Natural Gas Supply Behavior under Interventionism: The Case of Argentina

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ABSTRACT

We address the causes behind the significant drop in natural gas production in the 2000s in Argentina, starting from a basic supply model that depends on economic incentives, and adding control variables related to different potential explanations such as firm specific (or area specific) behavior and the role of contractual renegotiation of concessions extensions. Results from a panel data of production areas between 2003 and 2013 show that once a basic supply-past production (or reserve) relationship is modeled, other often mentioned effects become non-significant. Chiefly among them are firm specific effects that were used as a central argument for the nationalization of YPF in 2012. Rather, the evidence shows that the observed downcycle conforms to the prediction of a simple model of depressed economic incentives acting upon mature conventional natural gas fields and hindering investment in reserve additions or new technologies. The results are robust to the nationalization of YPF, after which aggregate production continued a downward trend for two years, although are insufficient to capture an ongoing reconfiguration of incentives and risks in the forthcoming transition to shale gas production.

Keywords: Natural gas, Production, Exhaustible resources, Argentina

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1. INTRODUCTION

Argentina became, in the last quarter of the past century, an important producer of natural gas after some important discoveries of conventional resources in Patagonia. The country followed a rapid and economy-wide substitution in residential and commercial segments, the industrial sector, electricity generation and even transport. Indeed, it has been recognized as part of the group of countries used to illustrate a fast and deep penetration process of natural gas (see Hansen and Percebois, 2010, chapter 4). At the beginning of the 2000s natural gas had a share well above 50% in the primary energy mix and several exports projects mainly to neighbor countries (mainly Chile) were set to take up to 20% of domestic production. More than two decades ago, an evaluation mission by the World Bank (1990) commended the important substitution to natural gas performed by the country, but alerted that unless supply could evolve rapidly too, there could be problems in attending all segments of demand (including exports). The report even conjectured that if the status quo they were observing extended into the future, the country could hit a critical reserve-production ratio in 2002. This prediction actually happened, but with the unfortunate coincidence of a large

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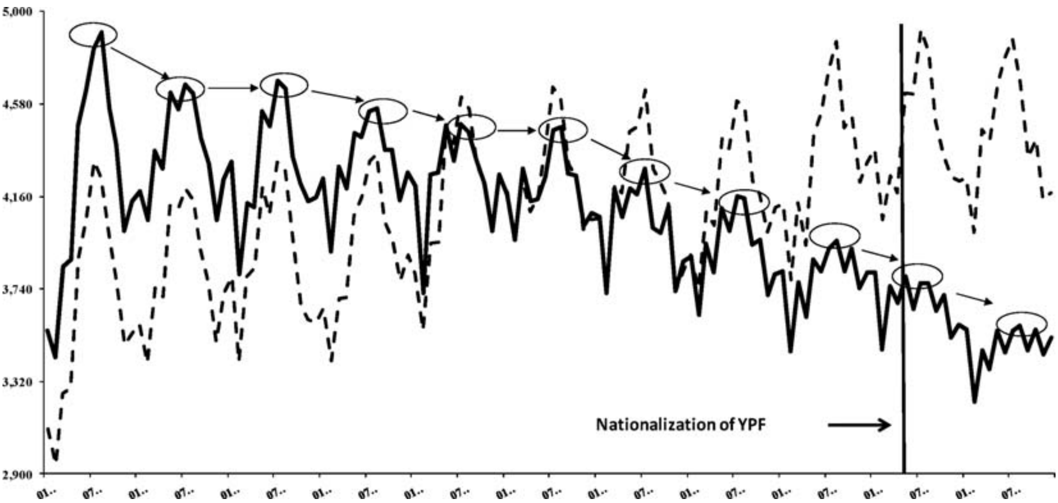
Figure 1: Argentina: Natural Gas Production and Consumption 2003–2013



Note: In million m[3], production (solid line), consumption (dotted line)
Source: IAPG and Enargas

macroeconomic crisis, an extensive contractual default and the introduction of long-government intervention in energy markets (see e.g. Pollitt, 2008; Cont et al. 2011). In less than two years, the country faced an energy-crunch in the natural gas market which led to mandatory export cuts to Chile, broken contracts (Navajas, 2008) and a command-and-control management of imbalances, while electricity and natural gas prices were kept frozen for main demand segments.[1]

Earlier quantitative decompositions of the energy imbalances attributed a central role to demand (see e.g. Cont and Navajas, 2004), but after peaking in 2004 natural gas production has been falling consistently. Figure 1 represents the monthly evolution of aggregate natural gas production and domestic consumption from 2003 to 2013. The Figure shows that the fall in production has been matched by a corresponding increase in net imports in order to satisfy domestic demand. Thus, supply and demand behaved in an unrelated manner during the sample period, both contributing at different stages to the widening gap covered by a drastic switch in the net export position. Demand did not show, on this basic accounting, an effect upon supply dynamics, except for demand shocks years with harsh winters or due a very short and mild recession in 2009. Furthermore, the nationalization of the leading firm in the gas market (YPF) in early 2012 did not change the observed underlying dynamics.

