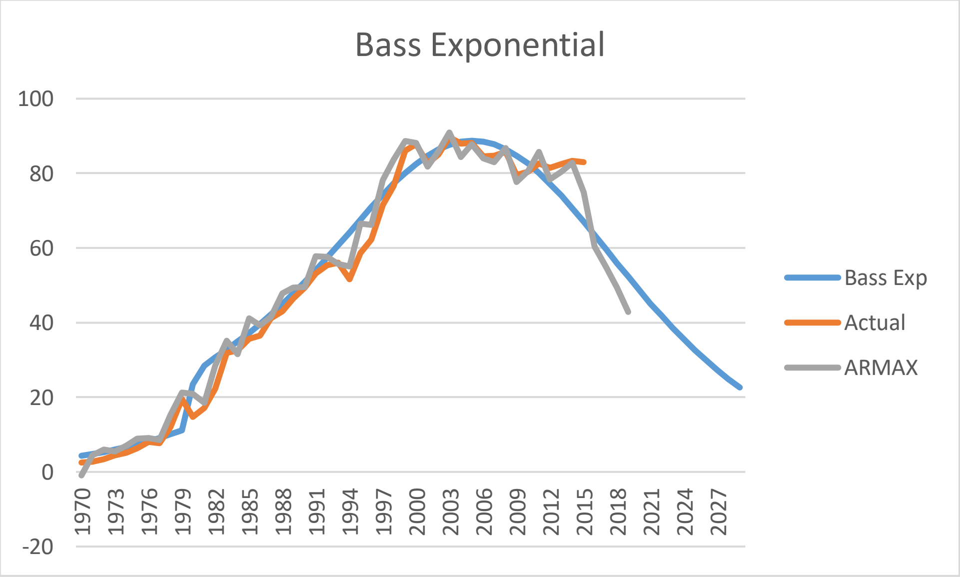
In the table above there is the application of the F-test which gives quantitative information regarding the significance of the additional parameters. The first evident fact is the elevated values of F with respect to the standard Bass, so we have a clear information that the increased complexity is always worth compared to Bass. The same is always true for the values computed with respect to the standard Bemmaor model; none of the F statistics fall in the acceptance region of the null hypothesis of non-significance. The opposite happens when the GBM's based on the BMM are compared with the standard BMM. As I reported before, they give uncertain estimates for the asymmetry parameters and the standard BMM already yields an elevated value of fitting without increase the number of parameters. Therefore, the three extra parameters in the GMB's configuration for this model, which is already heavy parameterized, do not give further information.

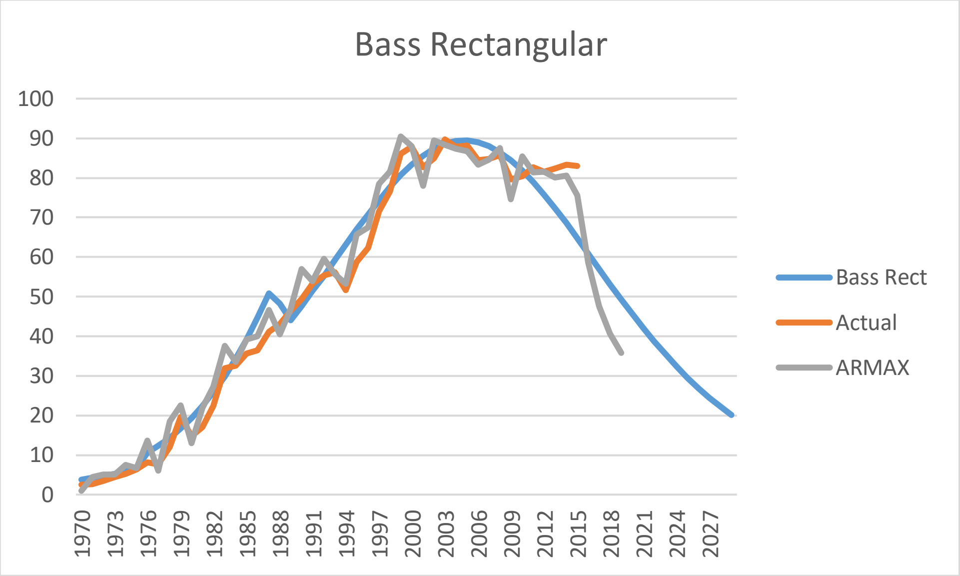
The Space model is compared only with the standard Bass and standard Bemmaor because it has less parameters than the BMM and its fitting is very elevated.

The ARMAX refinement gives better R^2 coefficients for all the models, and, above all, the final part of the series is more precisely identified with respect to the predictions obtained with the diffusion models alone.

The list of figures below shows, for each model, three series: in this way, it is possible to appreciate the contribution given by the diffusion process alone and the diffusion process plus the ARMAX refinement. It is absolutely clear how the ARMAX works, in fact the stochastic fluctuations around the deterministic trend are the outputs of the ARMAX and help in recognising these oscillations impossible to be managed by the deterministic part alone.

