VALUING THE FLEXIBILITY OF SWITCHING OUTPUTS IN A FERTILIZER PLANT

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ABSTRACT

Fertilizers are extremely important to agricultural production worldwide due to the productivity improvements in cropping that it allows. This paper uses the Real Options Theory to evaluate the switch-output option, ammonia or urea, in a nitrogen fertilizer plant. The Monte Carlo simulation method was used to define the value of the switch output option in a fertilizer plant where the uncertainties considered are the prices of natural gas (main raw material), ammonia and urea, all of them following a mean reversion movement – MRM – as stochastic process. The results show that the option of the investor is valuable.

Key Words: Real Options, Switch Option, Fertilizer, Monte Carlo simulation, Ammonia, Urea, Mean Reversion Model.

1. INTRODUTION

Fertilizers are substances that promote soil nutrition in order to increase agricultural productivity. These nutrients can have an organic origin, such as compost from animal and vegetable waste, or synthetic derived primarily from the mineral and petrochemical industry.

The main deficiencies found in soil are from chemical elements nitrogen (N), phosphorus (P) and potassium (K). From that arise the main compounds of NPK fertilizers that are sold in varying amounts of each of the three macronutrients according to the deficiency found in the soil. While phosphate and potassium fertilizers come from mineral reserves, nitrogenous fertilizers have natural gas as main raw material.

The relevance of this industry is the fact that it is essential for increasing productivity in agribusiness. The world scenario shows that both the production of fertilizer and its consumption are concentrated in a few countries. Production is concentrated due to the scarcity of natural resources that are used as the raw materials in the production process of the nutrients. Most of the demand, on the other hand, concentrates on countries that are major agricultural producers worldwide.

The fertilizer industry is capital intensive and requires high initial investment. The focus of this paper is in the production, by the petrochemical industry, of intermediate and basic nitrogen fertilizers - Urea and Ammonia – which have characteristics of commodities and serve as inputs for companies that distributes the compounds to the final consumer.

In the industrial process of a fertilizer plant, urea depends on the production of ammonia, however both commodities have market value. In other words, the manager may define which product will produce to maximize its outcome, considering the variations in the prices of its inputs and the final products market. It means that, depending on fluctuations on the prices of natural gas, ammonia and urea, it can be more profitable to sell ammonia instead of urea and vice-versa.

Given this dynamic of the fertilizer market and the great capital expenditure in a fertilizer plant, it is necessary to properly assess the value of the business. The Real Options Theory allows going beyond traditional discounted cash flow valuation methods, such as NPV and IRR, because it allows valuing the management flexibility that a real investment project has in an uncertain environment.

The purpose of this paper is to evaluate the switch-output option in a hypothetical fertilizer plant, which can produce either ammonia or urea, using Real Options. This appraisal is done using a Monte Carlo simulation approach to define the price paths that influence the project cash flow, following two different stochastic processes – GBM and MRM.

This paper is organized as follows. After this introductory section, the second section brings a literature review on the Real Option Theory. Then, the third section briefly overview of the fertilizer industry around the world and the brazilian scenario. In section 4 is presented the model and the parameters of the simulations that will be detailed in section 5. The sixth section presents the results of the simulations and a sensitiveness analyses and section 7 concludes.

2. REAL OPTIONS IN INVESTMENT PROJECTS

Traditional methods of discounted cash flow, despite being the most widespread and most easily applied in the evaluation of investment projects, do not capture the intrinsic flexibility characteristic of real assets. In other words, techniques such as Net Present Value (NPV) and Internal Rate of Return (IRR) are not suitable when the manager has options or alternatives to be taken in an environment of uncertainty.

Real Options Theory expands the possibilities of analysis of these traditional discounted cash flow methods as it allows real projects valuation to capture the value of the alternatives that managers actually face in their day to day decisions.

Dias (2014) classifies these alternatives, or real options, in three types – Investment (Timing), Operational and Learning. One type of real options in the Operational group is the Switch/Modifications, which are subdivided into Input, Output, Use and Location.

In this field, Bastian-Pinto, Brandão and Lemos (2009) assessed the value of the switch-input option of *flex fuel* cars in Brazil, a car that accepts both ethanol and gasoline as fuel.

Other example of switch option is brought by Brandão *et al* (2011), they conclude that the option to choose the input in the biofuels industry has value and that it is not captured by traditional methods of discounted cash flow.

In the sugar industry, Bastian *et al* (2009) found that in fact the option of switching outputs practiced by producers of sugar and ethanol has incremental value.

Other application can be found in Ozório *et al* (2013) that used Monte Carlo simulation to evaluate the option of switching outputs in the steel industry, where the uncertainties were the prices of different types of steel produced, in this case the price diffusion followed a Mean Reversion Model - MRM.

There are few studies in the literature about the use of real options in the fertilizer field. Among then Wang and Li (2009) assessed the value obtained by the flexibility of a urea plant in China by expanding the choice of primary feedstock (switching inputs), the plant may use fuel oil or natural gas as a raw material in the process. The authors conclude that the theory of real options can be used effectively to evaluate the decision to expand fertilizer plants.

Another example is the use of real options by Brazil, Aronne and Rajão (2011) to evaluate opportunities for expansion and verticalize of phosphate fertilizers production mine.

Also in fertilizer industry, Dockendorf and Paxson (2009) evaluated the option of switching outputs in a flexible plant fertilizer, as well as the value of the temporally suspend the production. They used an analytical method, which considered prices of urea and ammonia as the two variables of uncertainties, both following a geometric Brownian motion (GBM). The authors suggested as an research opportunity the replication of the study in which the variables follow other stochastic process, such a mean reversion movement- MRM.

This article, although have a similar aim of Dockendorf and Paxson (2009) research, differs in two aspects. The first is that in this paper a Monte Carlo simulation approach is used to define the risk neutral price path. Another important difference is that we add a third variable to study stochastic, Natural Gas. Natural gas is the principal raw material in the production process and much of the cost of production of nitrogen fertilizers depends on the price of this input. Thus, we consider in this paper the price of Natural Gas, Ammonia and Urea of behaving like an MGB and MRM, all correlated.

3. THE FERTILIZER MARKET

Fertilizers are of great importance to agriculture industry, as they are responsible for increasing agricultural productivity through enrichment of the quality of the soil for cropping.

As the main shortcomings of cropland are the nutrients nitrogen (N), phosphorus (P) and potassium (K), fertilizers widely produced and marketed are products composed by a mix of these three nutrients, called NPK. Figure 1 shows the global annual production of fertilizer nutrient for the period 1998 to 2011 which has a continuous growth over the years and nitrogen representing the largest share among the three nutrients, reaching 58% of total production in 2011.

