Instituto de Investigaciones Socio Económicas

Documento de Trabajo No. 09/09
Septiembre 2009

Aproching Optimal Depletion Path: Natural Gas Market in Bolivia

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***Research Area*:** Energy Economic and Non Linear Optimal Models.
Key words: Depletion rate, Discount rate, Natural gas, Price path.
JEL classification: E63, C68, 054

Acknowledge: Renan Goetz, PhD Professor at Köln Economic Energy Institute (Germany) and Project SEJ2006-02328/ECON.

Abstract

This exercise tries to be the first approach in order to understand the overall feedback effects of price path over optimal depletion rate in natural gas market in Bolivia. The simulations attempt to reproduce year-by-year evolution of natural gas depletion. While the initial conditions, parameters the model corresponds to exogenous measures in non linear optimal scheme. Therefore, the numerical values shown in the simulation should not be interpreted as forecasts. Some preliminary key result shows that: opportunity cost of depletion is high especially the first years; companies have low incentives to stop depletion or to be cost-efficient; the effective gas sales to regional markets is not enough yet; contract operation might regards in higher discount rate; exogenous commodity price bid up pressures depletion rate; companies hold expensive ratios of useless reserves related to possible market sales; it is not probable that price path converge with optimal depletion rate neither in short or long run and vice versa.

1. Introduction

The importance of energy in any economy, developed or underdeveloped, became clear after the first oil shock in 1973 and the break even point of electricity growth around the world in the mid sixties. Those oil shocks modified the belief that at a world-wide level, abundant sources of energy existed and they would not be an impediment or brake to the economic growth especially in final energy demand. The world took conscience that energy is a critical element in contemporary economies. The industrialized world started to look for less oil-dependent growth, and diversified electricity generation sources, since then, different studies have been made to formulate energy policies and their impacts.

Recently, economic-environment-energy modellers were also concerned with the lack of other natural resources and with the impacts on the environment and climate fundamentally provoked by energy-related activities. These relationships has been theoretically discussed and numerically assessed since that decade.

The persistently high unemployment rates and external shocks in prices and investment in almost every country and the upcoming decisions on future local energy systems create a current need to understand the interaction and impacts between the relationship of macroeconomic and energy policies, as well as the environmental and energy relation.

Therefore is essential to incorporate a theorical and quantitative methodology in order to analyze this problem. Two kinds of models provides an interaction framework for these purpose, from one hand we have the Energy Technology Assessment Model (ETA), on the other hand there are Optimal Dynamic Models (i.e. Linear, Non Linear and General Applied Equilibrium Models) which provides quantification instruments of energy impacts and environmental policy measures on the economy.

The aim of this paper is to develop the first approach in order to understand the overall feedback effects of price path over optimal depletion rate in natural gas market in Bolivia. For that porpoise we attempt simulations to reproduce year-by-year evolution of natural gas depletion. While the initial conditions, parameters the model corresponds to exogenous measures in non linear optimal scheme. Therefore, the numerical values shown in the simulation should not be interpreted as forecasts.

The first section introduces the general topic. In the second section we describe the Oil & Natural Gas dynamic and the main energy linkage with MACRO behaviour. The section three gives an overview of natural gas sector in Bolivia regarding their depletion convergence. The fourth section introduces the theorical framework of Non Renewable Natural Resources. The fifth section is split between simulations, design experiments and their basis results. The last section remarks final conclusions.

2. Oil & Natural Gas Dynamic

Energy affects the economy in more subtle ways: energy prices have outpaced inflation for most of the decade, adding to inflationary pressures; growing capital requirements for energy production threaten investment in other sectors of the economy, financial markets strain to accommodate their revenues, and the dollar falls in value as prices rise.

The health of the economy depends critically on energy, that is the main reason to explain why economic policy can no longer be made without considering its impact on the energy system and energy policy can no longer be made without regard to its economic repercussions. Yet there is little agreement on the nature, strength, and relative importance of the myriad interconnections between energy and the economy.

Theorical framework is needed to integrate in a consistent and realistic manner the long-run effects of energy phenomenon like depletion rate (exploitation, exhaustion, etc.), substitution between energies and energy costs on investment, economic growth, unemployment, the standard of living, distributional effects and inflation.