Figure 14: Graphs of the Different Specifications

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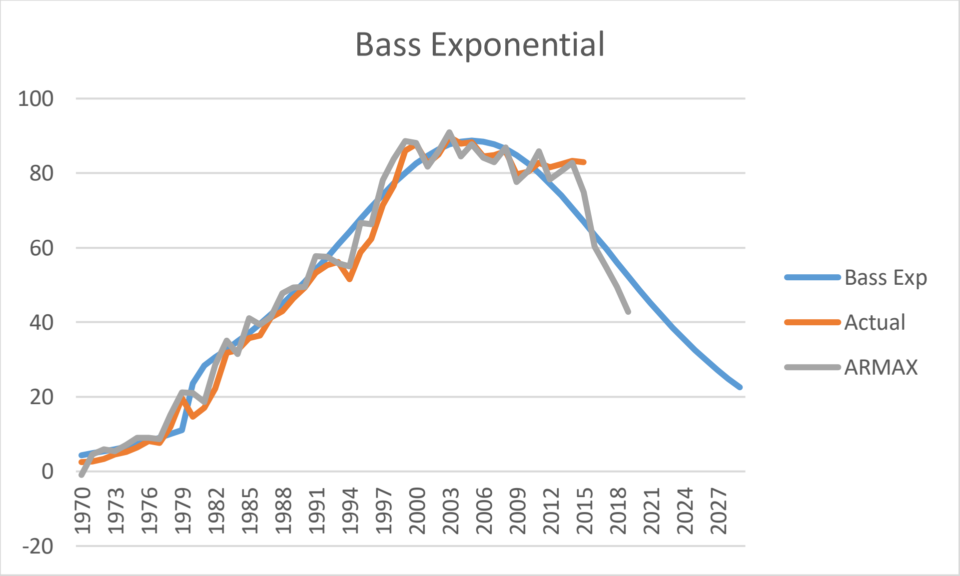
Bass Rect
Actual
ARMAX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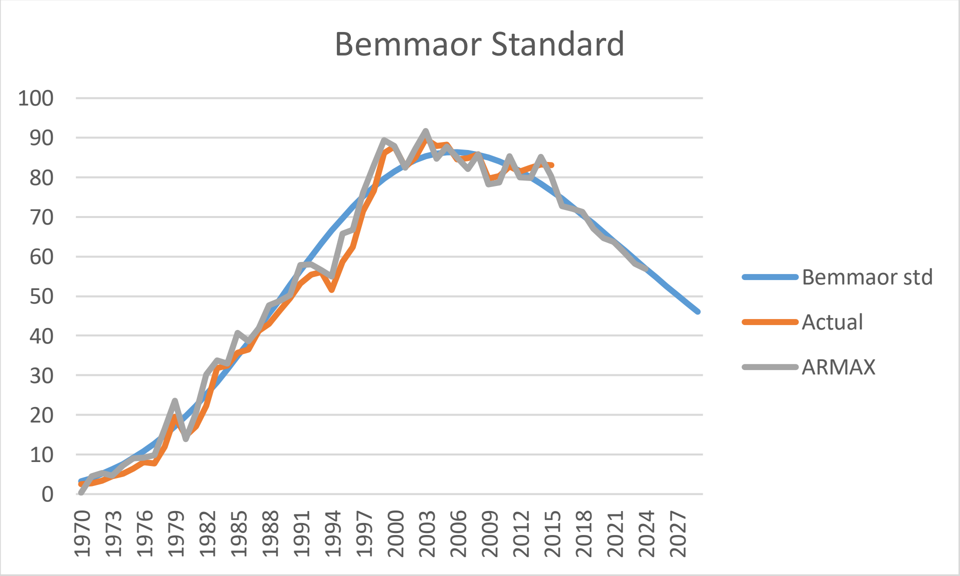
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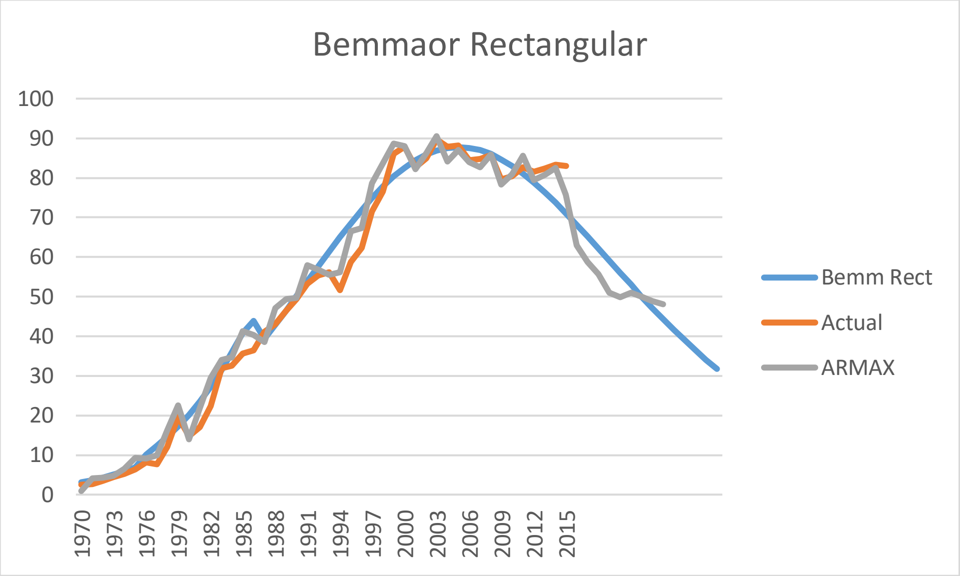
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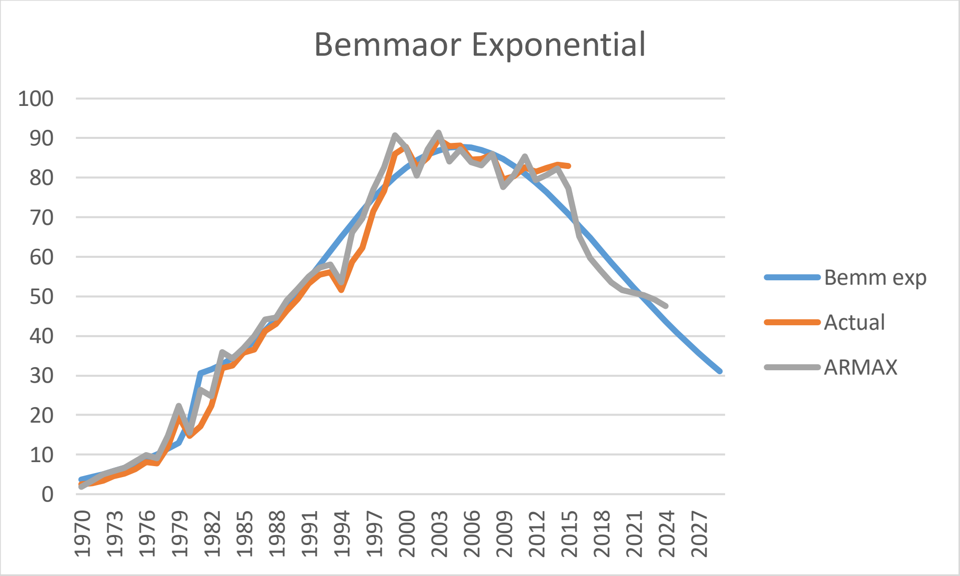