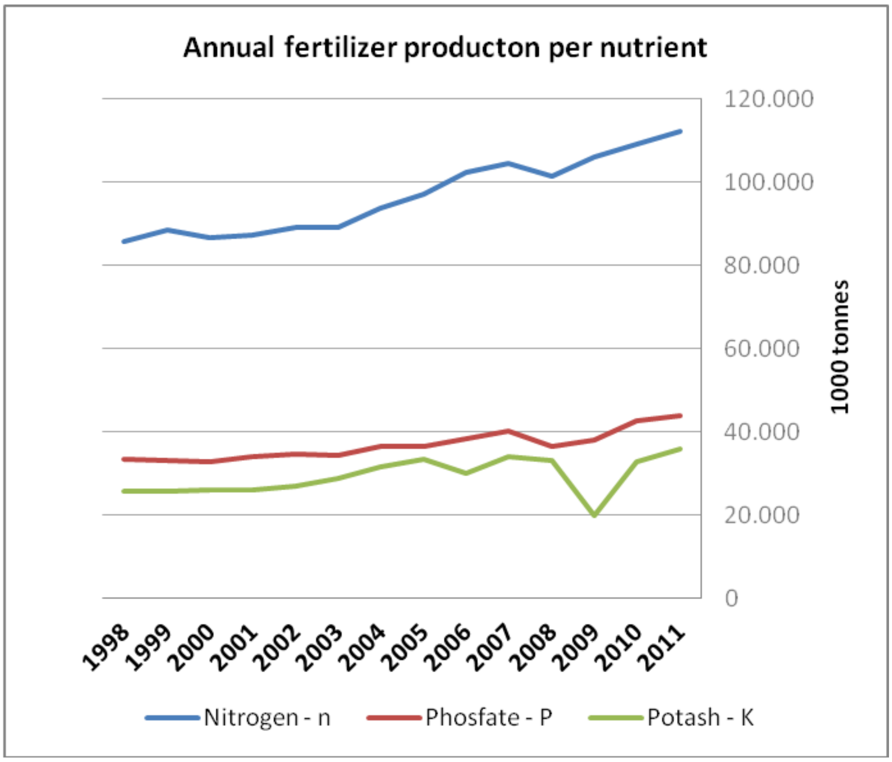


Figure 1: Total annual fertilizer production per nutrient. Source: IFA (International Fertilizer Industry Association)

To obtain these chemicals, industrial processes start from the exploitation of natural resources by mining activity and exploration of hydrocarbon reserves.

Nitrogen fertilizers raw materials are mainly natural gas. From a chemical process ammonia is obtained, which in turn can be commercialized as raw material for other industries, such as explosives, cleaning products and fiber and plastic, or go through various industrial processes producing basic fertilizers such as Urea, Ammonium Nitrate or ammonium phosphate - DAP and MAP.

3.1 WORLD FERTILIZER MARKET

According to IFA *(International Fertilizer Industry Association)*, the world's largest consumer of fertilizers are China, India, USA and Brazil. China also stands as the largest producer of nitrogen and phosphate, while the largest producer of potash fertilizers is Canada, followed by Russia. It is noted that both, production and consumption of fertilizers, are concentrated in a few countries.

The concentration of production of fertilizers is determined by the availability of mineral deposits that provide raw material for industrial processes. Observe from Figure 2 that in the case of the production of nitrogenous fertilizers eight countries hold 70% of production.

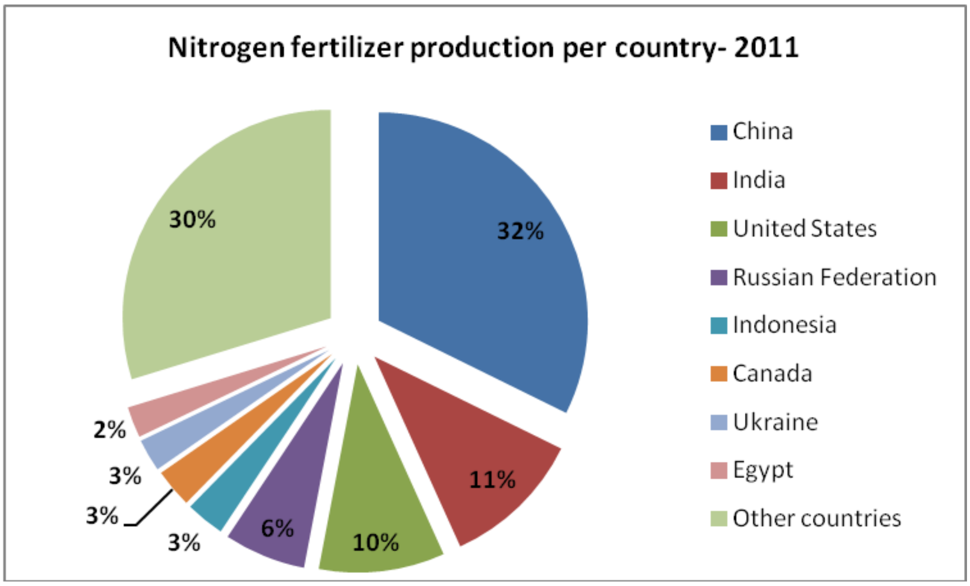


Figure 2: Nitrogen Fertilizer production per country in 2011. Source: IFA (International Fertilizer Industry Association

The consumption is closely related to the major agricultural activity in each country. The greater agribusiness larger is the need of using nutrients to ensure productivity and maintenance of soil fertility. Thus countries where agriculture and cattle breeding are bulky, the volume of fertilizer consumed is proportional. It is noted in Figure 3 that China, India, USA and Brazil are the world's largest consumers of nitrogen.

