Natural Gas Shortage Dynamics in Argentina

Investigating Argentinian natural gas demand and supply patterns and shortage causes using a system dynamics approach

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This paper presents a system dynamics model of Argentina's gas industry. Through our analysis we explore various factors affecting supply and demand of natural gas and analyze causes of gas shortages in Argentina. Our analysis shows that the wellhead price of gas in Argentina seems to be the main driver of supply and demand and higher-price imports may be preferred in times of economic upheaval and increased per capita consumption as opposed to local exploration, financially regulated by the government.

1. Introduction

Argentina had a major economic crisis in 2001 (Recalde 2011). At this time, the Law of Economic Crisis was issued freezing all energy prices, including the wellhead price which is the price received by local producers for their natural gas production. This tariff freeze has been present ever since (2012). Additionally, Argentina is highly dependent on natural gas (it is around 52% of the energy mix). The result of the situation is recurrent gas shortages that affect especially the supply to the industry and power sectors (O'Keefe 2007).

Growing imports with an average LNG price of 18 USD/MMBTU versus the 2.2 USD/MMBTU paid to local production (2012) are insufficient to fulfill a growing demand that results from the relative value depreciation of the good. Particularly, because of dispatch priorities, the retail sector grows at the expense of the industrial sector. Power plants and industries see their gas supply stopped when there are circumstances (e.g. low temperatures, delay in the arrival of LNG cargo) that may threaten the demand requirements of the retail sector (residential and commercial demand) impacting the industrial activity, and as a result, the economy as a whole. In 2012, the number of equivalent days of gas cuts to the industry and power plants surpassed the 100 days (Nagayama and Kashiwagi 2007).

At the end of 1992, the energy sector in Argentina was privatized providing the companies a License Agreement for 35 years, including the natural gas industry (production, transportation and distribution). Most data is available, at the earliest, from this point and on. The regulatory framework of the business was ruled by the License Agreements that provided clear guidelines regarding pricing. The wellhead price (the natural gas itself) was a pass-through component of the tariff while distribution and transportation tariffs were also adjusted by an efficiency factor and an investment factor. However, in 2002, the Law of Economic Crisis changed the rules of the game in the energy sector in Argentina; even though companies remained private, the License Agreements stopped being the regulatory framework of the industry. Instead, all the prices were fixed including the wellhead price, the transportation tariff and the distribution tariff. In this context, Argentina started to import natural gas from Bolivia and, later, LNG.

In this paper, we present a system dynamics model that explores the dynamics of natural gas supply and demand in Argentina, and we identify policies that could be implemented to alleviate the effects or eliminate the gas shortages in Argentina.

2. Modeling Framework

Due to the dynamic and complex nature of the described problem, with many types of interacting socio-technical and physical systems, it seems feasible to use a system dynamics modeling approach in order to account for the dynamic nature of the involved quantities. One of the anchor works in natural resources modeling using system dynamics is that of (Sterman and Richardson 1984), while specifically for gas resources is the work of Chi (2009) in a study done about the UK. Since the natural gas industry is closely tied with the electric power sector, Ford's Jay W. Forrester Prize lecture (1996) has also been studied. The problem of industry regulation is studied in (KADOYA, et al. 2005) while a case study specifically for Argentina is presented in (Ponzo, et al. 2011) and (Artana, Navajas and Urbiztondo 2001). An analysis of utilizing system dynamics for decision making support for natural resources has been presented by Dyner in (Dyner 2000), and a more specific example of Argentina is treated in (Olaya and Dyner 2005) and (Nagayama and Kashiwagi 2007).

Likewise, we assume that the natural gas industry in Argentina is composed of three sectors: exploration and extraction, transportation and distribution.

In our model, however, transportation and distribution industry will be excluded for model simplification. Undiscovered reserves which are the total volume of natural gas expected to be found in the future is excluded. Technological innovations that can accelerate the extraction are not considered and thus, unit cost of extraction is also not part of our model.

In addition, we presumed the following assumption to build our model:

- The willingness to invest in exploration is assumed to be proportional to its sales revenues just as Chi (2009) presents.
- Population growths at a constant rate (1% per year, this is the growth rate between the 2001 and the 2010 census).
- As natural gas is a pass-through component of the tariff, we assume that the consumption per capita is decreased by an increase in the wellhead price.
- The adjustment time for the discovery rate in Argentina is assumed to be 7 years. Chi (2009) estimates for the case of natural gas industry in UK a delay between discovery and investment for extraction as 4-5 years.
- Undiscovered reserves are outside of our model boundaries and are considered 0.
- Production rate is only the sum of fraction of discovered reserves and desired demand.
- We are modeling the desired demand (not actual demand which will be always equal to the total natural gas supply) and the gas shortage as the gap between the desired demand and the supply. As a result, the economic growth, temperature and population assumed to be the main variables that determine the evolution of the desired demand.

The main variables used to describe the dynamics of natural gas industry in Argentina are listed in Table 1. The endogenous variables are the supply and demand of natural gas industry in Argentina, and the exogenous variables such as population growth rate, GDP growth rate and prices are given as a constants or historical tables.

Table 1: Model boundaries

Module	Endogenous	Exogenous	Excluded
Supply	Total supply Production rate Discovery rate Discovered reserves Investment Imports Profit	Transportation capacity Unit cost of extraction Adjustment time Wellhead price Imports price	Transportation industry Distribution industry Undiscovered reserves Technological innovations in extraction Natural gas exports
Demand	Desired demand Consumption per capita Population	Temperature GDP growth Population growth rate	
	Natural gas shortage		

We have developed several reference modes were developed to understand the behavior of the gas industry in Argentina. These were then used to calibrate our model. Figure 1-7 illustrate historical variation of the following variables: natural gas local production, natural gas imports, natural gas reserves, per capita consumption of natural gas, natural gas prices, economic growth (GDP per capita), and temperature.

Figure 1 shows the production of natural gas in Argentina, which is the yearly amount of cubic meters of natural gas extracted from national territories. Natural gas production has increased 70% since the privatization of the energy industry. The growth comes mainly from a higher utilization factor which is triggered by an increasing desired demand that cannot be fulfilled by local production.

Figure 2 shows the evolution of natural gas imports in Argentina which started in 2001. The imports are composed of natural gas imported through pipelines from Bolivia and LNG that comes in cargoes from diverse countries (especially Trinidad and Tobago, but also Qatar, Nigeria and Spain)..