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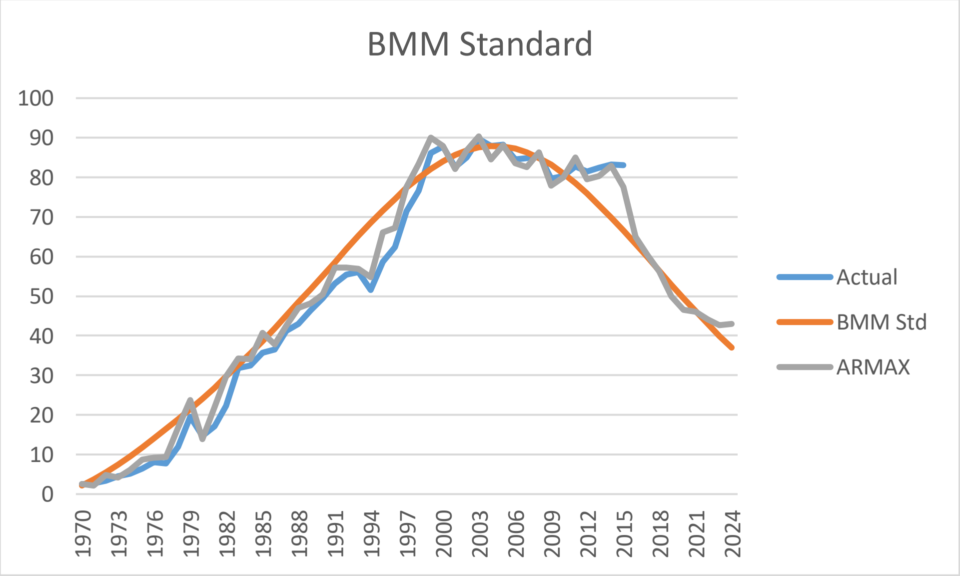
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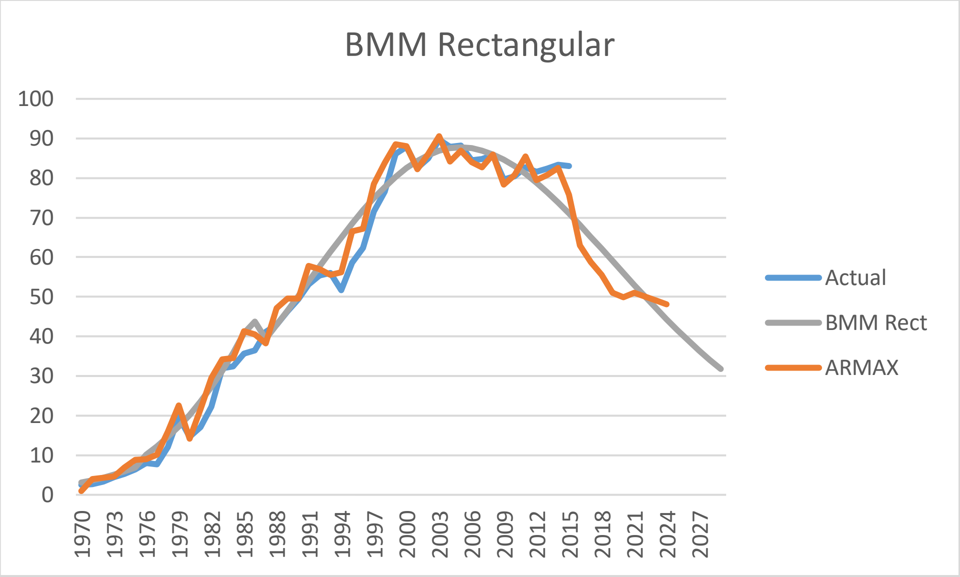
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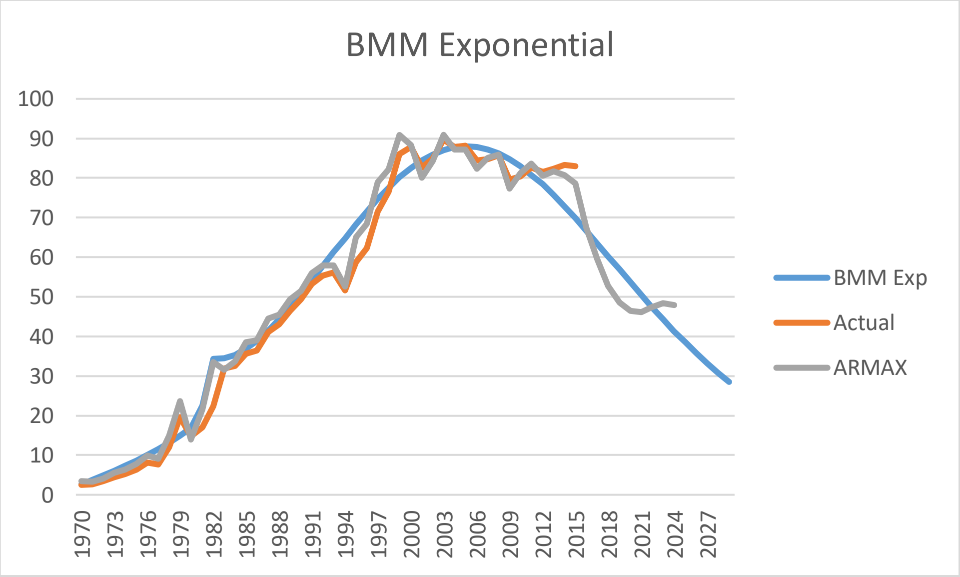
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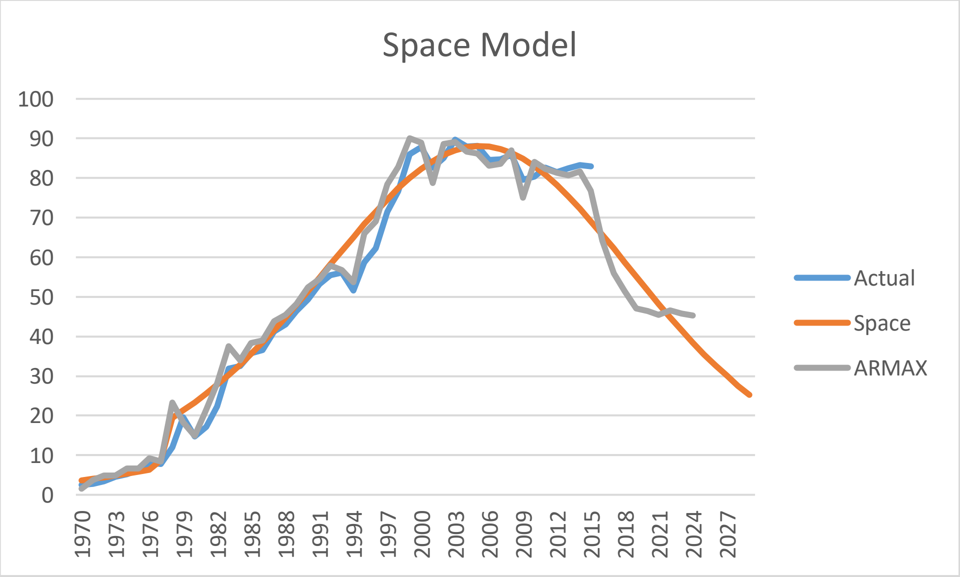
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Space
ARMAX