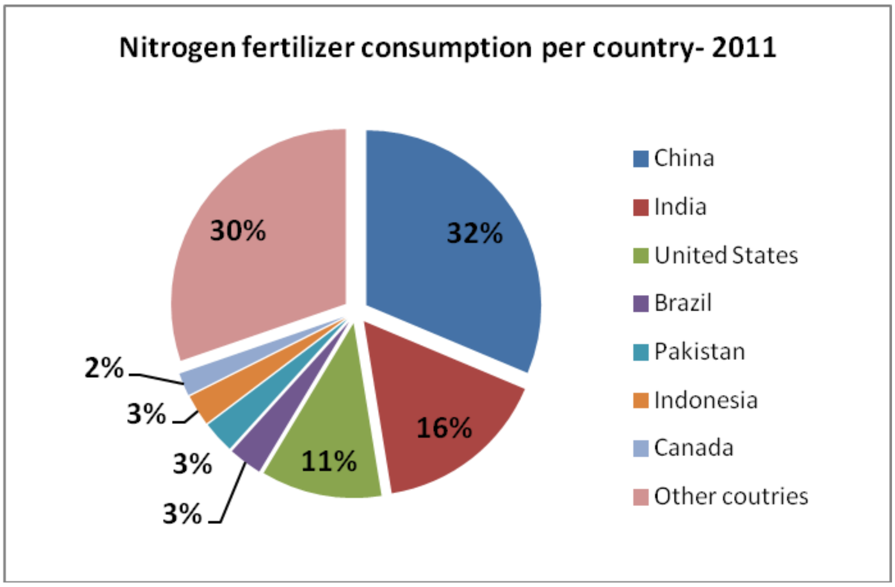


Figure 3: Nitrogen Fertilizer consumption per country in 2011. Source: IFA (International Fertilizer Industry Association)

3.2 BRAZILIAN FERTILIZER MARKET

As a major agricultural producer, Brazil is a major consumer of fertilizers. Data show the country among the five largest consumer markets, especially of nitrogenous and potash fertilizers. However, the capacity of national production does not meet demand and, with it, the country became a major importer of these nutrients. Figure 4 shows data of production and consumption of nitrogen fertilizers in Brazil from 1998 to 2011.

Specifically on the consumption and production of nitrogenous fertilizers in Brazil, according to Figure 4, we notice a decrease in the ratio between the total production and total consumption in the country in the period 1998-2011. These years, we note that the domestic supply is virtually stable while consumption is likely to grow. Therefore, in 2011 the national production of nitrogen supplies only 24% of domestic demand.

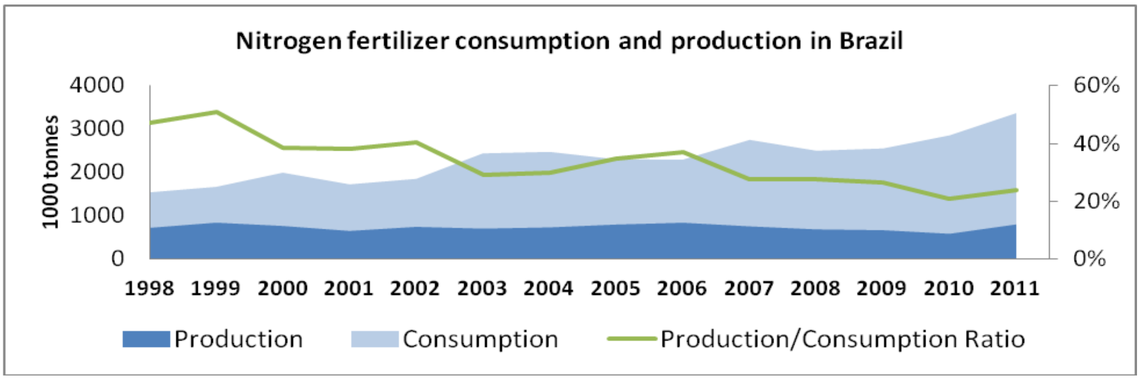


Figure 4: Annual production am consumption in Brazil. Source: IFA (International Fertilizer Industry Association)

Because the largest share of local consumption is imported, the country can be considered a price taker in relation to fertilizer, since the fluctuations in international prices of fertilizer directly impact the local prices and, consequently, Brazilian farmers. This also true for the prices of nitrogen fertilizers, focus of this paper, in which use international prices in the analysis to portray this characteristic of the Brazilian market.

3. METHODOLOGY

In this section the methodological aspects that guide this analysis will be defined. First we will establish the hypothetical model of simplified fertilizer plant, then the assumptions of the model is established and finally its described how the parameters of the simulation were estimated.

3.1 MODEL

Before setting the parameters, it is necessary to establish the model of a hypothetical plant of ammonia and urea. As stated previously, the basic raw material for the production of nitrogen fertilizer is natural gas.

In a simplified form, the synthesis gas undergoes a chemical process for the production of ammonia which in turn is a raw material for urea production. Thus, considering the variations in the price of the products and raw material, the manager of a plant of nitrogen fertilizers may choose to sell the product that maximizes return on investment. Figure 5 illustrates the simplified procedure.

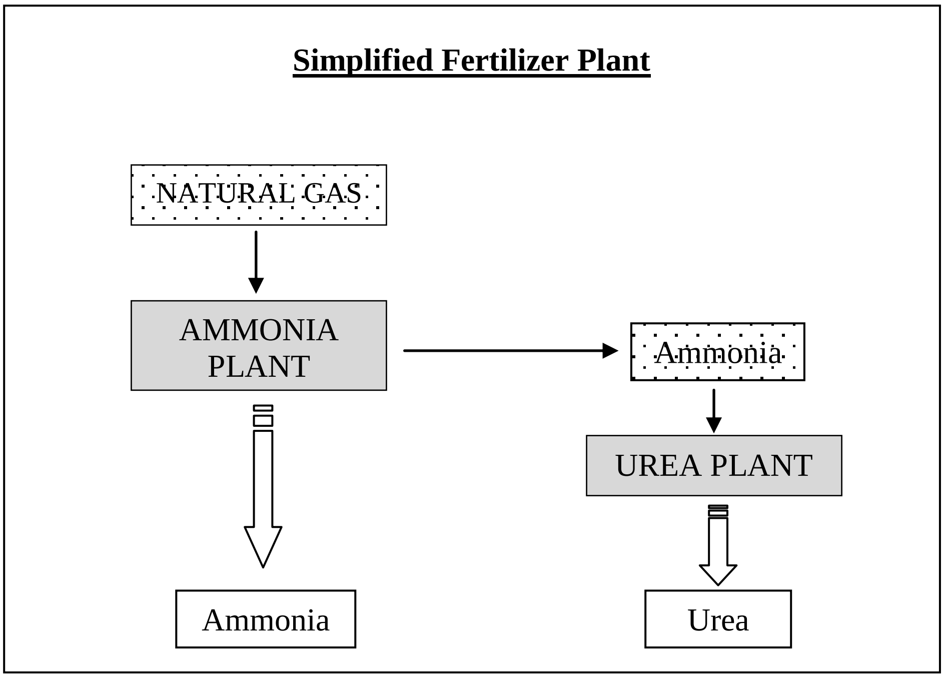


Figure 5: Simplified industrial process of a fertilizer plant

In this simplified model, we consider as uncertainties the price of natural gas, the price of ammonia and urea prices.

3.2 ASSUMPTIONS

Having defined the hypothetical simplified model of a flexible fertilizer plant, we define the parameters of the analysis.