The imports (millions of cubic meters) from Bolivia are determined by a long-term contract although the price may be adjusted. The LNG imports are short-term (spot) purchases made by ENARSA (the government energy company in charge of purchasing and financing the imports of LNG) through a tender. In 2012, ENARSA tendered 81 cargoes (of 130 thousands of cubic meters of LNG each cargo) but bids were presented for less than 70 cargoes with prices as high as 25 USD/MMBTU (in comparison to 2.2 USD/MMBTU paid to local producers).

Figure 3 shows the depletion of the reserves (in millions of cubic meters) that started after the price freeze in 2001. This behavior was the result of a decreasing discovery rate and an increasing production.

As shown in Figure 4, the per capita consumption of natural gas grew 169% between 1993 and 2011. The per capita consumption of natural gas in Argentina (in cubic meters per person) isolates the effect of the population growth from the demand growth. It is important to consider that this is the reference mode for the actual demand and not necessarily the desired demand. As the actual demand also depends in the economic growth and temperature, its evolution can be used as an indicator for the desired per capita consumption.

The wellhead price has remained constant since the Law of Economic Crisis was issued in 2001. The specific data about the wellhead price for the 1990 decade was not available. For this reason, the reference mode was constructed for prices since 2001. The price of the natural gas imports has been increasing since the imports started, especially as LNG (the most expensive imports) has gained larger participation in the imports share. Figure 5 shows the evolution of both prices.

The reference mode for economic growth is shown in Figure 6, which is a determinant of the desired demand for natural gas.

The desired demand for natural gas is highly dependent on temperature. Cold winters boost demand showing high variations even when analyzing the data on a yearly basis. The gas industry uses the Heating Degree Day (HDD) as an accumulated measure of the heating requirements that result from low temperatures. The reference mode for Heating Degree Day per year is shown in Figure 7.

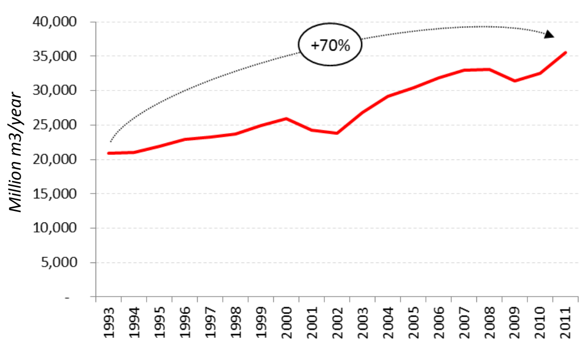

Figure 1: Natural gas production in Argentina (Source: ENARGAS)

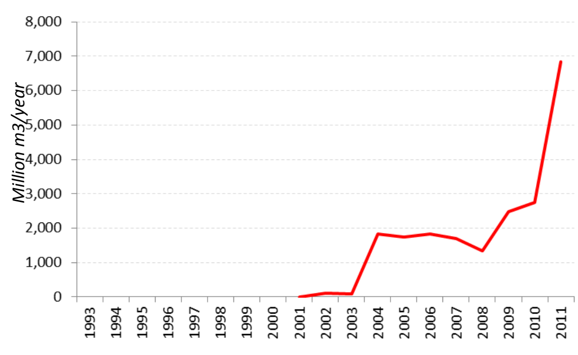

Figure 2: Natural gas imports in Argentina (Source: INDEC)

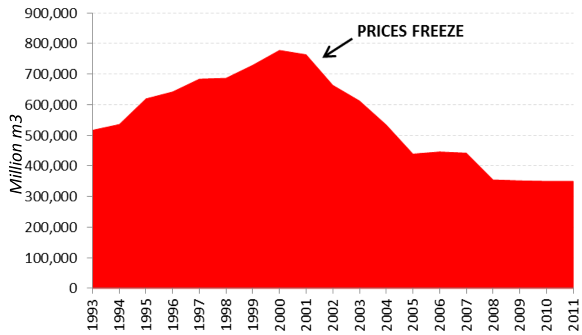

Figure 3: Natural gas reserves in Argentina (Source: IAPG)

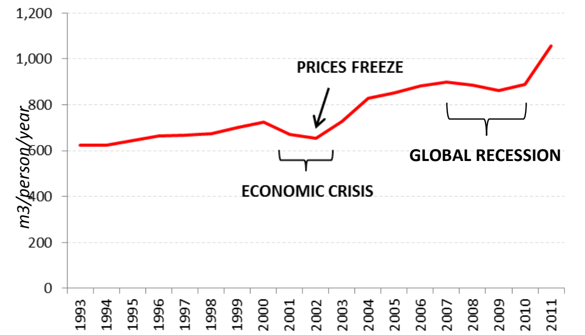

Figure 4: Per capita consumption of natural gas in Argentina (Sources: ENARGAS and INDEC)

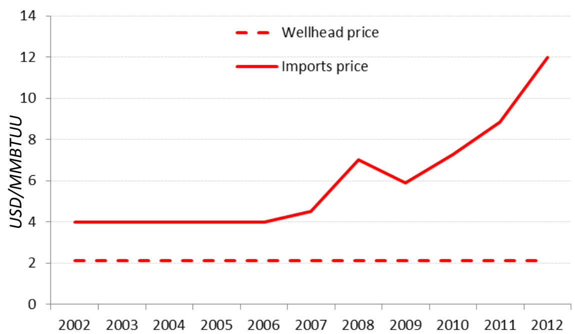

Figure 5: Imports price (Source: ENARGAS and ENARSA)

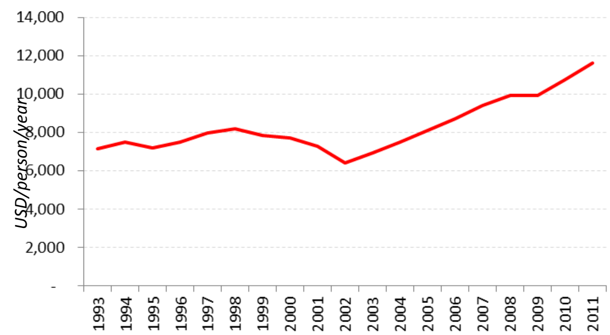

Figure 6: GDP per capita (Source: World Bank)