CONCLUSIONS

In the first part of the thesis the focus was on the description of the general energy market. The major results are the firm shift in energy consumption towards Asiatic countries and the decline in energy demand of Europe.

The implementation of the liquefied natural gas (LNG) technology has allowed many geographically peripheral countries, such as Japan and Qatar, to benefit of this flexible solution to manage their needs of natural gas, both for import and export aims. The pipeline gas has a rigid structure with long term contracts between the counterparties and the LNG has the possibility to increase the spot transactions smoothing out gas prices in different regions of the world.

In developed countries, natural gas seems to be the energy source of the future along with renewables, instead in developing regions, especially China and India, oil and coal are the major source of energy production.

Recent directives from Europe push towards a higher utilization of natural gas and renewables, trying to diversify European suppliers, for example a new interesting gas producer is the Caspian Region, and creating a more interconnected gas market inside Europe.

Then the analysis is focalized on Algeria, a long-standing supplier of natural gas for Europe, especially for Italy and Spain. I have described its energy market and its major problem that will affect its energy policy in the near future: gas production is plateaued while internal gas demand is sharply increasing. This fact will compromise the export of natural gas, which is the major source of state revenues, therefore creating a risky situation for the Government that currently grants sizeable welfare spending in turn funded by energy export revenues. Thus, recent energy policies suggest to increase the development of renewable resources trying to preserve falling gas reserves.

Then, I have showed an empirical application of a class of statistical models called “diffusion models”. The decision to exploit these statistical tools relies on the alleged intrinsic features of the time series under consideration. Starting from a visual analysis of the observable time series, that suggests a process coherent with the shape of diffusion models, I have proposed several data generating processes to fit the realisations. Each model exploited in this thesis has specific characteristics that distinguish it from others, therefore the correct analysis procedure should involve the specification of several models and then, based on statistical tests and indexes, evaluate their soundness.

In this work, I have implemented ten models. There are four basic specifications: the standard Bass, the standard Bemmaor, the Modified Bemmaor Model and the Space model, and for each of them, except for the latter, two nested models are proposed, that is the rectangular and exponential shock. The specification of each of them is obtained with the non-linear least square procedure and the results are reported in the table showed in the previous chapter. The estimate of each parameter is presented with the related confidence interval to test its stability.