From Energy Technology Assessment (ETA) models the characterisation of framework consists of a dynamic interaction system of national economy. The relevance of the approach permits the policy analysis regarding the evaluation of energy interaction over economic activity, investment, and the standard and distributional effect of living. In particular some of the following questions will be addressed:

- What is the relationship between GNP and energy use?
- Can depletion of energy resources cause or worsen an-economic downturn? Therefore which is the optimal depletion rate?
- How do lags in the substitution process affect economic performance?.
- Is shortage of capital likely to constrain the expansion of energy supplies?

This is a huge range of analysis; hence we try to reduce the discussion toward natural non renewable resources depletion. Since many energy models initially where designed for supply problem (treated the energy sector aside from the rest of the economy), first we will try to describe some basis assumption and limitations of these kinds of models. The assumptions commonly made ignore potentially important interdependencies among energy costs, capital formation, growth, and inflation. As a result the common assumptions of energy supply models simplify the analysis in several ways as we will see in the following paragraphs:

- ***The Capital Costs of New Technologies are Exogenous***

The capital costs of technologies such as coal liquefaction and gasification, shale oil, and nuclear power have risen over the past decade in real terms, often faster than the price of oil itself. Such behaviour is not surprising since these technologies are extremely energy- and capital-intensive. When energy costs raise, the costs of producing any good rise, yet these interdependencies are ignored by the supply models.

- ***The Investment in Energy is Unconstrained by Investment***

As the economy grows, the national output has to be divided among consumption, investment and government spending. But the increasing capital requirements of energy sector can only be satisfied at the expense of investment in some other sector or at the expense of consumption.

- ***The Interest Rates are Exogenous***

Growing investment requirements of energy sector put upward pressure on interest rates modified opportunity costs. As interest rates rise, investments earning only marginal returns will become unprofitable and will be crowded out, reducing capital investment in other sectors. Energy projects on the edge of profitability may become unprofitable, requiring government subsidies for completion.

- ***Inflation is Unaffected by Energy Prices and Availability***

Inflation is exogenous - yet energy prices rose faster than the consumer price index adding to inflationary pressure. As the price of energy rises, the cost of producing every good and service in the economy rises. Higher costs are passed into prices, possibly triggering a wage-price spiral, reducing the standard of living, and adding to the demand for credit and to government deficits.
In the past few years, a variety of models have been constructed to address the deficiencies noted in the supply-oriented models (e.g. demand models, optimal models). These "energy-economy" models are primarily designed to assess the impact of energy availability and price not only on economic growth. The models employ a wide range of techniques, from linear and non linear programming, econometrics and input-output analysis. However, we still have to improve the models in several of the following ways:

- ***Equilibrium Direction***

Energy markets have been heavily regulated for decades, introducing market imperfections by distorting and biasing the information that normally would cause consumers and firms to respond to the growing scarcity of energy. Thus, the assumption in many models of a market determined equilibrium is not defensible. Yet even without government-imposed imperfections, the energy system is characterized by extremely long delays.

- ***Impact over Energy Aside Sector***

Several of the models treat capital and investment in energy production exogenously or have exogenous energy prices. Yet capital production is an energy-intensive sector of the economy and thus highly dependent on the price and availability of energy. Further, the ability of the economy to generate enough capital to satisfy the growing needs of the energy sector is a key question.

- ***Physical and Financial Flows not Conserved***

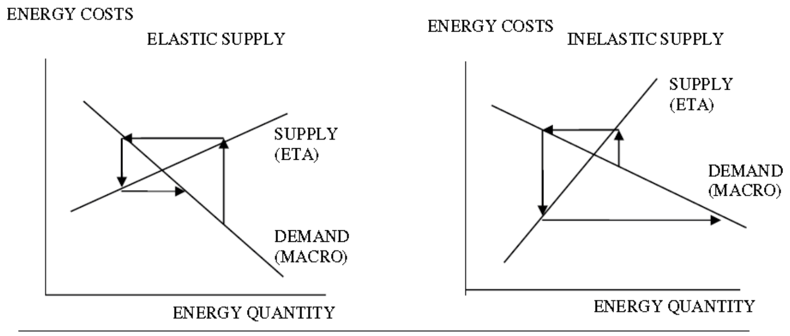
It is extremely important to conserve both physical factors (capital, labour, energy) and financial flows (wage payments, profits, taxes) so the full effects of depletion and energy policies are captured.