Different arguments put forward by academic studies or policy debates have attempted to explain this phenomenon, depending on the role attributed to firm behavior on the one hand and the policy or regulatory environment on the other. The government or official view attached the culprit of the fall in production to the lack of investment efforts by large firms and in particular YPF (controlled by Repsol since 1999), which ended-up in an expropriation announcement in April 2012.[2] Other views regarded the drop in production as the expected evolution of conventional

1. Price controls were asymmetric in the sense of being too strong in electricity and natural gas and less restrictive or relatively soft in other segments. In the case of LPG (the main substitute for natural gas for households—about 33%—without access to natural gas) higher prices led to very different and testable behavior of demand (e.g., Navajas, 2009).

2. This view was officially stated in a government report that justified the expropriation of Repsol (De Vido and Kiciloff, 2012) but had been voiced much earlier. It was also stated in a Federal Agreement on Hydrocarbons signed in February 2012 by the Federal Government and the oil producing Provinces (which, by the 1994 Constitution own hydrocarbon

natural gas resources beyond the impact of regulatory interventions (Ponzo et al., 2011). Others see a central responsibility in energy policy either due to earlier planning pitfalls—like the one waved by the World Bank report mentioned above—or as a contractual disruption in natural gas markets created by an interventionist paradigm adopted since 2002 (see e.g. Navajas 2008; Recalde, 2011). Yet other commentators have mentioned strategic market behavior given the dominant role of YPF, albeit no paper has attempted to model or quantify the argument. Variants of these many explanations put different weights to investment efforts, lack of contractual renegotiation to extend concessions, a too permissive exports program in the late 90s, the under-performance of the major area (Loma de la Lata), departure from border prices embedded in imports from Bolivia and the like. However, these effects have not been tested in the received literature, and the empirical support for many claims relies on casual observation, descriptive statistics or partial relationships that do not control for other effects and therefore do not fit, in our view, into a credible methodological testing. Simple evaluations of production performance are not robust since they do not control for the maturity of areas. Investment performance is endogenous to economic incentives faced by firms. The observed drop in production is more general than a simple pattern attributed to certain areas or firms. Besides, strategic (coordinated) behavior explanations require some collusive behavior that does not fit into observed features such as asymmetries in market shares and excess capacity in the transport system (see Ivaldi et al., 2003 for structural elements that raise the likelihood of tacit collusion) or is contradicted by the absence of a policy reaction function that adjust prices to shortages (strategically engineered by shortages).

All these arguments were stated before the decision to nationalize YPF in early 2012 and therefore do not consider the empirical evidence on performance that emerged after such drastic change which was a culmination of several years of interventionism in natural gas markets. As Figure 1 shows, the evidence of pre and post nationalization performance in natural gas production in Argentina does not show structural change. Despite government short run expectations, the decline became more severe after nationalization for both the new YPF but in particular for the rest of the firms. This more recent evidence tilts the priors in favor of the central argument made in Barril and Navajas (2011) that associates the drop with depressed economic incentives acting upon mature conventional natural gas fields and hindering investment in reserve additions or new technologies. This is particularly important as Argentina was in 2013 just starting up the development of non-conventional natural gas[3] production with YPF now leading that process, after a substantial correction of price incentives.

resources and are the only power able to grant concessions for exploration and production). Under the umbrella of this agreement, most Provinces started to suspend and withdraw concessions in many oil and gas areas, with YPF suffering the strongest hit, amidst a political process that in April led to a government decision to declare a nationalization of YPF through an expropriation of 51% of the shares of YPF under the control of Repsol.

3. The turnaround from this situation is just beginning and will consolidate in the next decade. Leading this process is the substantial potential resources of non conventional hydrocarbons that were first recognized in April 2011 by a technical report prepared for the US Department of Energy (EIA, 2011) and later reconfirmed in a June 2013 report by the Energy Information Administration (EIA, 2013), both pointing to Argentina as having the second largest potential reservoirs outside North America. Estimates of (unproven) technically recoverable shale resources, in the case of natural gas, amounted to 802 Tcf (trillion cubic feet) which are equivalent to 21,654 billion of m^3 (cubic meters), about 67 times the amount of the current proven reserves of the country (the magnitude was 11 times in the case of shale oil resources) and 13% of the world resources identified in the US DOE reports. Uncertainty about these estimates does exist, both in terms of technical and economically recoverable magnitudes (Di Sbroiavacca, 2013), with some recent more prudent positions that show skepticism about the degree of profitability associated with initial exploration activities vis à vis uncertainties surrounding the tax and overall contractual/governance regime.