First, we define the initial investment to build flexible plant fertilizer. According to Dockendorf and Paxson (2009), experts point out that the initial investment required to assemble a plant with capacity of 730,000 metric tons (mt) of ammonia per year is 550 million dollars and the amount for the installation of a urea plant with a production capacity of 1,260,000 metric tons (mt) per year is 340 million dollars. These amounts are consistent with the information capital expenditure issued by companies in similar projects of nitrogenous fertilizers plants in Brazil.

We assume real risk free rate of 4% per year and a cost of capital used to determine the present value of the deterministic assessment is 10% in real terms.

The initial prices considered in simulations, which were the current prices of the commodities by the time of the analysis, of Natural Gas, Ammonia and Urea - the three variables of model uncertainty - were respectively US$ 4.30/mmBtu, US$ 423/mt and US$ 330/mt.

Another definition is the time interval that will be used to analyze the cash flow and the frequency in which the switch option may be exercised. In our hypothetical plant that interval will be quarterly, with a 5 years horizon of assessing the option and thereafter considering a perpetuity without real growth.

Its also necessary to identify the production cost of ammonia and urea. Both are related to the price of natural gas, the main raw material of the process. YARA, a major producer of fertilizers, has available on its website (http://www.yara.com/tools/cashcost.html) the formula for calculating the cost of production, or *cash cost*, ammonia and urea. According to the company, the typical consumption of natural gas to produce one ton of ammonia is 36 million Btu. Other production costs amount to US$ 26 per ton of ammonia. Thus, we obtain the total cost of producing one ton of ammonia by multiplying the price of natural gas by the amount of natural gas required in the production process (36 mmBtu) and add 26 dollars relative to other production cost per ton.

We then have the cost of production of ammonia represented by the formula:

$$C_A = 36 \times P_{GN} + 26$$

Where:

- C_A: Cost of ammonia in US$/mt;
- P_{GN}: Natural Gas price in US$/mmBtu.

The urea production process uses 0.58 tons of ammonia, plus more than 5.15 million Btu of natural gas per ton of urea. There are other production costs that amount US$ 22 per ton of urea. So we define the cost of production of urea as a function of the market price of ammonia, natural gas, plus the additional costs of the production process of the urea plant.

We have then a formula that to assess the production cost of urea, as follows:

$$C_U = 0.58 \times P_A + 5.15 \times P_{GN} + 22$$

Where:

- C_U: Cost of urea in US$/mt;
- P_A: Ammonia price in US$/mt;
- P_{GN}: Natural Gas price in US$/mmBtu.

Its important to notice a significant conceptual difference in the form of calculation of cash flows between the present study and analysis done by Dockendorf and Paxson (2009), which uses the cost of ammonia production to compose the cost of urea. Differently, in this article the price of ammonia in considered in the formation of production cost of urea. The motivation for adopting this methodology is that we cannot ignore the opportunity cost of negotiating ammonia instead of using it in a subsequent manufacturing process to produce another product.

The next step, is to establish how to assess the free cash flow of the Base Case (100% Ammonia), the Incremental Case (100% Urea) and the cash flow of the Switch Option Value.

We then have to define the free cash flow of the Base Case (100% Ammonia) at time t as:

$$FC_t = Cap_A \times Ut_A \times (P_A - C_A) \times \Delta t$$

Where:

- FC_t: Free cash flow of the Base Case (100% Ammonia) at time t in US$;
- Cap_A: Capacity of Ammonia Plant;
- Ut_A: Capacity Utilization of Ammonia Plant;
- P_A: Price of ammonia in US$/mt;
- C_A: Cost of ammonia in US$/mt;
- Δt: time interval between cash flows in years.

The free cash flow of the Incremental Case (100% Urea), when the plant is set to produce and sell urea, is defined as follows:

$$FCI_t = Cap_U \times Ut_U \times (P_U - C_U) \times \Delta t$$

Where:

- FCI_t: Free cash flow of the Incremental Case (100% Urea) in US$;
- Cap_U: Capacity of Urea Plant;
- Ut_U: Capacity Utilization of Urea Plant;
- P_U: Urea price in US$/mt;
- C_U: Cost of production of Urea in US$/mt;
- Δt: time interval between cash flows in years.

Finally, we set the value of the Switch Option at time t as the maximum value between the revenue from the sale of Ammonia less revenue from the sale of Urea plus the additional costs of producing Urea and zero. That is, if the free cash flow of the option value is greater than zero at any instant, it means that the possibility of switching the *output* s is valuable. The free cash flow of the Switch Option in defined as:

$$FCOTt= [Max(Cap_U \times Ut_U \times (0{,}58xP_A - P_U + OCP_U) \times \Delta t; 0)]$$

Onde:

- $FCOT_t$: Free cash flow of the Switch Option in US$;
- Cap_U: Capacity of Urea Plant;
- Ut_U: Capacity Utilization of Urea Plant;
- P_A: Ammonia price in US$/mt;
- P_U: Urea price in US$/mt;
- OCP_U: Additional costs from the Urea in US$/mt;
- Δt: time interval between cash flows in years.

Note that the factor of 0.58 multiplying the price of ammonia is used to achieve the production capacity of the ammonia plant. And the additional cost of producing urea consists of 5.15 million Btu per ton produced, plus US$ 22 per ton of urea from other production costs.

3.3 PARAMETERS OF THE SIMULATION OF PRICES

We use in this paper, as already mentioned, two distinct stochastic processes - a Geometric Brownian motion and the mean reversion movement - that will determine asset prices in the simulations.

In the case of the MGB, diffusion process of prices follows the formula:

$$P_t = P_{t-1} \exp\left[(\mu - \pi - \frac{1}{2}\sigma^2)\Delta t + \sigma N(0,1)\sqrt{\Delta t} \right]$$

Where:

P_t: asset price at time t;
P_{t-1}: asset price with a lag period;
μ: drift parameter of the asset;
π: risk premium parameter of the asset;
σ: volatility parameter of the asset;
Δt: time interval analysis.

In the case of mean reversion movement, we use Model 1 of Schwartz (1997), in which diffusion is in log of prices. The equation that determines the stochastic process is described below:

$$lnP_t = lnP_{t-1}e^{-\eta\Delta t} + (ln\bar{P} - \lambda)(1 - e^{-\eta\Delta t}) + \sigma\sqrt{\frac{1 - e^{-2\eta\Delta t}}{2\eta}}N(0,1)$$

Where:

P_t: asset price at time t;
P_{t-1}: asset price with a lag period;
$\bar{P}$: long-term equilibrium price of the assets;
λ: normalized risk premium parameter of the asset;
η: speed of reversion parameter to the long-term equilibrium price;
σ: volatility parameter of the asset;
Δt: time interval analysis.