Current available models are insufficient representations of complex energy linking with their overall behaviour. To assess the importance of these interactions properly, a model should capture the feedbacks between the energy sector it self and the rest of the economy. It should generate and allocate the productive resources of the economy endogenously and represent the shifting balance between these resources. Important delays and disequilibrium effects should be included.

2.1 Energy Linkage with MACRO

According to the fact that energy sector make up less than 5% of the gross output in most economies, it is still discussed the impact of energy price increases in the overall industry cost. This concerns to energy convergence and if the dynamic is achieved fairly rapid (regarding supply and demand elasticities). If the supply elasticity is much greater than the absolute value of demand elasticity then convergence can be assured. However, if the opposite is true - then even if energy is only a small share of overall industry costs it still regards as consumption constraint (Figure 1).

Figure 1: Energy Elasticities



Source: Own elaboration

The ETA adjustment is also related to technologies constraint' linked with endogenous and exogenous factors. They define the limits to which existing technologies can be substituted. ETA constraints might introduce institutional factors, but is still difficult with this approach to split private opportunity cost and social opportunity cost.

3. Overview of Natural Gas in Bolivia

Bolivian hydrocarbons framework was developed in 1990s (Law 1169), with the aim to attract Foreign Direct Investment (FDI), develop the regulatory system and restructure the Oil & Gas (O&G) chain. These guiding assure large amounts of capital inflows into the country (average 6.3% of GDP) the next five years mainly – mainly for cross border gas pipeline to Brazil.

Sectoral forthcoming forecast huge hydrocarbons fields – since Bolivia succeeded their exploration activities; the discovery of huge dry natural gas reserves increases the total stock (from 5 Trillions Cubic Feet to almost 54 TCF). Therefore, Bolivia switches from a dependent buyer toward to strategic supplier in South America. The increases of O&G stock allows the country to signed regular sales to Brazil (7.7 TPC of natural gas for the next twenty years) and decide to bid up domestic consumption.

Three basic axes were designed for these porpoise. First, the new regulatory scheme aim to generate market structure conditions well-matched with investment cycle and sustainable supply of energy in the long run. Second, the regulatory system guarantees well domestic market operation and limited cross subsidies along the whole chain. Finally, the sector tries to increase the gas consumption as share of the energy mix, with more domestic uses and foreign trade.

The natural gas boons during this period represented the most important external shock in the last two decades. The gas phenomenon might be split in three mechanisms which characterise the dynamic behaviour (i.e. Investment Cycles, Price Cycle & Price Swings and Government Take Booming).

After a decade Bolivia modified again the hydrocarbons rules (Law 332 of 2005). The main change implies the government activity in the whole O&G chain (i.e. Upstream and Downstream), regarding to change the energy mix toward natural gas (i.e. increase gas trade, bid up domestic gas consumption and add value to natural gas with transforming process), enlarge government take and distribute gas income.

3.1 Bolivian Gas Convergence

Bolivian natural gas market suffers from numerous failures, which imply that market forces by themselves and also technological constraint cannot be expected to allocate resources efficiently among user and over the time. Each of theses markets failures (i.e. property rights, exclusivity, security, transferability) affect the optimal extraction path and the whole sectoral behaviour.

The natural gas reserves have grown in the last decade but it is still exactly unknown or certified, so the owner would not know exactly what he owns. As government grants companies rights to explore and extract resources for limited time, there are higher incentives to extract without any regard to the socially optimal extraction path.

Since natural gas is hidden in the ground, expensive exploration is needed to found the recourses, this effect works in direction of too slowly production. Since companies cannot keep certified reserves for more than ten years without starting their operations, in the next years we probably will see a cut down in exploration activity until new markets will be secured.

Notice the natural gas is regionally segmented; therefore there is low liquidity in the market and price is fixed by formula through bilateral monopoly negotiation. This equation does not take in count the *Principle of Price Value Market* and social opportunity cost are aside. Thus the price mechanisms not assure that the resources will go to the user with the highest benefit now or in the future.

Since both, prices and quantities are typically negotiated for periods spanning several decades, there is little space for adjustment to unexpected changes in scarcity value, and current extraction rates can be below or above the socially optimal extraction.