The aim of this paper is to use a basic theoretical framework and empirical modeling so as to contribute to the scrutiny of the likely factors behind the post 2003 sharp fall in natural gas supply in Argentina. The importance of clarifying at least some aspects behind recent production performance is crucial from both positive and normative perspectives. From a positive perspective we attempt to critically evaluate simple unconditioned arguments that explain aggregate production as arising from certain areas or firms and show instead that the phenomena is more general and therefore more market-driven. At a normative level, we hope to contribute to the current energy policy debate, pointing to economic incentives problems behind the status-quo policy and, while modeling the performance of conventional natural gas, helping at calling for the urgency to move towards non-conventional gas development.[4]

The structure of the paper is the following. In section 2 we provide a basic framework that we claim should be the starting point from where to refer the empirical evaluation of the drop in production. We do so by using a simple supply model of a non-renewable natural resource with a basic framework adapted from the literature (see e.g. Pickering 2008 and Medlock 2009) that allow us to derive an optimal supply from a producer—that in our representation is constrained by regulated prices—and is facing a depletion process (as reserves fall) that raises production costs (i.e. decreases productivity). We do not wish or attempt to proceed to structurally estimate or adjust this simple model to Argentine data. Instead, we use one main representation—the fact that production should be seen as conditional on reserves or, equivalently, cumulative past production—as a guidance to specify our empirical research on a large data base constructed for this paper and used for the first time in an econometric assessment of natural gas production performance in Argentina. In section 3 we account for the characteristics of our data set—a panel of the change in annual production of 168 areas of production between 2003 and 2013, the specification of our econometric equation and the definition and sources of the main variables. Natural gas supply depends on past accumulated production (or alternatively on remaining reserves) that represents resource depletion and on a set of controls to capture basin and area heterogeneity, firm effects, investment efforts, extension of concession contracts, link to an export project and demand effects as a reaction to winter rationing of industrial customers and electricity generators. Section 4 presents the results of our econometric testing and discusses the main results. Finally, concluding remarks and suggested extensions are included in section 5.

2. SUPPLY BEHAVIOR

Alternative strategies to model the behavior of natural gas production depend on the use of an optimization framework to derive supply in a manner related to the basic theory of exhaustible resources[5] and the explicit modeling of the exploration (drilling and discovery) process that precedes extraction or production either from geological models or from empirical econometric relationships.[6] In this section we sketch a simple model that is based on an explicit optimization and is simplified to capture the essentials of the factors we perceive as crucial in the particular period of the Argentine natural gas market that we are studying. Our setting is a workable simplification that

4. Simulations performed by Ponzo et al. (2011) also warn about the prospects of stabilizing production within conventional production processes, but do not stress the move to mobilizing investments in non-conventional (shale gas) production and instead call for demand management and renewable energy.

5. See for instance Heal and Dasgupta (1979); Krautkraemer (1998); Krautkraemer and Toman (2003) and Medlock (2009).

6. See Wells (1992) for thorough critical survey of these strategies.

lacks a detailed description of the exploration process and in particular the channel between exploration development and production. This should not be a nuisance given that we are data-constrained to study these channels, have much less comparative advantage to understand past and current geological processes and are interested in the final outcome represented by the dynamics of production.

Our setting is also very simple compared to more elaborated dynamic optimization models that allow interactions with price expectations formation and market structure and behavior. This is also a necessary simplification due to prevailing direct market interventionism, which implies fix pricing, absence of demand side interactions and diffuse expected parameters. Market structure in the upstream segment of the natural gas sector in Argentina has been recognized as a concentrated one since privatization in the mid-1990s (e.g. Petrecolla and Martinez, 2010). However, despite this inherited market structure,[7] a heavy interventionist regime was put in place since 2002, with open command-and-control features. Prices have been controlled and kept very low in real terms and in relation to border prices or opportunity cost values (see for example Cont et al. (2011)).[8] The excess demand regime (along with excess capacity in the transport system of domestic gas) that emerged since 2004 has been covered by imports or rationing of some (industrial) customers in cold winters. Mandatory or forced reallocation of quantities from exports or private sector contracts to regulated segments have been also a central part of an allocative mechanism that superseded market clearing and intervened in firm decisions. Given all this, price expectations have remained dominated by the interventionist market regime (particularly due to interventions to contracts between private parties to redirect quantities to serve regulated segments) and expectations on price changes in such a regime have been difficult to form. Even recent announcements concerning new pricing rules for unconventional gas discoveries have been blurred by pervasive potential temporal inconsistencies in the taxation of natural resources (see Boadway and Keen, 2009). Thus, firms have been adjusting passively to this regime and despite concentration and oligopoly interactions there is no room for strategic setting of prices or quantities, as the policy reaction function to the observed imbalances has been in practice very insensitive so as to avoid price adjustments.