The estimation of the above parameters for the Monte Carlo simulation for both the MGB and for the MRM, were done from a price series of about 10 years, from July 2004 to December 2013, with prices of Natural Gas (Henry Hub), Ammonia (Yuzhnyy) and Urea (Yuzhnyy) in US$. Monthly data totaled 114 observations and were deflated by the IGP-DI (Fundação Getúlio Vargas - FGV) to perform the analysis in real terms, as shown in figure below.

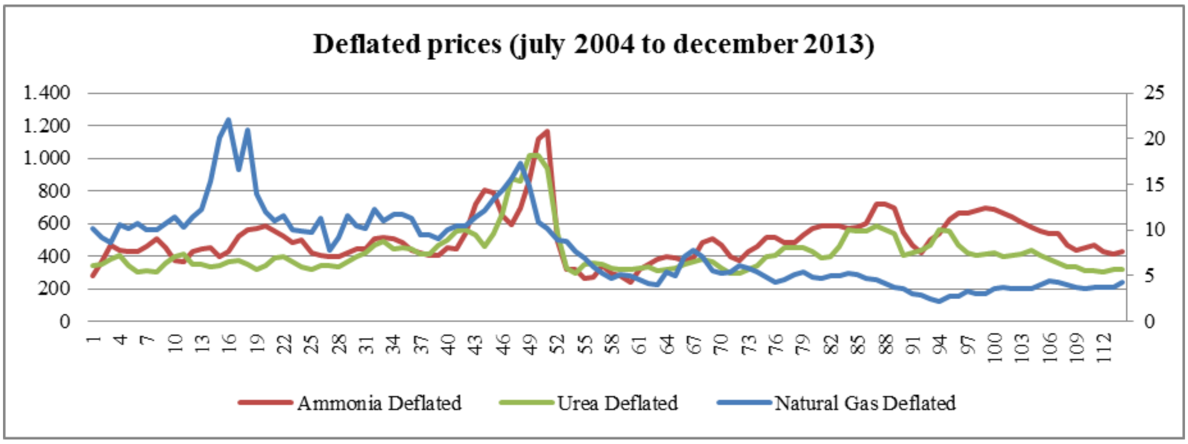


Figure 6: Historical deflated prices

In order to verify the existence of a unit root, it was performed the Augmented Dickey-Fuller test, using the software Eviews 7.0, in the series of log returns of each price. Table 1 shows the results of the tests.

Augmented Dickey-Fuller	*Natural Gas*	*Ammonia*	*Urea*
T statistic	-4,74	-4,74	-5,77
Evaluation	Don not reject GBM.	Don not reject GBM.	Don not reject GBM.

Table 1: Augmented Dickey-Fuller test results

The rejection of the hypothesis of existence of unit root statistically significant suggests that the dynamics of the returns follows a stationary process, meaning that we cannot reject that prices follow a GBM. Schwartz (1997), was only able to reject that oil prices do not follow a geometric Brownian motion for very long series, 120 years. Although there is no consensus on which to use stochastic process, Bastian-Pinto and Brandão (2007) argue that there are economic justifications for the use of mean reversion stochastic processes.

From the same price series it was established the correlation between the log returns of the asset, as shown in Table 2. These correlations are inputs to generate correlated the normal distributions of simulations, using the Choleski decomposition.

Correlation matrix	*Natural Gas*	*Ammonia*	*Urea*
Natural Gas	1	-4,58%	9,06%
Amonia	-	1	42,90%
Urea	-	-	1

Table 2: Log return correlation matrix

Next, we used the same series of prices to estimate the *drift* and volatility parameters that will be used to simulate prices in GBM. The mean of the log return of the asset represent the drift parameter and the standard deviation of them are the volatility parameter. It was found a value of *drift*, μ, of -9.01% per year for natural gas, 4.4% per year for ammonia and -0.75% per year for urea. Regarding the annual volatility parameter, we have σ_{GN} equal to 45.09%, σ_{GN} equal to 48.84% and 39.15% for $\sigma_{U.}$

When adopting MRM as stochastic process, the required parameters are the reversion speed, volatility and long-term equilibrium price. The reversion speed, η, found were: 0.3403 for natural gas, 1.9521 for ammonia and 1.1773 to urea.

The volatility of the MRM parameter obtained, σ_{GN} equal to 45.83%, σ_{A} equal to 51.03% and 40.50% for $\sigma_{U.}$ And the of long-term equilibrium prices that will be used in the simulation, found from the data of the above, were US$ 7.14/mmBtu for natural gas, US$ 530.99/mt to ammonia and US$ 432.91/mt to urea. These prices of long-term equilibrium suggest that the current prices of these commodities are below the long-term price.

Regarding the parameters of risk premium and normalized risk premium, which are the measure we subtracted of the stochastic process so that the return on the risk-neutral measure discounted at the risk free rate is equal to the total return of the asset, we used the same approach of Ozorio (2013), which mentions the work of Irwin (2003), Brandao and Saraiva (2007), Blank, Baydia and Dias (2009) that also estimated these parameters as described by Hull (2006).

4. SIMULATIONS AND RESULTS

The Monte Carlo simulation is a very flexible tool for the valuation of European options. Dias (2014) emphasizes the practical use of Monte Carlo simulation, especially for situations where multiple variables are considered in the model.

In the present article, the objective is to evaluate the option of exchanging the final product, ammonia or urea. Managerial decision of switching outputs can be taken at each instant of time, regardless of what happened in the previous period. Considering this we have a bundle of European options, which can be evaluated using Monte Carlo simulation.

Based on the parameters defined in the previous section, we used the software @Risk® running 10,000 interactions every new simulation of prices that define the model. Four different simulations will be made. In the first two simulations uncertainties considered were the prices of ammonia and urea, firstly following a GBM and then MRM. Then we included the third variable of uncertainty to the model and perform two more simulations, following the same stochastic processes with all the variables correlated to each other.

4.1 SIMULATION 1: TWO VARIABLES – GBM

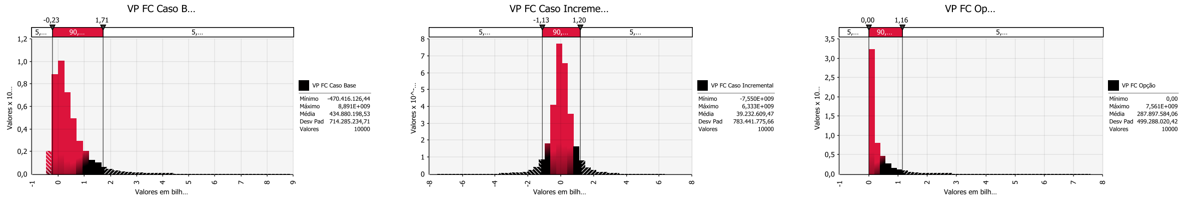
In this first simulation, prices of ammonia and urea will be simulated according to a geometric Brownian motion and discounted at the risk free rate of 4% per year. In this case the risk premium, discount parameter for the risk neutral valuation, was 0.168 for ammonia and 0.139 for urea.