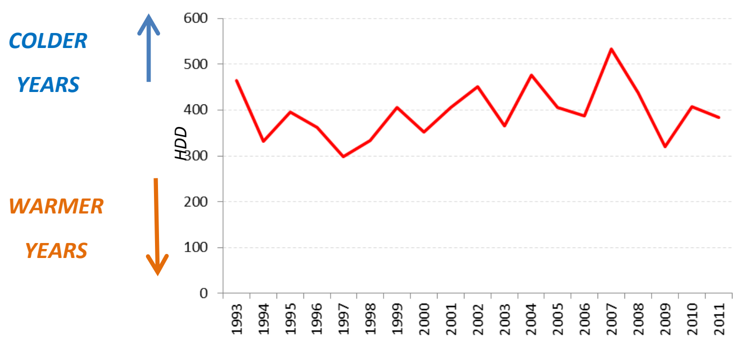

Figure 7: Heating Degree Days per year (Source: SMN)

3. The Gas Industry Dynamics in Argentina (GIDA) Model

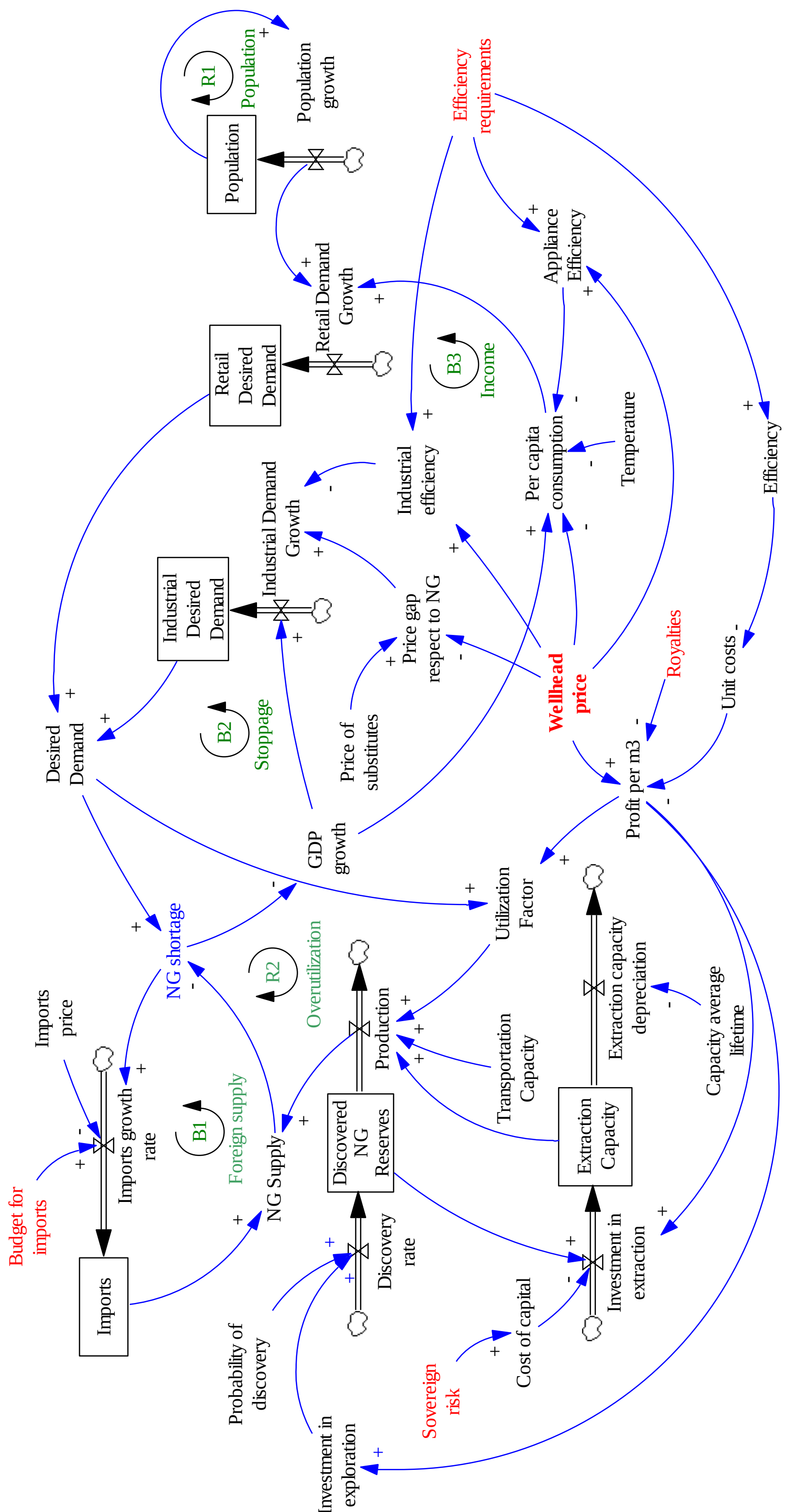

Figure 8: Main Stocks-and-Flow and Feedback Structures of the GIDA model

In his section we present the structure of the Gas Industry Dynamics of Argentina (GIDA) system dynamics model, which we developed in order to understand and describe the driving dynamics of demand and supply of the Argentinian gas market. The dynamics of the gas shortages can be mainly explained by the factors behind the supply and demand of gas in Argentina. An extensive description of the GIDA model can be found in Appendix 1, with downloadable executables in Appendix 2.

Demand Dynamics

The aggregate desired gas demand in Argentina is mainly constituted of the retail demand and the industrial desired demand. GDP is the main driver of both the industrial desired demand and retail desired demand, the higher the GDP the higher the consumption.

The industrial desired demand is also augmented by the price gap between the wellhead price of gas extraction and the price of gas substitutes in Argentina (diesel oil, coal, biomass) the increase in the price of substitutes in respect to the fixed wellhead price drives industries to prefer to use the cheaper gas for production and thus boosting the gas demand further.

What curbs the industrial demand is the efficiency of the industry which is driven by the respective efficiency requirements mandated by the government on the industries to control gas demand.

The consumption per capita and the population growth positively drive the growth in the retail demand stock.

Many factors affect the consumption per capita each year: the Wellhead price of gas extraction, the temperature (number of heating days per year in Argentina) and the efficiency of appliances used.