Transaction costs are important since the contract is very expensive, but the gas pipeline is the most expensive cost while transport cost is comparative slow. Initial investment requirement may also be prohibitive. These arguments point out that current extraction rate may be lower than the optimal.

Since large share of the natural gas is still not “effective” sold (only 37% of current reserves in the next 20 years); only gas export contract to Brazil is available (non including Cuyba) – and recent short time “effective” sales to Argentina (without long run complementary agreement, which is not still operative) remarks that this constrain is likely to be the most binding, because implies that natural gas production will be below what Bolivia consider optimal.

Government itself is likely to apply much higher discount rates than social planner in order to obtain financial recourses during their own period. This myopia tends to imply too fast extraction.

Extraction is also highly affected by oil price, since this commodity is the closest substitute. Notice that this price is difficult to forecast, because it increases and decreases over time due to scarcity and other fundaments factors. Nonetheless this relationship is not evident since many facilities doesn't present switch energy capacities.

Finally, extracting natural gas is an irreversible process regarding physical and technological assessment (i.e. field and refining management; infrastructure and techno-planning), hence the option value of not extracting should be taken into account.

4. Theorical Framework - Non Renewable Natural Resources

The energy sector differs from the other sectors in two important aspects. First, energy production depends on non-renewable resources. As they easily exploited resources are consumed, hence the productivity of the energy sector declines. Second, if the energy sector is unable to meet the total demand for energy, it will attempt to close this gap from other sector.

The consumption of non renewable resources implies the complete destruction. Since there is a fixed stock - nonetheless their level is not usually known and exist many external and technological constraints. Therefore is difficult to define optimal depletion policies.

The major focus of this study is characterizing the depletion of exhaustible resource. Notice that optimal path is identified for a given planning period - during the economy has important reserves. The issues related to terminal depletion, albeit interesting and important, are not considered in this study. One important feature of the present model is the dynamic inter-period market equilibrium. If the government chooses the private marginal propensity to save and investment in O&G – is likely a planner maximizes the social welfare function.

In real terms well defined optimal depletion rate is complex to develop since: (1) during reserves depletion the shortage makes go up prices until a breakpoint which backstop technology operates; (2) the extraction marginal costs of depletion usually grows reducing the extraction profitability.

Two opposites approaches might be described: (1) depletion rate is extremely quick, which lack the capacity to guarantee adequate production levels over the time; (2) the extraction is too slow, because several constraint (technology, prices, operative factor, institutional aspects). In both cases the path doesn't maximize the welfare function.

The social optimal depletion path require to: (1) set up economic acceptable conditions to deplete; (2) define the optimal depletion rate over the time; (3) define criteria's in order to analyse certain extraction paths according to sectoral strategies over the time.

In order to design the simulation experiment we suppose: (1) natural reserves are completely private or completely public; (2) gas market is regionally segmented, but the sale price formula capture the correct price evolution in competitive markets (them we relax). These assumptions compares competitive behaviour with monopoly market structure, in both cases the current consumption modifies the future opportunity cost. In order to maximize the entire welfare along depletion period we define:

$$\text{Max} \int_0^\infty \left[F(E(t)) - C(S(t), E(t)\right] e^{-\varphi t} dt \quad (1)$$

s.a.

$$\dot{S} = -E(t)$$

$$E(t) \succ 0; E(t) \prec \varphi(t)$$

$$S(0) = S_0$$

Where:

$S(t) =$ Stock Reserves

E(t) = Resources Depleation

F(E) = Imcome Sales Resources

C(E,S) = Cost of depleation measure by E units when S units still exist

$\varphi = Descuont - Rate$

The variable $F(E)$ might be modelled with to types of closures: (1) monopoly revenues $F(E) = D^{-1}(E)E$ where $D^{-1}(E) = P$ is the inverse demand. The production level is lower than competitive market, therefore this assumption regard slower depletion rate; (2) if $F(E)$ is the social consumption utility of E units at moment "t"; them the demand represent the marginal social preferences measure by marginal payments. The dynamic optimization problem is defined by the following Hamiltonian:

$$\text{H} = F(E) - \eta E + \mu_1 E + \mu_2 (S - E) \quad (2)$$

First order condition for control variable is $\text{H}_E = F^{;}(E) - m = 0$ which is solved by