The present value of the simulation period in which we assess the option was US$ 0.43 billion for the PVFC and the perpetuity present value after five years amounted US$ 1.63 billion. Altogether it amounts total a present value of US$ 2.06 billion that discounted investment of US$ 550 million for the fertilizer plant operating to produce and sell ammonia bring a net present value of the Base Case (100% Ammonia) of US$ 1.51 billion.

When the plant is operating to produce urea, the Incremental Case (100% Urea), we have the PVFCI the first five years equal to US$ 0.04 billion plus a negative present value of perpetuity of US$ 0.26 billion, which means a net present value for the Incremental Case (100% Urea) negative in US$ 0.56 billion after discounting the incremental investment of US$ 340 million.

Finally, the net present value of the Switching Option, PVFCOT, totaled US$ 0.29 billion. Figure 7 illustrates the distribution of the results of Monte Carlo simulation for the results evaluation of the Switch Option.

PV FC PV FCI PV FCOT



Simulation 1 – Two variables GBM

Figure 7: Distribution of results Simulation 1

	Results Simulation 1 (2 VARIABLES - GBM) in US$ billions			
	BASE CASE (100% Ammonia)	**INCREMENTAL CASE (100% Urea)**	**SWITCH OPTION**	**TOTAL**
PV	0.43	0.04	0.29	0.76
$PV_{Perpetuity}$	1.63	-0.26	0.00	1.37
Investiment	0.55	0.34	0.00	0.89
NPV	**1.51**	**-0.56**	**0.29**	**1.24**

Table 3: Simulação 1 results (2 variables - MGB)

4.2 SIMULATION 2: TWO VARIABLES – MRM

In the second simulation, the prices of ammonia and urea will be simulated according to a mean reversion movement and discounted at the risk free rate of 4% per year. In the case of the mean reversion as stochastic process, we need the normalized risk premium, to perform the risk neutral simulation. This parameter in Simulation 2 was 0.47 for ammonia 0.51 and for urea.

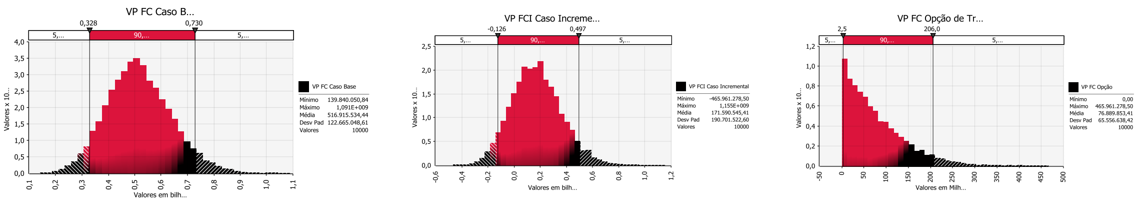
The PVFC, present value of the Base Case (100% Ammonia) of the five year time spam that the option is assessed, was US$ 0.52 billion and the perpetuity present value after this five years period amounted US$ 1.65 billion. A total present value of US$ 2.16 billion that discounted the required investment of US$ 550 millions brings a net present value of US$

1.61 billion.

In case the plant operating to produce urea, the Incremental Case (100% Urea), that has an initial investment of US$ 340 million, the PVFCI of the first five years equals US$ 0.17 billion, plus a present value in perpetuity thereafter of US$ 0.65 billion, which means a static net present value for the incremental case of US$ 0.48 billion.

The present value of the Switching Option, PVFCOT, totaled US$ 0.08 billion.

PV FC PV FCI PV FCOT



Simulation 2 – Two variables MRM

Figure 8: Distribution of results Simulation 2

	Results Simulation 2 (2 VARIABLES - MRM) in US$ billion			
	BASE CASE (100% Ammonia)	**INCREMENTAL CASE (100% Urea)**	**SWITCH OPTION**	**TOTAL**
PV	0.52	0.17	0.08	0.77
PV$_{Perpetuity}$	1.65	0.65	0.00	2.30
Investiment	0.55	0.34	0.00	0.89
NPV	**1.61**	**0.48**	**0.08**	**2.17**

Table 4: Simulation 2 results (2 variables - MRM)

4.3 SIMULATION 3: THREE VARIABLES – GBM

In the next simulations, in addition of ammonia and urea prices, the prices of natural gas will be simulated and the cash flows generated will be discounted at the risk free rate of 4% per year. As a consequence, the model becomes more complex by the inclusion of a third variable correlated the previous two. However, the analysis is closer to reality. Again, we have to define the risk premium for the variables of the model to perform adequately the risk neutral simulation. For natural gas, in this case, the risk premium was 0.15; for ammonia was 0.09 and the urea was 0.078.

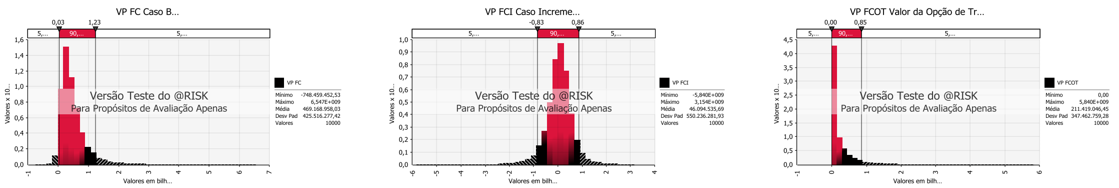
In the first case with three variables, the present value of the Base Case (100% Ammonia), PVFC, in the period in which we analyze the option value was US$ 0.47 billion and the present value of the perpetuity after five years period is equal to US$ 1.89 billion. Summed it represents a total present value of US$ 2.36 billion, that discounted the initial investment of

US$ 550 million for the fertilizer plant operating to produce and sell ammonia, amounts a net present value of the base case of US $ 1.81billion.

Then we calculated the value of the plant operating to produce urea, the Incremental Case (100% Urea) that has an initial investment of US$ 340 million. The PVFCI, incremental case present value, of the first five years totaled US$ 0.05 billion that added to a negative present value of the perpetuity after this period of US$ 0.19 billion mounted a negative net present value for the incremental case of US$ 0.49 billion.

The present value of the switching option, PVFCOT, amounted US$ 0.21 billion.