The cheaper the wellhead price the more consumption (current case now in Argentina). The increase in the number of heating days in a respective year will definitely increase the demand for gas for heating purposes thus driving the retail demand to go higher. The increase in the appliance efficiency, which would be increased if the government sets efficiency requirement on appliances supplied in the market) would reduce the consumption per capita due to gas usage reduction as a result of higher efficiency.

The aggregate increase in the desired demand will thus contribute in increasing the gas shortage in the country.

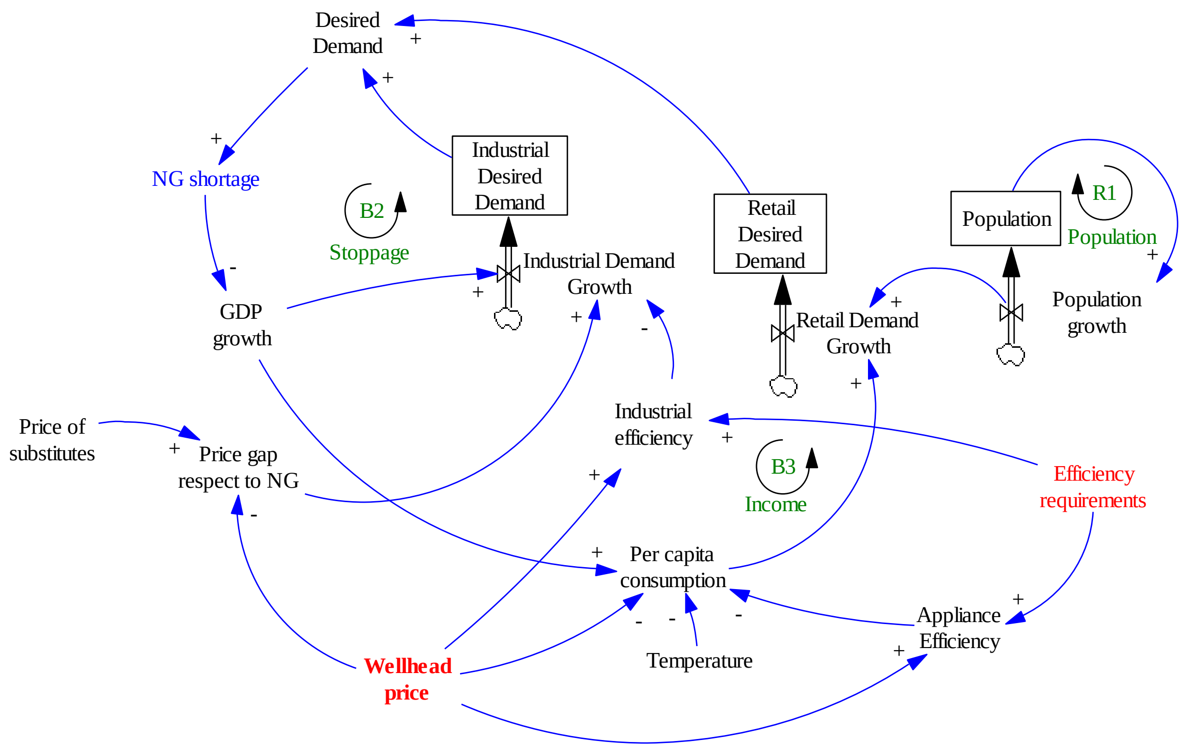

Figure 9: Demand dynamics

<u>Supply Dynamics</u>

Natural Gas supply in Argentina is the combination of the local production and the imports.

Foreign supply

The foreign supply is driven by the gas shortage; its dynamics has been previously explained while explain the main loops of the model.

Local supply

The local supply in this model is disaggregated into two main stocks and the variables affecting them: the extraction capacity and the discovered NG reserves.

The extraction capacity is increased of the "investment in extraction" inflow. In other words the more investment in the gas extraction sector, the more installed extraction capacity Argentina would have, resulting eventually in increasing the production rate. Investors would be less motivated to invest in gas extraction if the capital costs were too high, in which the decrease the corporation sovereignty, the sovereign risk (Government policies that threatens the security of a corporation inside a country, such expropriating corporation, canceling contracts, etc.).

The investment in extraction would increase by offering incentives to investors, basically by having a higher profit per m3 value for the extraction of the gas. The profit per m3 is increased by increasing the wellhead price, reducing the units cost (by increasing the efficiency of extraction technologies). The profit is decreased by royalties (taxes imposed on corporations which vary from province to province.)

The investment in extraction would also be increased by the increase of Argentina's discovered NG reserves.

The extraction capacity is decreased through the years by the depreciation of the installed technologies, determined by their "capacity average lifetime".

The discovered NG reserves stock is increased by the gas discovery rate and decreased by the outflow of the production. The discovery rate would increase by a higher probability of discovery, and by the increased investment in exploration driven by how much profit the investors would get.

In conclusion, the local production is determined by the desired demand (through the utilization factor), transportation capacity (the installed capacity of pipes transporting the gas from the wells to the city gates; which could be a restriction if not expanded according to the production capacity, in other words if the production capacity was more than what the transportation capacity, the production of gas would be limited to the transportation capacity) and the exploration rate.

The local production per year is increasing by the increased exploration capacity, increasing the utilization of the existing facilities (the utilization would be increased in the increase in the desired gas demand), and by increasing the transportation capacity.