All the models share the same *a priori* hypothesis of closed life cycle, which is the most important feature to take into consideration dealing with these statistical applications. Whatever the value of the parameter estimates, sooner or later the cycle will end up and this can be hard to reconcile with the actual behaviour of the series. This is clear in the case of Algeria's gas production, because the process shows an unexpected path in the final part of the observed period, which is difficult to manage with diffusion processes alone. In fact, all the models, some more some less, fail to recognise the final horizontal path. Besides the closed life cycle, another constraint affects the stand-alone diffusion models, that is its deterministic form: in other words, a diffusion process is a mathematical formula that do not involve any stochastic behaviour. Dealing with phenomenon such as the diffusion of a product implies the interconnection with other variables, considered explicitly or not in the formulation, and the result is that the actual series can show unexpected movements difficult to handle with the deterministic model alone that describes only the mean trajectory.

It is for this reason that the introduction of statistical tools able to recognise the stochastic features of the series is crucial. In this work, I have employed ARMAX model, where the exogenous variable is the mean diffusion process specified in the first step of the analysis. Interesting level of fitting are reached for most of the models involved after this refinement but, above all, the greatest contribution is in the problematic final part of the observable time series. Looking at the graphs reported in the previous chapter, is clear how the ARMAX allows the predicted series to follow more closely the actual series, gaining higher level for the determination coefficient. Notwithstanding the plug-in of the ARMAX, the *a priori* hypothesis has not changed: in other words, the recognition of stochastic structures in the process does not change the general architecture of the diffusion model.

The aim of developing statistical models is to gather insights about an event and possibly retrieve forecasts. The graphs showed before go well beyond the current date, thus they help in defining a future scenario for gas production. According to the specific model, the shape of the deterministic curve changes, anticipating or delaying the definitive closure of the life cycle.

The specification that closes more rapidly the life cycle is the standard Bass and its nested models, maybe because of the rigidity imposed by the symmetry of the curve. The standard Bemmaor, which has an elevated asymmetry parameter, suggests a closure that goes very far in time and it is the most elevated among all the specifications. Its nested models reduce their asymmetry but the predicted closures remain higher than the Bass specifications.

The Modified Bemmaor models have comparable closure time with respect to Bemmaor models so these estimates confirm each other. Moreover, the Space model, which does not have asymmetry parameters, strengthens the estimates retrieved with the two previous classes, setting aside the results of Bass.

Having outputs that corroborate each other is a good fact in terms of validation of the results but this does not mean that the specifications are free from drawbacks. I want to highlight what is, in my opinion, the major source of uncertainty in carrying out an analysis like this: I have implemented several models that permit to investigate many features of the population but, anyway, they belong to the same class of models. It means that the point of view from which we approach the problem is the same despite the sizeable number of models involved. In order to gain a broader understanding of the problem we are facing, is necessary to undertake a, let’s say, multilateral approach: with this definition, I mean that different approaches lead to different solutions and the ability of the researcher is to select the relevant information that each approach can supply. Looking at the problems from different perspectives open the possibility to explore solutions that have different *a priori* hypothesis so is possible to differentiate the risks of possible bias stemming from the utilization of models that share the same assumptions.

Anyway, the aim of this thesis is to show an application of how diffusion models work; certainly, this approach is interesting and useful but if the aim of the analyst would be the development of a policy measure, several approaches, not just several models, should be considered in order to apply a research procedure that encompasses many points of view broadening the spectrum of possible solutions.

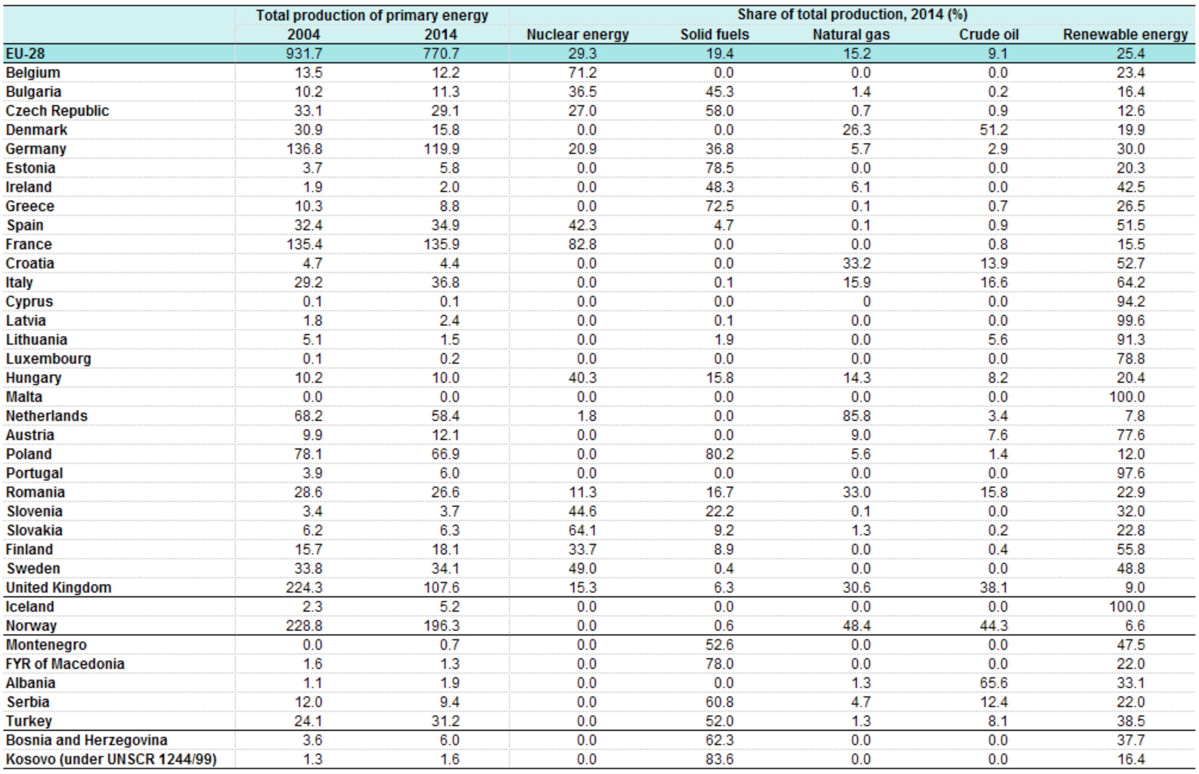
I have tried to do so, describing the general energy situation, the possible trends and energy policies that will drive the evolution of the future energy market and put them together with the results of the diffusion models. In my opinion, the facts surrounding the Algeria’s situation are good indications of a looming decline of gas production. The inaccessibility, for the moment, of new gas fields and the overproduction in past years of the giant Hassi R’Mel can have negative impact for the future, corroborating the output of the quantitative analysis.