PV FC PV FCI PV FCOT



Simulation 3 – Three variables GBM

Figure 9: Distribution of results Simulation 3

	Results Simulation 3 (3 VARIABLES - GBM) in US$ billions			
	BASE CASE (100% Ammonia)	**INCREMENTAL CASE (100% Urea)**	**SWITCH OPTION**	**TOTAL**
PV	0.47	0.05	0.21	0.73
$PV_{Perpetuity}$	1.89	-0.19	0.00	1.70
Investment	0.55	0.34	0.00	0.89
NPV	**1.81**	**-0.49**	**0.21**	**1.53**

Table 5: Simulation 3 results (3 variables - MGB)

4.4 SIMULATION 4: THREE VARIABLES – MRM

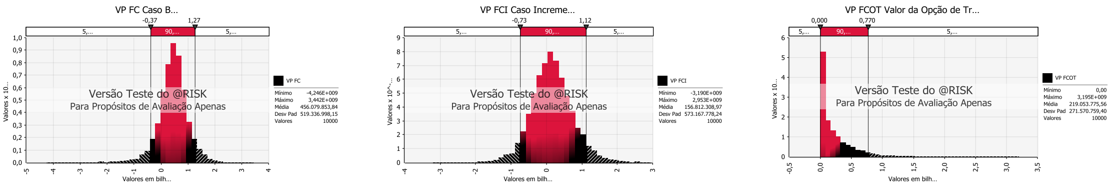
In this latter case, it was repeated the previous case, but now following a stochastic process of mean reversion, in which risk premiums normalized natural gas, ammonia and urea were, respectively, 0.025; 0.68 and 0.785.

Considering this parameters, the Base Case (100% Ammonia) reached a net present value of US$ 1.18 billion, a result of the sum a PVFC of US$ 0.46 billion related to the cash flow of the first five years plus the present value of the perpetuity of US$ 1.27 billion minus the initial investment of US$ 550 millions.

The net present value of the Incremental Case (100% Urea) summed U$ 0.38 billion, result of the PVFCI equals to US$ 0.16 billion plus a perpetuity present value of US$ 0.56 billion, minus the incremental investment of US$ 340 millions.

Finishing the analysis, the present value of the switch option simulated amounted US$ 0.22 billion.

PV FC PV FCI PV FCOT



Simulation 4 – Three variables MRM

Figure 10: Distribution of results Simulation 4

	Results Simulation 4 (3 VARIABLES - MRM) in US$ billions			
	BASE CASE (100% Ammonia)	**INCREMENTAL CASE (100% Urea)**	**SWITCH OPTION**	**TOTAL**
PV	0.46	0.16	0.22	0.83
$PV_{Perpetuity}$	1.27	0.56	0.00	1.83
Investment	0.55	0.34	0.00	0.89
NPV	**1.18**	**0.38**	**0.22**	**1.77**

Table 6: Simulation 4 results (3 variables - MRM)

4.5 RESULTS AND SENSIBILITY ANALYSIS

The simulation results show, according to Table 7, the present value of the switch option tends to fall when the stochastic process changes from a GBM to MRM. This result is expected, according to Dias (2014) mean reversion processes are more predictable. In this stochastic process, as prices tend to approach an equilibrium price of long-term, the conditions of exercise of the option are more restricted.

Another point that can be noted when comparing the simulations following a GBM to a MRM, is that the present values of the Base Case (100% Ammonia) and Incremental Case (100% Urea) are larger in simulations 2 and 4, in which prices follow a mean reversion movement. In this sense, this variation can be explained by the fact that the initial prices of the product variables are below the long term equilibrium price and the reversion speed parameter is considered high for ammonia and urea.

So, prices tend to quickly return to the long-term level what makes the present value of the Base Case (100% Ammonia) and Incremental Case (100% Urea) greater in the MRM than in the GBM. Also explains this fact the negative value of the urea drift in the geometric Brownian motion, which reduces the present value of the incremental case.

Comparison – Results of the simulations (in US$ billions)

NUMBER OF VARIABLES	STOCHASTIC PROCESS: GBM		MRM	
2	NPV FC	1,51	NPV FC	1,61
2	NPV FCI	-0,56	NPV FCI	0,48
2	Total	0,95	Total	2,10
2	Switch Option	0,29	Switch Option	0,08
2	**Switch Option/Total**	**30%**	**Switch Option/Total**	4%
3	NPV FC	1,81	NPV FC	1,18
3	NPV FCI	-0,49	NPV FCI	0,38
3	Total	1,32	Total	1,55
3	Switch Option	0,21	Switch Option	0,22
3	**Switch Option/Total**	**16%**	**Switch Option/Total**	**14%**

Table 7: Comparison of simulations results

Regarding the sensitivity analysis, it was tested how the value of the Switch Option behaved due to changes of some of the parameters used in the simulations described above.

The first sensitivity analysis was made by changing the value of the correlation of the price log returns of urea and ammonia, while the other parameters of the simulations remain unchanged. Thus we find the value of the switch option for the four simulations with the correlation between ammonia and urea ranging from 0% to 95%.

It is noted that the simulations whose variables ammonia and urea (Simulation 1 and 2) are more sensitive to changes in correlation. Figure 11 shows that there is a decrease in the value of the switch option with increasing correlation between the products.

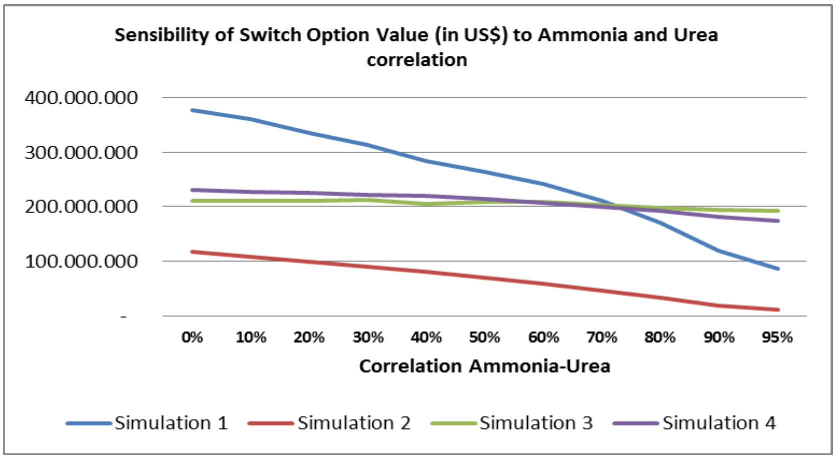


Figure 11: Switch Option value sensibility to Ammonia-Urea correlation

The other sensitivity analysis is related to the simulations that followed a mean reversion stochastic process, simulations 2 and 4. As the values for the speed reversion parameters to long-run equilibrium prices of ammonia and urea are considered high, we believe it is important to assess how the option value changes due to the gradual reduction of these parameters.