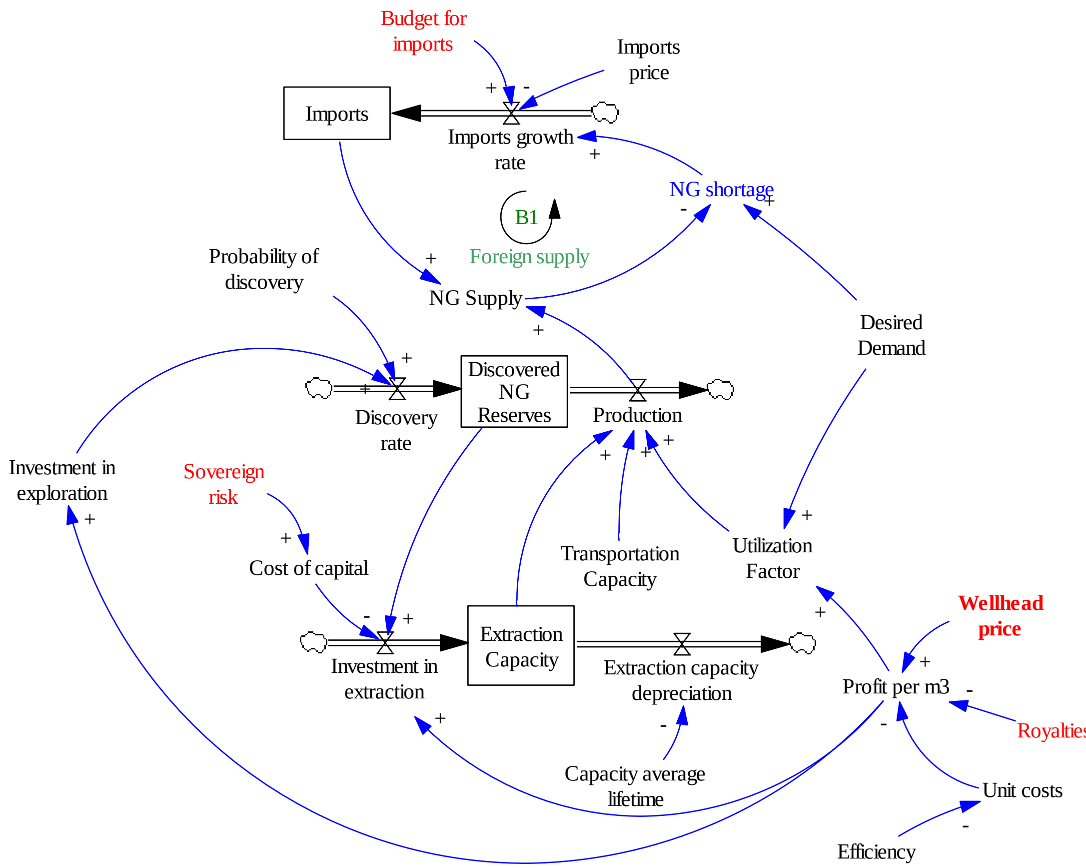

Figure 10: Supply dynamics

4. Model setup

Calibration

For detailed calibration results and model validation, please run the models found in Appendix 2. We have used a staged calibration approach, calibrating against historical values of the following variables:

- Production Rate
- Consumption Per Capita
- Imports
- Discovered Reserves

The graphical results of this process are presented below.

Simulation

In the following, we present the graphs of the reference case, simulated using the values and assumptions presented in Section 3.

The population growth rate in Argentina is 1% per year (INDEC) and we assume linear growth from the given initial value 36.26 million people in 2001. Population will affect the increase in desired demand of natural gas.

The desired demand is growing as population and consumption per capita grows. Desired demand has a very similar behavior with production rate. In 2012, current desired demand is 63,000 million m^3 and will grow up to 72,400 million m^3 which is equivalent to a 15% increase.

The production rate is showing gradual increase until the slight decrease occurs during the economic slow-down in 2008. Fixed and low price reduces the production efforts and the less production efforts and exploration decreases production. Current production (2012) is 30,000 million m^3 and will hover around the same values in our model which will not be sufficient to meet the desired demand without increasing imports in the given conditions.

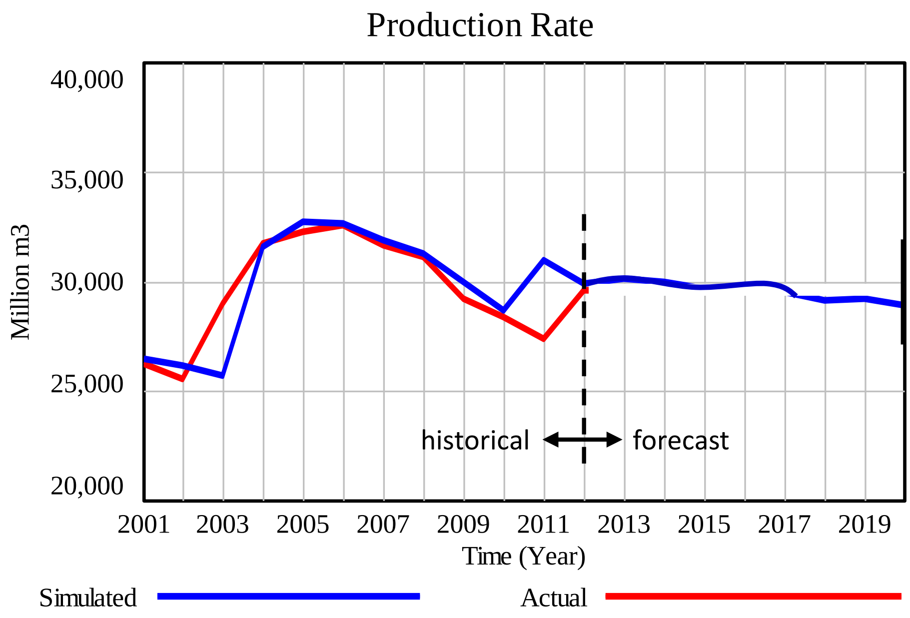

Figure 11: Natural gas production rate

The natural gas shortage is caused by the unmet demand. After increasing imports, gas shortage is decreasing and increases during the economic crisis. As natural gas shortage can be filled up by the imports, the higher shortage triggers more imports.