But, as reported in the dedicated section, Algeria has a huge estimated amount of shale gas resources which cannot be used at least for the moment. Nothing assures that in the future these reserves will be exploited, changing the path of production of natural gas disregarding the forecasts of the models; moreover, natural gas could see a strong increase in its demand, because of lower pollution with respect to oil, and Algeria could tap this to spur new field researches and ameliorate its infrastructures so that also distant discoveries can be used.

In conclusion, the future is partially unwritten and these models can “observe” only the past, therefore future energy policy cannot be completely predicted, despite they could be important game changer for the future of Algeria. Anyway, the energy policies under way, directed towards renewables and not towards shale gas, support the forecasts obtained with diffusion models corroborating the results of this thesis.

APPENDIX

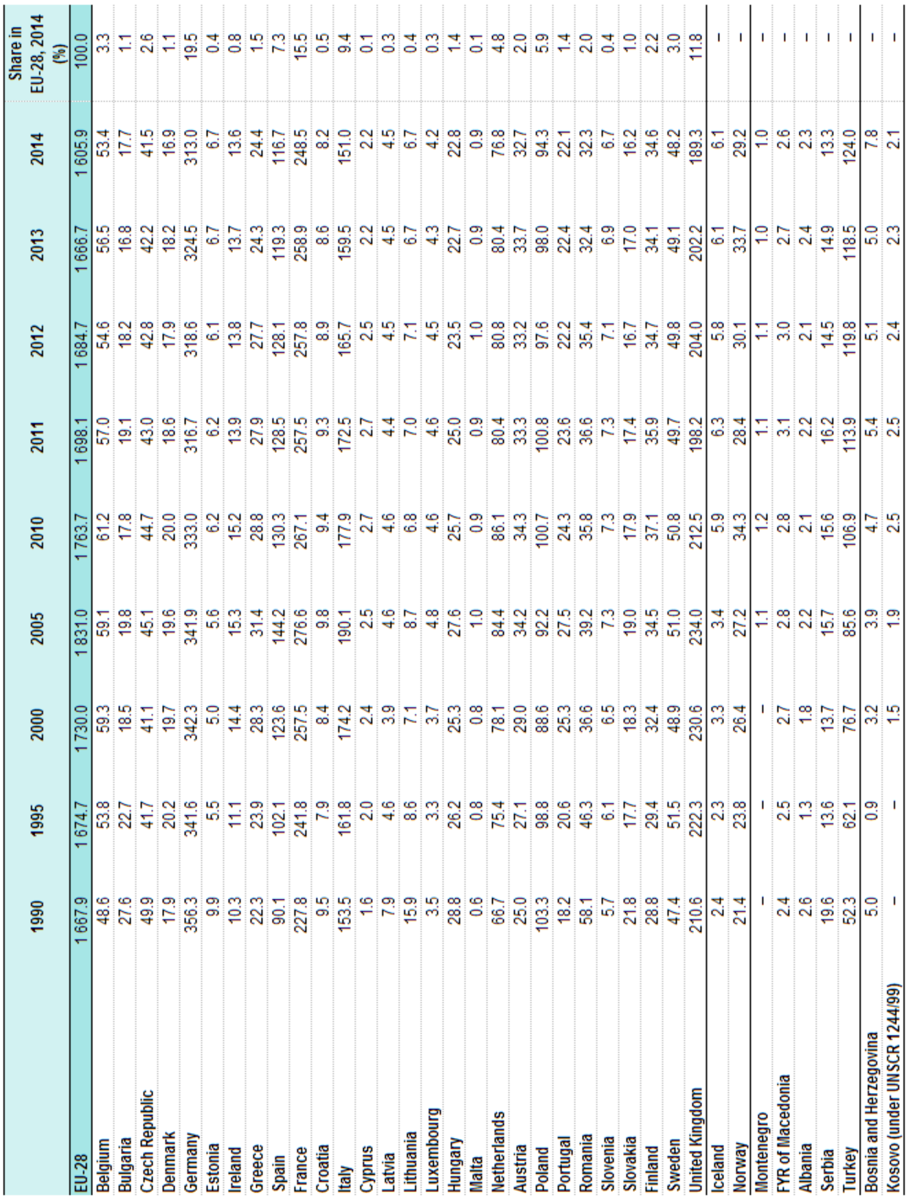
Appendix 1: Energy Production in Europe (Billion toe)