$$F^{;}(E) = m \quad (3)$$

The marginal revenues in monopoly are equal to marginal non depletion value (marginal cost). Marginal cost of uses "m" (Royalty, Hotelling Rent or Scarcity Price) is not the monopoly price since the buyer pays is $F(E)/E$ - the average income is $\frac{D^{-1}(E)E}{E} = D^{-1(E)} = P$. In case $F(E) = \int_0^E D^{-1}(\tau)d\tau$ is the consumption utility, the balance condition is $F^{;}(E) = D^{-1}(E) = P = m$ (hence the market price is equal the scarcity price). Consumers suppose $P(t)$ is the competitive balance path since producers considered is $m(t)$ - the equilibrium is $m = p$. Modelled the competitive behaviour is the same to maximize the current value of the area under the demand curve.

First order condition for state variable $\text{H}_S = 0$ is:

$$\frac{\dot{m}(t)}{m(t)} = \varphi \quad (4)$$

The economic explanation is that scarcity price bid up with the discount rate. If Hotelling rule didn't prevail in the market there will be the possibility to earn money through arbitrage; this is the underlying investment maximal NPV (Net Present Value). Let us image a person who doesn't know if is a good or bad idea to exploit some non renewable resource - if he doesn't extract the wealth increases since price does - when he extract the resource the wealth increases due to the return rate, hence marginally both should be the same.

With dynamic path over non renewable resource (storage versus consumption) there is a positive relation with the discount rate:

$m(t) = m(0)e^{\varphi t} = \rho$ (5)

Notice the important of defining border condition $m(0)$. Since $\int_0^\infty D(m(0))dt = S_0$ there is only one $m(0)$ which satisfied this constrain. The maximal principle condition let as to extract the whole resource $\lim_{t \to \infty} m(0)S(t) = 0$ given that $\lim_{t \to \infty} S(t) = 0$; therefore $\int_0^\infty E^*(t) = S_0$.

Other possibility is to impose the following constraint $\int_0^\infty E(t) = S(0)$. Finally, is also possible to introduce the range in which one substitute price P_S restrict the average rise ($P = m(0)e^{\delta t} \leq Ps$).

Till we supposed that extraction costs are null - we assume that extraction marginal cost increases with the depletion rate, the marginal costs is the current overall society sacrifice. If extraction costs are lineal and constant for each depleted unit the balance condition is the following:

$F''(E) - \gamma = m$ (6)

Now monopoly prices are the gap between marginal incomes and marginal cost to equal the scarcity price.

$$\frac{d/dt(IMG - \gamma)}{(IMG - \gamma)} = \varphi \quad (7)$$

According to this Perfect Competition rules the following:

$$\frac{d/dt(P - \gamma)}{(P - \gamma)} = \varphi \quad (8)$$

Since we apply Integration Operator to (8) we obtain the price path.

$$P(t) = \gamma + (P(0) - \gamma)e^{\varphi t} \quad (9)$$

If γ increases the slope $P(t)$ decreases - the function moves up. When φ limits the infinite (free resource market availability) the resource deplete as much as possible since the price is higher to the cost. Finally, if $C(S,E) = C(E)$ the rule becomes the following:

$$F'(E^*) - C'(E^*) = \left[F'(E^*(0)) - C'(E(0)\right]e^{\varphi t} \quad (10)$$

When the cost bid up with the extraction rate, the current depletion affects negatively the future extraction costs.

Regarding the technology two possibilities exist: (1) the resource is depleted and the alternative technology is not employee; (2) the resource is drained and only alternative technology is used (backstop technology is needed). When $F'(E) = P \leq \bar{C}$ and exist T (transition Technology Period); the initial condition is $P(0) = \gamma + (\bar{C} - \gamma)e^{\varphi T}$; hence $P(t)$ path is given by:

$$P(t) = \begin{cases} \gamma + (\bar{C} - \gamma)e^{(t-T)\varphi}; t \prec T \\ \bar{C}; t \geq T \end{cases} . \quad (11)$$

The changing time is determined solving the equation $\int_0^T D(\gamma + (\bar{C} - \gamma)e^{\varphi(t-T)})dt = S_0$.