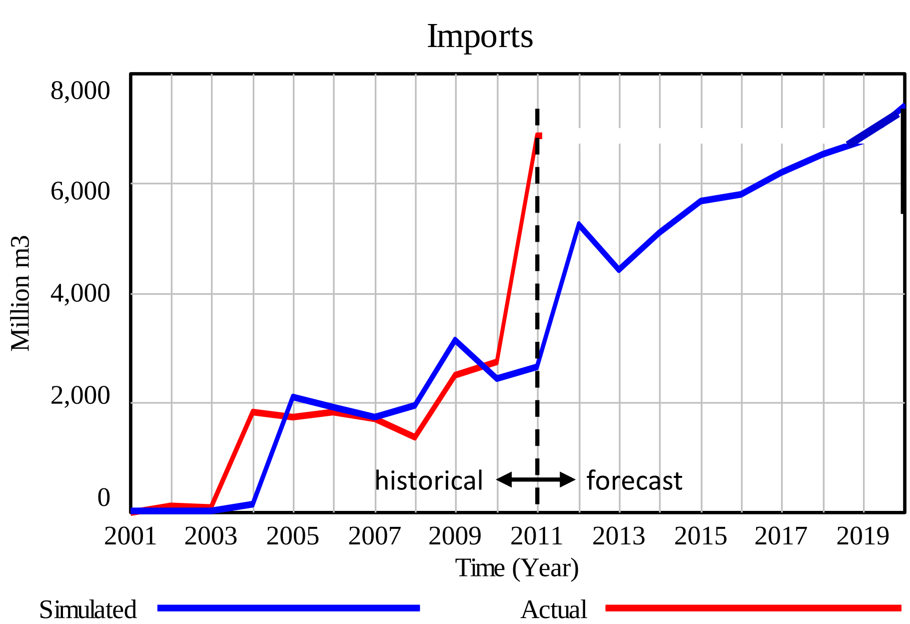

Figure 12: Natural gas imports

Since 2001, the imports started to increase which is similar to the real data. As imports started to begin Bolivian gas in 2004 and local production hit a plateau of 143 million m^3, local production itself was not enough to meet the peak demand. Thus, the government started to increase imports and this increasing tendency is shown in the graph. Also the sudden decrease captured in 2008 can be explained by economic crisis. From 2011 to 2012, the significant jump of the imports is affected by the reduced production. Reduced production leveled down the total supply and natural gas shortage increased. The increase in the shortage finally increased imports from 2011 to 2012. If the import price rises, imports should decrease due to the budget limitation, however, as the budget limitation is not included in the model, natural gas shortage and imports moves together.

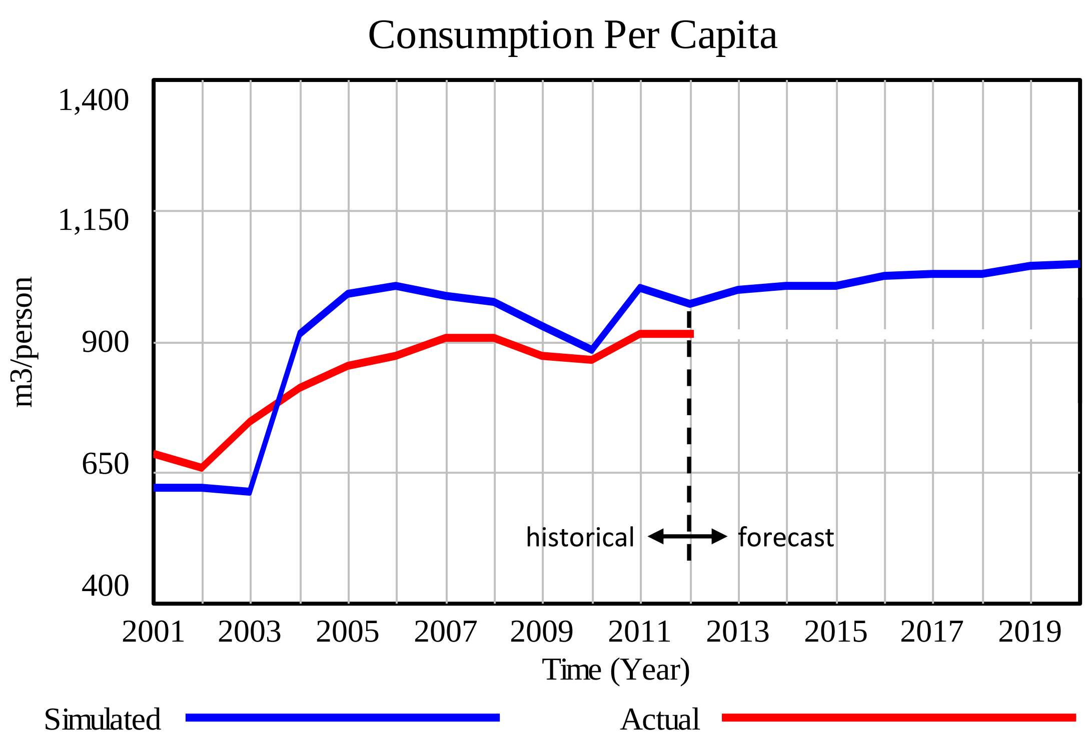

Figure 13: Per capita natural gas consumption

The consumption per capita increases according to the GDP growth and the temperature measured by average heating day based on the assumptions. As GDP growth rate was dropped to around 1% in 2010, the consumption per capita also decreased.

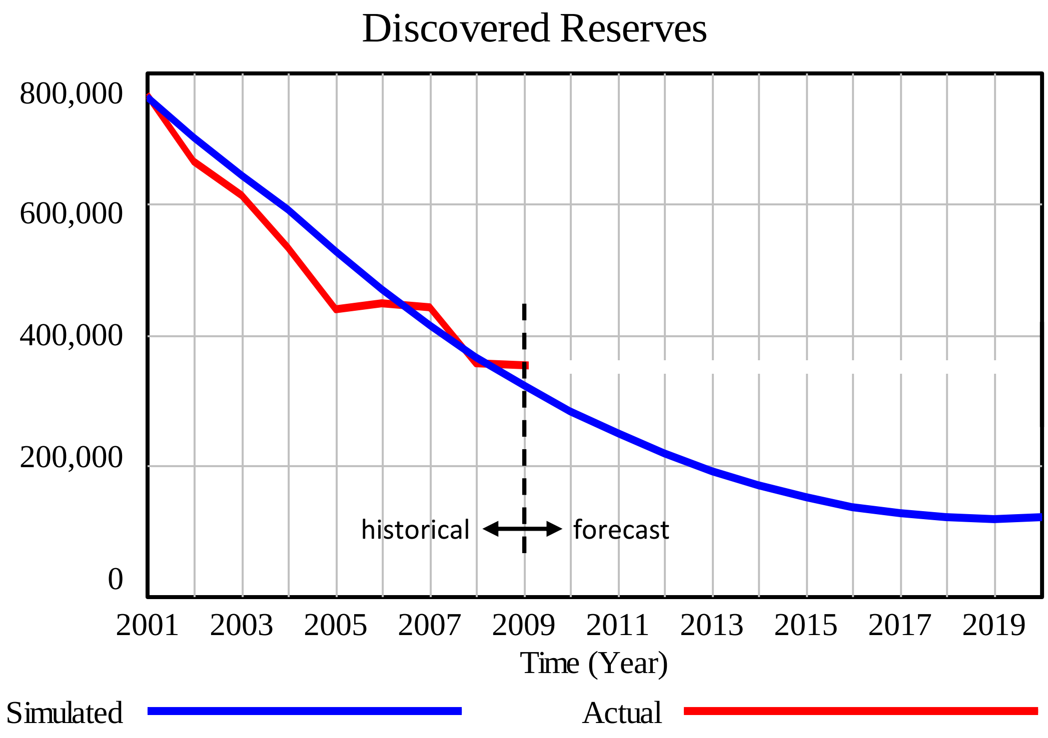

Figure 14: Discovered natural gas reserves

The discovery rate is estimated by the investment and the adjustment time (delay) which is 7 years in this case. Investment is exogenously given as a constant.