	Total production of primary energy		Share of total production, 2014 (%)				
	2004	2014	Nuclear energy	Solid fuels	Natural gas	Crude oil	Renewable energy
EU-28	931.7	770.7	29.3	19.4	15.2	9.1	25.4
Belgium	13.5	12.2	71.2	0.0	0.0	0.0	23.4
Bulgaria	10.2	11.3	36.5	45.3	1.4	0.2	16.4
Czech Republic	33.1	29.1	27.0	58.0	0.7	0.9	12.6
Denmark	30.9	15.8	0.0	0.0	26.3	51.2	19.9
Germany	136.8	119.9	20.9	36.8	5.7	2.9	30.0
Estonia	3.7	5.8	0.0	78.5	0.0	0.0	20.3
Ireland	1.9	2.0	0.0	48.3	6.1	0.0	42.5
Greece	10.3	8.8	0.0	72.5	0.1	0.7	26.5
Spain	32.4	34.9	42.3	4.7	0.1	0.9	51.5
France	135.4	135.9	82.8	0.0	0.0	0.8	15.5
Croatia	4.7	4.4	0.0	0.0	33.2	13.9	52.7
Italy	29.2	36.8	0.0	0.1	15.9	16.6	64.2
Cyprus	0.1	0.1	0.0	0.0	0	0.0	94.2
Latvia	1.8	2.4	0.0	0.1	0.0	0.0	99.6
Lithuania	5.1	1.5	0.0	1.9	0.0	5.6	91.3
Luxembourg	0.1	0.2	0.0	0.0	0.0	0.0	78.8
Hungary	10.2	10.0	40.3	15.8	14.3	8.2	20.4
Malta	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Netherlands	68.2	58.4	1.8	0.0	85.8	3.4	7.8
Austria	9.9	12.1	0.0	0.0	9.0	7.6	77.6
Poland	78.1	66.9	0.0	80.2	5.6	1.4	12.0
Portugal	3.9	6.0	0.0	0.0	0.0	0.0	97.6
Romania	28.6	26.6	11.3	16.7	33.0	15.8	22.9
Slovenia	3.4	3.7	44.6	22.2	0.1	0.0	32.0
Slovakia	6.2	6.3	64.1	9.2	1.3	0.2	22.8
Finland	15.7	18.1	33.7	8.9	0.0	0.4	55.8
Sweden	33.8	34.1	49.0	0.4	0.0	0.0	48.8
United Kingdom	224.3	107.6	15.3	6.3	30.6	38.1	9.0
Iceland	2.3	5.2	0.0	0.0	0.0	0.0	100.0
Norway	228.8	196.3	0.0	0.6	48.4	44.3	6.6
Montenegro	0.0	0.7	0.0	52.6	0.0	0.0	47.5
FYR of Macedonia	1.6	1.3	0.0	78.0	0.0	0.0	22.0
Albania	1.1	1.9	0.0	0.0	1.3	65.6	33.1
Serbia	12.0	9.4	0.0	60.8	4.7	12.4	22.0
Turkey	24.1	31.2	0.0	52.0	1.3	8.1	38.5
Bosnia and Herzegovina	3.6	6.0	0.0	62.3	0.0	0.0	37.7
Kosovo (under UNSCR 1244/99)	1.3	1.6	0.0	83.6	0.0	0.0	16.4

Source: Eurostat (2016)

Appendix 2: Energy Consumption in Europe (Billion toe)