If price only grows according to discount rate rhythm, we have to settle down the initial price which equalizes to substitute technology for the marginal consumption unit. Also is possible to endogenize depletion horizon (T is determined by maximal condition).

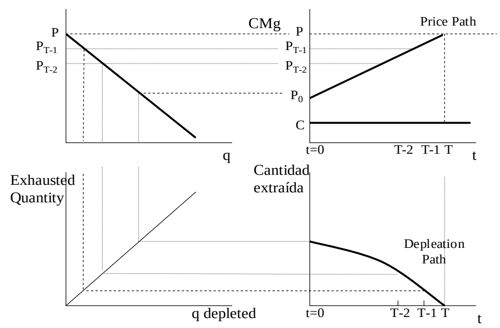
Since backstop technology exists the optimal depletion of non renewable resources will be $P(T) = P_T$. The last depleted unit price has the same price that makes most profitable the substitution technology. When price resource reach P_T and there are still reserves to extract, these weren’t be paid at the same level (last units must be extracted lower than scarcity price). These ranges of depletion will be carried out as quickly as it can in order to reduce the losses.

When the resource is depleted before the backstop technology price the exhaustion will be under optimal. Therefore, there is only one initial optimal price that maximal the non renewable depletion (maximum discount of production and consumption surpluses). In case non backstop technology is possible the last depleted unit reaches the highest market price.

If discount rate decreases the marginal non depletion cost follow since the horizons extraction grows - if depletion horizon increases the demand diminishes since price increases. Therefore there is a negative relationship between depletion horizon and discount rate - since high discounts rate prevail the horizon reduces (when discount rate bid up the depletion rate follows the path and demand contracts) see Figure 2.

The following closures might be modelled: (1) since discount rate bid up the price will grow quickly. With the previous initial price the path will be under optimal (depletion will be lower inferior and when the price of the substitution technology is reached there still will be reserves without extraction). The intertemporal efficiency will only be able to maintain if the initial price decreases (optimal depletion horizon reduces); (2) backstop technology become cheaper (the resource is more abundant), the initial price decreases (depletion rate increases since the horizon reduces); (3) if the reserves stock increases (resource becomes more abundant) depletion arise since prices reduces (lagged backstop technology price); (4) if demand increases the resource become relative scarce (the initial price increases reaching backstop technology price and the depletion is quicker).

Figure 2: Price and Depletion Path



Source: Own elaboration

5. Simulation Experiment

In the first simulation (reference run) the resource base is assumed to be equal to t-1 years of consumption at current usage rate (18 years). Till the method is Non Linear Maximizing procedure - as it was described in previous section we constrained with border conditions in order to maximize the welfare function. As depletion proceeds, the energy stocks declines, reaching lower level than the original one. Thus, the backstop technology is assumed to be freely more expensive in real terms than the original cost of the non-renewable resource.

5.1 Experiment Design

We assume as initial natural gas reserve measured in TCF the committed reserves of Chaco S.A. as domestic market base line - then we added another committed reserves toward this kind of consumption. The domestic consumption is consider to reach 1,8 TCF in next 20 years for the exercise we assume a range of +/- 25%.

Regarding the current demanded reserves for export we added other possible committed reserves in two supposed scenarios: (1) the whole long run export commitments succeeded at constant level; (2) the export value increases since price grows. The experiment defines total natural gas reserves as the added consumption of domestic and export market (non total reserve stock).

Natural gas market is regulated (fixing the price) the price is given by reference weighted fuel oil basket. The exercise takes the weighted mobile average price of the last 5 years in order to capture the underlying evolution of commodities prices. From that base line we simulate in range of +/- 10%. The average operation costs reached $0,23 mpc with a range of +/- 10%.

Natural gas trade is carried out from fields to the domestic market or foreign markets - Transredes Company charges (stamp transport price) $ 0,41 for mpc to domestic market and $ 0,18 for mpc for export market. Since both price and volume were negotiated for long run contract the depletion rate doesn't modify substantially during the period of analysis.

Notice that fixing prices method in general doesn't take into account intertemporal opportunity costs; since the mechanism was designed to stabilize the profitability of investment mainly in upstream. Therefore decreases the incentives of being cost-efficient. The current experiment defines "rho" parameter which is the discount intertemporal rate from a base level of 12% in a range of +/- 5%.