The higher the discovery rates we have, the less discovered reserves remains as the undiscovered reserves are not included in the model.

Investment started to increase steeply from 2002 and slowed down until 2008. Low price resulted in the low production, exploration and investment also decreased. From 2012, however, investment rate is showing linearly by 2020 which will drive the discovery rate.

Total supply for the natural gas is calculated as the sum of local production rate and the imports. In 2012, the total supply reached 42,400 million m^3 in a real data, and 35,000 million m^3 was projected in the model and grows around 38,000 million m^3 by 2020, due to a combination of stagnating or decreasing domestic production and increasing imports. In the meantime, demand increases significantly, leading to an ever bigger supply gap.

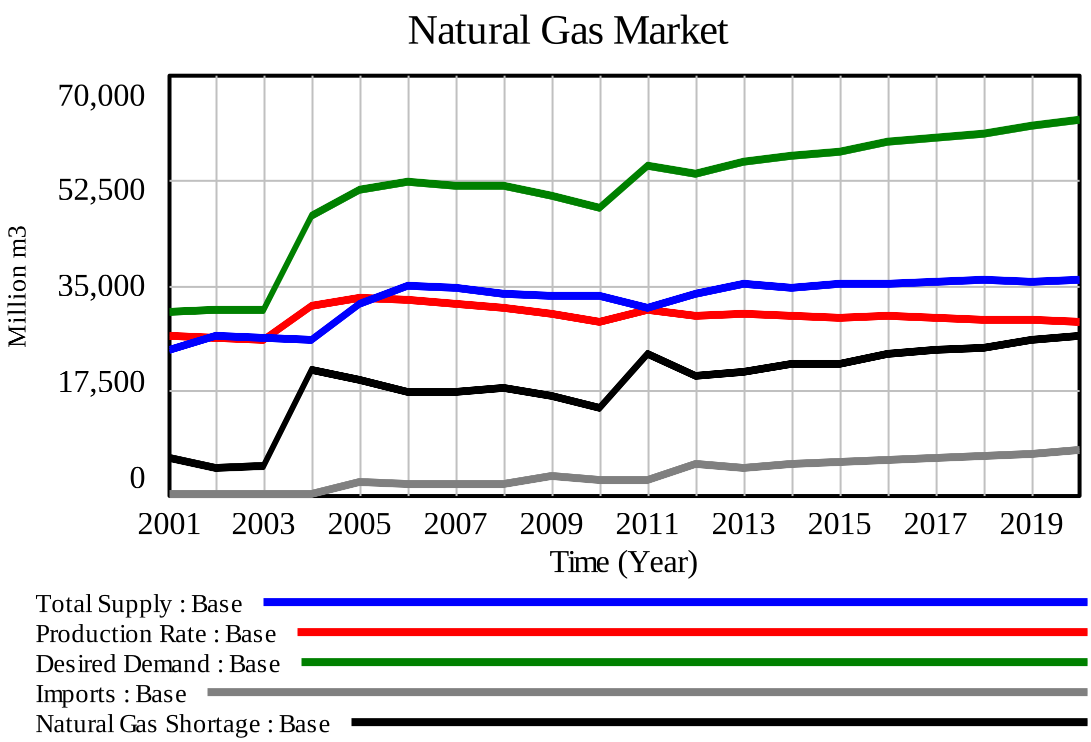

Figure 15: Argentinian natural gas market dynamics

5. Model dynamics

In order to study the Argentinian gas industry dynamics using the GIDA model, a sensitivity analysis of multiple parameters has been conducted. The key factors that were varied are: wellhead price, unit cost, adjustment time of the discover rate and Imports price, each variable was once decreased by 25% and increased 25% while the other variables remained constant.

To explore the dynamics of the model, we chose to analyze the Desired Demand, Discovered Reserves, Natural Gas Shortage, Production Rate, and Imports. The values of the variables at the end of year 2020 were taken into account to analyze the behavior of the model.

Table 2 demonstrates the results of our sensitivity analysis. As can be inferred from the table, increasing the wellhead price by 25% would decrease the desired demand and incentivize a higher production rate, thus decreasing the natural gas shortage and as a result imports needed would decrease also. This would ultimately lead to the increase of the existing reserves as a result of increasing discovery rates due to higher investment. Decreasing the wellhead price by 25 % would have the opposite effect of increasing the price by 25%.

Varying the unit cost by 25% will only affect the discovered reserves as a result of affecting the discovery rate, by increasing the unit cost by 25% the reserves would decrease and by decreasing the unit costs by 25% the reserves would increase.

On the other hand, varying the adjustment time by 25% only affects the discovered reserves and natural gas shortage. Increasing the adjustment time will consequently decrease the reserves through decreasing the discovery rate. On contrast, decreasing the adjustment time will consequently increase the reserves through increasing the discovery rate. Decreasing or increasing the adjustment time will result in reducing the gas shortage and this may show a flaw in our model because the production is not sensible enough to changes in reserves.

Increasing the imports price by 25 % will definitely decrease the imports and thus increasing the shortage while not affecting the other variables. Decreasing the imports price will have the opposite effect.