	1990	1995	2000	2005	2010	2011	2012	2013	2014	Share in EU-28, 2014 (%)
EU-28	1 667.9	1 674.7	1 730.0	1 831.0	1 763.7	1 698.1	1 684.7	1 666.7	1 605.9	100.0
Belgium	48.6	53.8	59.3	59.1	61.2	57.0	54.6	56.5	53.4	3.3
Bulgaria	27.6	22.7	18.5	19.8	17.8	19.1	18.2	16.8	17.7	1.1
Czech Republic	49.9	41.7	41.1	45.1	44.7	43.0	42.8	42.2	41.5	2.6
Denmark	17.9	20.2	19.7	19.6	20.0	18.6	17.9	18.2	16.9	1.1
Germany	356.3	341.6	342.3	341.9	333.0	316.7	318.6	324.5	313.0	19.5
Estonia	9.9	5.5	5.0	5.6	6.2	6.2	6.1	6.7	6.7	0.4
Ireland	10.3	11.1	14.4	15.3	15.2	13.9	13.8	13.7	13.6	0.8
Greece	22.3	23.9	28.3	31.4	28.8	27.9	27.7	24.3	24.4	1.5
Spain	90.1	102.1	123.6	144.2	130.3	128.5	128.1	119.3	116.7	7.3
France	227.8	241.8	257.5	276.6	267.1	257.5	257.8	258.9	248.5	15.5
Croatia	9.5	7.9	8.4	9.8	9.4	9.3	8.9	8.6	8.2	0.5
Italy	153.5	161.8	174.2	190.1	177.9	172.5	165.7	159.5	151.0	9.4
Cyprus	1.6	2.0	2.4	2.5	2.7	2.7	2.5	2.2	2.2	0.1
Latvia	7.9	4.6	3.9	4.6	4.6	4.4	4.5	4.5	4.5	0.3
Lithuania	15.9	8.6	7.1	8.7	6.8	7.0	7.1	6.7	6.7	0.4
Luxembourg	3.5	3.3	3.7	4.8	4.6	4.6	4.5	4.3	4.2	0.3
Hungary	28.8	26.2	25.3	27.6	25.7	25.0	23.5	22.7	22.8	1.4
Malta	0.6	0.8	0.8	1.0	0.9	0.9	1.0	0.9	0.9	0.1
Netherlands	66.7	75.4	78.1	84.4	86.1	80.4	80.8	80.4	76.8	4.8
Austria	25.0	27.1	29.0	34.2	34.3	33.3	33.2	33.7	32.7	2.0
Poland	103.3	98.8	88.6	92.2	100.7	100.8	97.6	98.0	94.3	5.9
Portugal	18.2	20.6	25.3	27.5	24.3	23.6	22.2	22.4	22.1	1.4
Romania	58.1	46.3	36.6	39.2	35.8	36.6	35.4	32.4	32.3	2.0
Slovenia	5.7	6.1	6.5	7.3	7.3	7.3	7.1	6.9	6.7	0.4
Slovakia	21.8	17.7	18.3	19.0	17.9	17.4	16.7	17.0	16.2	1.0
Finland	28.8	29.4	32.4	34.5	37.1	35.9	34.7	34.1	34.6	2.2
Sweden	47.4	51.5	48.9	51.0	50.8	49.7	49.8	49.1	48.2	3.0
United Kingdom	210.6	222.3	230.6	234.0	212.5	198.2	204.0	202.2	189.3	11.8
Iceland	2.4	2.3	3.3	3.4	5.9	6.3	5.8	6.1	6.1	–
Norway	21.4	23.8	26.4	27.2	34.3	28.4	30.1	33.7	29.2	–
Montenegro	–	–	–	1.1	1.2	1.1	1.1	1.0	1.0	–
FYR of Macedonia	2.4	2.5	2.7	2.8	2.8	3.1	3.0	2.7	2.6	–
Albania	2.6	1.3	1.8	2.2	2.1	2.2	2.1	2.4	2.3	–
Serbia	19.6	13.6	13.7	15.7	15.6	16.2	14.5	14.9	13.3	–
Turkey	52.3	62.1	76.7	85.6	106.9	113.9	119.8	118.5	124.0	–
Bosnia and Herzegovina	5.0	0.9	3.2	3.9	4.7	5.4	5.1	5.0	7.8	–
Kosovo (under UNSCR 1244/99)	–	–	1.5	1.9	2.5	2.5	2.4	2.3	2.1	–

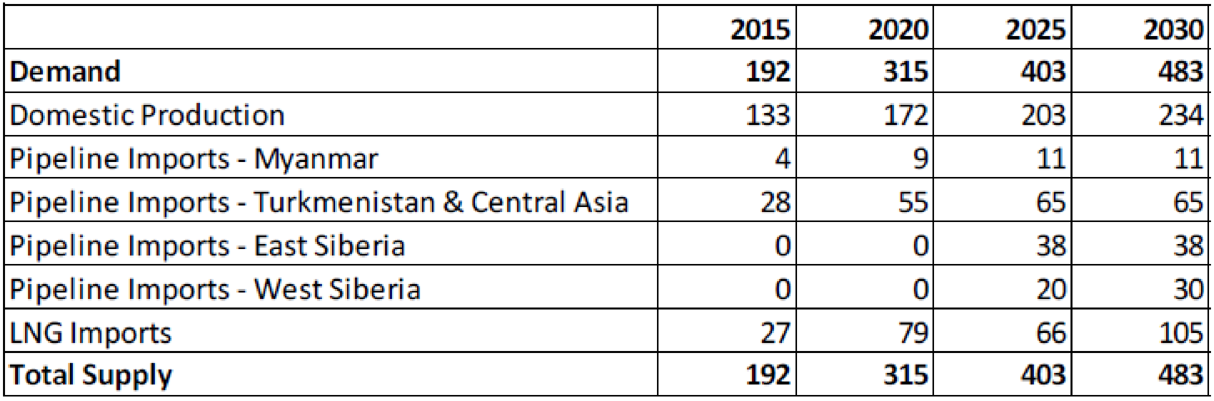
Source: Eurostat (2016)

Appendix 3.1: China Supply and Demand on Base Case Demand Assumptions (Bcm/y)

	2015	**2020**	**2025**	**2030**
Demand	**192**	**285**	**350**	**418**
Domestic Production	133	172	203	234
Pipeline Imports - Myanmar	4	9	11	11
Pipeline Imports - Turkmenistan & Central Asia	28	50	60	60
Pipeline Imports - East Siberia	0	0	30	38
Pipeline Imports - West Siberia	0	0	0	0
LNG Imports	27	54	46	75
Total Supply	**192**	**285**	**350**	**418**

Source: Rogers (2016)

Appendix 3.2: China Supply and Demand on High Case Demand Assumption (Bcm/y)



	2015	2020	2025	2030
Demand	**192**	**315**	**403**	**483**
Domestic Production	133	172	203	234
Pipeline Imports - Myanmar	4	9	11	11
Pipeline Imports - Turkmenistan & Central Asia	28	55	65	65
Pipeline Imports - East Siberia	0	0	38	38
Pipeline Imports - West Siberia	0	0	20	30
LNG Imports	27	79	66	105
Total Supply	**192**	**315**	**403**	**483**

Source: Rogers (2016)

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