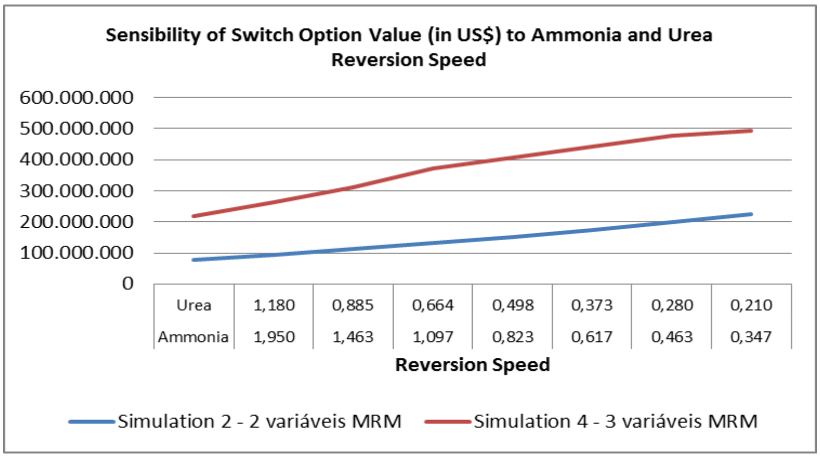


Figure 1: Switch Option value sensibility to Ammonia and Urea reversion speed

It is verified by the plots in Figure 12, that as we subtract the mean reversion factor the value of the switch option grows. This result was expected, since when prices take longer to move toward the long-term equilibrium price the option becomes more valuable.

5. CONCLUSION

This article aimed to evaluate the switching outputs option the in a flexible plant fertilizer, in which the manager can decide whether the factory will produce Ammonia and Urea, to do so we used the Monte Carlo simulation as an analysis tool.

Besides the relevance regarding the test and provide a more comprehensive and realistic way that traditional techniques of discounted cash flow, another motivating the research was the Dockendorf and Paxson (2009) paper, who used a different methodology of the approach taken in this article, however with the same goal - to evaluate the option of exchanging product in a plant fertilizer.

It is worth notice two conceptual features adopted in this study diverge from that assumed by the aforementioned authors. The first is to consider the prices of natural gas, the main raw material for fertilizer plant, as a variable of uncertainty in the model. On the contrary, Dockendorf and Paxson (2009) assume constant costs of production, while prices of ammonia and urea have growth trend, which results in the extrapolation of business value. The other concerns the formation of the cost of production of urea. In this paper, we consider the price of ammonia, and not the manufacturing cost in the plant itself, compounding the cost of producing urea. Differently, the authors disregard the price of ammonia to form the cost of production of urea. The implication is to ignore the opportunity cost to sell ammonia instead of using it in the subsequent production process.

Regarding the results of the simulations, we saw that the switch option is more valuable when we use the geometric Brownian motion with respect to the cases we use mean reversion. When comparing the MRM with two three variables we note that the option present value is higher with more realistic model that consider natural gas as business uncertainty. It was also found, in the sensitivity analyzes of the correlation ammonia-urea and the speed reversion factor, the major impact that these parameters have on the value of the option.

We can raise as limitations of this paper the simplicity used to define the cost in cash flows, not considering costs such as depreciation, taxes and transportation. Besides this, there are other research opportunities as testing other stochastic processes, propose a surface of prices to define the switching timing and simulate production constraints in the model.

REFERENCES

BASTIAN-PINTO, C.; BRANDÃO, L. Modelando Opções de Conversão com Movimentos de Reversão à Média. Revista Brasileira de Finanças, v. 5, p. 10-40, 2007.

BASTIAN-PINTO, C.; BRANDÃO L.; HAHN W.J. Flexibility as a Source of Value in the Production of Alternative Fuels: The Ethanol Case. *Energy Economics*, May 2009, Vol.31(3), pp. 411-422, 2009.

BLANK, F.F; BAYDIA, T.K.N.; DIAS, M.A. Private Infrastructure Investment Through Public Private Partnership: An Application to a Toll Road Highway Concession in Brazil, *13th Annual International Conference on Real Options* at University of Minho, Portugal & University of Santiago de Compostela, Spain, 2009.

BRANDÃO, LUIZ.E.; SARAIVA, E.C.G. *Revista de Administração Pública, v.41, n.6*. Risco Privado em Infra-estrutura Pública: Uma análise quantitativa de risco como ferramenta de modelagem de contratos, 2007

BRANDÃO L.; PENEDO, G. M.; BASTIAN-PINTO, C.; *European Journal of Finance*, The value of switching inputs in a biodiesel production plant, 2011.

BRASIL, H. G.; ARONNE, A.; RAJÃO, A. Valuation of the Options to Verticalize and Expand a Carbonatite Mine, 15th Annual International Conference on Real Options at Turku, Finland, 2011.

DIAS, M. A. G – Lecture notes – Análise de Investimentos com Opções Reais – Módulo II, 2013.

DIAS, M. A. G – Análise de Investimentos Com Opções Reais - Teoria e Prática com Aplicações em Petróleo e em Outros Setores, volume 1. Book manuscript to be published in 2014.

DOCKENDORF, J.; PAXSON, D. The Value of Switching Outputs in a Fertilizer Plant in the US in annals: 13th Annual International Conference on Real Options at University of Minho, Portugal & University of Santiago de Compostela, Spain, 17-20 June, 2009.

HULL, J. C.; Options, Futures, and Other Derivatives Securities; *Prentice Hall, 6th ed.,* 2006

INTERNACIONAL Fertilizer Industry Association. Paris - França, 2014. Available at: <http://www.fertilizer.org>. Accessed in: feb. 25, 2014.

IRWIN, T., Public Money for Private Infrastructure. *World Bank Working Paper, n.10,* 2003

OZORIO, L.M.; BASTIAN-PINTO, C.L.; BAIDYA, T.K.N.; BRANDÃO, L.E.T. *International Review of Financial Analysis*, Investment decision in integrated steel plants under uncertainty, 2013.

SCHWARTZ, E. S. The stochastic behavior of commodity prices: Implications for valuation and hedging. *The Journal of Finance*, 52(3):923–973, 1997.

WANG, Z. LI, L. Valuation of the flexibility in decision-making for revamping installations - A case from fertilizer plants., *Petroleum Science*, Volume 7, Issue 3, pp 428-434. 2010