Table 2: Sensitivity analysis results

[M m^3]	2020 Desired Demand	2020 Discovered Reserves	2020 N. Gas Shortage	2020 Production Rate	2020 Imports
Base case	62373	450943	18827	38945	5395
Wellhead price (+25%)	46780	1129983	14311	51513	4087
Wellhead price (-25%)	77967	282967	21497	28933	6239
Unit cost (-25%)	62373	774450	19669	40563	5080
Unit cost (+25%)	62373	227805	17626	37829	5622
Adjustment time (-25%)	62373	686293	19249	40122	5164
Adjustment time (+25%)	62373	338626	17951	38383	5508
Imports price (-25%)	62373	450943	17910	38945	6419
Imports price (+25%)	62373	450943	19847	38945	4263

[M m^3]	2020 Desired Demand	2020 Discovered Reserves	2020 N. Gas Shortage	2020 Production Rate	2020 Imports
Base case	**0%**	**0%**	**0%**	**0%**	**0%**
Wellhead price (+25%)	**-33%**	+150%	-22%	32%	-23%
Wellhead price (-25%)	**20%**	-62%	14%	-26%	15%
Unit cost (-25%)	**0%**	71%	5%	3%	-6%
Unit cost (+25%)	**0%**	-50%	-5%	-3%	4%
Adjustment time (-25%)	**0%**	50%	5%	1%	-2%
Adjustment time (+25%)	**0%**	-25%	-5%	-1%	2%
Imports price (-25%)	**0%**	0%	-6%	0%	19%
Imports price (+25%)	**0%**	0%	6%	0%	-21%

6. Policy Recommendations

The GIDA model captures the main policy variable that is capable of regulating supply and demand forces in the natural gas market of Argentina: the wellhead price. As it was explained earlier, an increase in the wellhead price would moderate the natural gas shortages. From the demand side, a higher price would decrease the consumption per capita which diminishes the total desired demand and, as a consequence, the gas shortages. From the supply side, higher profits will increase the incentives of investing in the exploration and extraction sector which increases the discovery rate and therefore the discovered reserves. This allows a higher production level that decreases the gas shortage.

Expanding the model allows the incorporation of other type of policies than price driven ones (see Figure 8: Main Stocks-and-Flow and Feedback Structures). However, it is worth noting that the effects of an increase in the wellhead price as a policy also gains more power when the model is expanded:

- Modeling the retail and industrial (power plants and industries) demands separately allows the incorporation of inter-fuel substitution. The industrial demand of natural gas is very sensible to changes in the prices of natural gas in the case that the gap between the prices of the alternative fuels (such as diesel oil and coal) and the natural gas is not large. Fuel substitution has a high potential of decreasing the desired demand as it accounts for more than 50% of the national natural gas demand.
- A more expensive natural gas augments the incentives to increase the efficiency in the demand side for the industries (through the technology they use) and retail demand (through the

efficiency of the appliances). Some activities are vital in both sectors so the end-users will have incentives to minimize the costs of their natural gas consumption.

- In the supply side, the larger profits allow two main mechanisms to increase the total natural gas supply in Argentina. A the long-term effect (as it takes time to make new discoveries) is that investment in exploration is increased which allows a larger discovery rate that increases the local production of natural gas, increases the total supply and finally diminishes the gas shortages. In the short-term, since producers perceive a larger profit, they are incentivized to increase their utilization capacity and production can be also increased (although it implies a more rapid depletion of the reserves).

The wellhead price is the variable in the Argentinean natural gas industry that needs urgently to be revised. Actually, two years ago it was announced that all the new natural gas wells are going to be paid for their production 7.50 USD/MMBTU (versus the current 2.20 USD/MMBTU) in an effort to increase the local production. It is a good start for a situation that has been constantly denied by the national government but there has not been a clear communication of how the increase in going to be financed (since the Law of Economic Crisis is still in force, the tariffs are frozen even though the wellhead price is a pass-through component of the tariff). One of the biggest challenges in the implementation of an increase in the wellhead price is the current high inflation rates (near 30%). An increase in the energy costs (tariffs) hides the possibility of accelerating the inflationary process that Argentina is going through right now with very serious political costs in the case this occurs.

There are other policies that can be mentioned (and expected to be included in the final version) are:

- Efficiency requirements: Just as price may encourage efficiency in the demand-side, regulation that creates the requirement of a minimum level of efficiency of the appliances (retail demand) or technology (industrial demand) is capable of limiting and even decrease the total desired demand for natural gas. This type of policies requires that the government has a budget in order to plan, implement and, especially, control the program. The biggest challenge for the Argentinean case, besides getting the resources to finance the program, is the control. Other similar programs (although not for natural gas) such as the elimination of incandescent light bulbs have been implemented but the lack of control allows very easy access to this type of bulbs.
- Royalties: The provincial governments get a percentage of the wellhead price in the concept of royalties. In case the royalties are lowered, it would have a similar effect as a decrease in the unit

costs. Profits for the producers would be larger and the utilization factor of the industry increases as well as the investment (dynamics explained for an increase in the wellhead price). The implementation challenge of this policy is that the provincial governments are not willing to give up a very important source of their revenues just because the national government does not want to carry with the political costs of raising the wellhead price (political interests). This is actually a continuous argument that the provincial governments have with the national government.

- Budget for imports: If the national government increases the budget destined for natural gas imports, it would be possible to increase the imports and the natural gas shortage will be reduced. However, it is evident that this is not the most efficient way to go. This is not an economically sustainable policy and because LNG is purchased through a tender process where the cheapest bids are bought first and then moves on to more expensive ones, increasing the imports of LNG will just imply that the money needed to finance them grows more than increase in the quantities imported. Obviously, government financial resources are limited and this option is not feasible and, even if it was, it would not resolve the problem in the long-run.
- Sovereign risk: This variable is added as a policy variable that summarizes possible policies that affect the institutional aspect of the country. When the sovereign risk increases, it just makes the cost of capital higher and it is harder to get investors that are willing to invest in the sector (and the country as a whole). The decision of expropriating the largest natural gas producer in Argentina (Repsol) without any compensation or support from international organizations makes the situation worse. The Argentinean government does not have the financial resources to run the industry and investors are not interested in being part of a business where rules are continuously changing and have not been favorable at all for more than a decade. Unless contracts are respected and the rules of the game are consistently and thoroughly followed, an increase in the wellhead price will not be enough to attract investors to the sector.

7. Acknowledgements

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9. Appendixes and other supporting materials

For your convenience, all of the appendices can be found in the cloud folder http://tiny.cc/sdasia.

Here is a list of files that have been included in the cloud folder:

Nr.	Name	Type	Size (kb)
1.	Appendix 1	*.pdf, Portable Document Format file	238
2.	Appendix 2	*.zip, ZIP package containing 5 *.mdl files	11