Finally, we suppose a range between 5% and 15% of non consumption over the total reserves committed for the experiment (non the total stock) in order to introduce the possibility of backstop technology – let as to model final stock convergence limits zero or o substitute technology arise. Although this technology process is quite complex and is not frequent in real terms.

5.2 Experiment Results

The simulation results remark that depletion will be a significant issue in the next 19 years- (especially the first years); conversion to the backstop no clearly occurs shortly before this period. We verify that prices rises steeply in the period of depletion from the base line. Therefore, we do not demonstrate the long run path equilibrium regarding backstop technology since the simulation is out of range. Therefore we assume the adjustment to equilibrium required more than 20 years.

The price rises as depletion occurs, reaching various times the initial level before dropping back to an equilibrium almost greater. The price overshoot is maybe due to indirect factor requirements of other sectors. Notice that since prices rise (capital costs increase), energy cost also rise.

The model or maybe the dynamic is not available to absorb the whole sensibilities we proposed. Feedback might worsen the problem by forcing the prices out of range and overshoot their equilibrium level. Depletion dynamic (explosive path) can trigger non-convergence prices; as depletion raises the future price bid up; this also increases the production costs and thus the price of capital and equipment. This feedback probably repeated several times during the simulation since the equilibrium overshoot.

Explosive paths (during adjustment periods or not) affects depletion in several ways. Lack depletion smooth the transition and reduce the under shoot, but regards in many cases non-profitable.

According to price evolution the current maximum value of total reserves is between $ 1.880.000.000 and $ 6.227.766.016 millions considering the whole range of experiment. This remarks the significant effect between price path and economy wealth. Since reserves become monetized some important distortion might appear (Dutch Diseases). Finally, depletion rate in all possible experiments showed very quick rate of depletion in all possible experiments especially the first 5-7 years of operation, then the discount rate reaches a convergence path.

Figure 3: Exhausted Quantity of Natural Gas

(Insert Three Graphs)

Figure 3 represent the fourth quadrant according to Figure 2 (the overall dynamics are presented in Appendix 1; Appendix 2 and Appendix 3): Here we summarize the basis evolution path of the experiment: (1) the whole long run export commitments succeeded at constant level (Scenario I); (2) the export value since increases since price grows (Scenario

II). Is not quite clear if domestic consumption clearly not arise since opportunity cost to export remain high or the initial value is too small to capture well the dynamic. The average operation cost varies less than 5% (since we assume a range of +/- 10%) - nevertheless the discount rate where still in range during large range of the exercise, but overshoot when it reached 13.5% in Scenario II (there is breakpoint in year 13) Finally, the non consumption reserves reach 1.39 TCF to 1.63 TCF with the admitted range of backstop technology.

6. Final Remarks

The simulations attempt to reproduce year-by-year evolution of natural gas depletion. While the initial conditions, parameters, and configuration of the model corresponds to exogenous calculations. Therefore, the numerical values shown in the simulation should not be interpreted as forecasts. The initial equilibrium should not be used as a as comparison for evaluating the simulation results since we do not use index.

The opportunity cost of draining natural gas reserves is very high the first years - the companies have low incentives to stop depletion or to be cost-efficient. Three main factors could explain incentives toward overshooting depletion: (1) the effective sale of gas reserves to regional markets is not enough (i.e. Brazil, Argentina and Chile); (2) contract operation time regards in higher discount rate; (3) exogenous commodity bid up price pressures (e.g. petroleum price and political concerns).

Let as assume that slow growth in natural gas consumption (i.e. domestic and export) drives under optimal depletion rate (private point of view). Companies hold expensive ratios of useless reserves related to possible market sales (without taking into account new needed investment). Therefore, the depletion maybe is not below monopoly behaviour but is certainly below the level of competitive market targets.

Fixing price dynamics doesn't allow reaching a liquidity market or incorporates correctly social opportunity costs. This mechanism is criticisable at theoretical level, because it doesn't assure a correct intertemporal assignment – hence it is not probable that price path converge with optimal depletion rate neither in short or long run and vice versa.

Finally, highlight that this exercise is the first approach with the aim to understand the overall feedback effects of price path over optimal depletion rate in natural gas market in Bolivia. The model needs to improve the experiment design in order to incorporate more consistent approaches.

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