We proceed by assuming three periods, where the current period of interventionism ("1") is preceded by a previous period ("0") of normal market behavior and followed by a future period ("2"). Past period values (denotes by "0") are all exogenous and given parameters in the optimization problem below, which considers only effects in the present ("1") and in the future ("2"). Total natural gas resources across periods are defined by $Y(IE_0, IE_1)$ and depend on initial reserves

7. Concentration measures have been relatively stable over our sample, with the HHI falling slightly from 1856 to 1796 in our data set and the CR_5 concentration ratio falling from 83.2% to 80.4%. The leading firm at the beginning of the sample (YPF) lost markets share (from 33.2% to 25.4%) and became the second biggest firm from 2010. Thus, the setting is not easily represented as one of a dominant firm, in part also for the considerations related to price reaction to a for example quantity setting oligopoly model. See for example Pickering (2008) for a supply/production performance model under different market structure in a quantity setting environment. See also Alhajji and Huettner (2000) and previously Griffith (1985) to model a dominant firm along with a competitive fringe setting in oil markets.

8. See Cont et.al (2011) Table A.1. Natural gas prices were kept frozen in nominal terms for regulated (residential, commercial and small industrial) segments until November 2008, when a partial de-freeze took place. Average end-user prices were about 1.3 dollars per MMBTU when a generalized freezing in 2002, after a large currency devaluation, send them to 0.5 dollars per MMBTU. Partial adjustments in some unregulated segments led average end-user prices to about 2 dollars per MMBTU at the end of our sample, while imports from Bolivia reached 10 dollars and substituting imports of LNG were above 14 dollars. The fact that seemingly unregulated segments faced prices at most at 3.5 dollars per MMBTU in such an unbalanced market with excess demand is an indication of the role of imports (made by the government who absorbed the cost of subsidies) and the overwhelming grip of command and control allocations.

at the beginning of 0 and exploration efforts driven by past investment IE_0 and current (period 1) investment IE_1, which increase available resources in the next period. Aggregate production across periods will necessarily add up to the resource size, i.e., $Y(IE_0,IE_1) = y_0 + y_1 + y_2$. Prices of natural gas at the wellhead are represented by the vector of past, current and (expected) future prices (p_0,p_1,p_2^e), which are assumed as fixed parameters with no interactions with domestic output equilibrium, as market clearing is provided from abroad through lower exports or higher imports, or simply by resorting to demand rationing.[9] Prices are assumed the same across areas of production, which fits into actual conditions. Cost functions associated with production of natural gas are simply assumed to depend on current production: $C_i = C_i(y_i)$ $i = 0,1,2$..[10] Investment spending in period 1 (the only period in which investment is chosen in our model) expands total resources (and therefore production in period 2) and enters into total costs separately at a cost $G_E(IE_1)$.

Given this setting, a firm in the current period 1 of (unexpected) intervention (with $p_1 < p_0$) will recalculate its optimal path of production and investment by maximizing the present value of profits as stated in (1), i.e. firms choose y_1 and IE_1 so as to maximize:

$$\Pi = [p_1 y_1 - C_1(y_1)] + \beta[p_2^e y_2 - C_2(y_2)] - G_E(IE_1) \tag{1}$$

$$\text{subject to } Y(IE_0,IE_1) = y_0 + y_1 + y_2 \tag{2}$$

where β is the risk-adjusted[11] discount rate applied to period 2 profits. Firms choose production and investment in period 1, while production in period 2 becomes endogenously determined by the total resource constraint (2), as $y_2 = Y(IE_0,IE_1) - y_0 - y_1$ and the maximization of (1) can be written in an unrestricted form in two variables.[12] The central motivation for using this simplified framework is to postulate a particular representation of the supply function that will serve as a starting point to our econometric specification in the next section. In the same vein, we further discuss the joint (along with y_1) determination of investment effort IE_1 (see expression (10) below).

A particular specification of problem (1)–(2) is the case of quadratic costs of production and investment, which allows a simple representation of the supply function. Assume that marginal

9. This conforms to the observed pattern in Argentina where cuts of exports to Chile and imports from Bolivia and an LNG facility have contributed to market clearing or rationing has been used as a last resort in the winter season. See Cont and Navajas (2004) and Navajas (2006) for a quantitative decomposition of the sources of the natural gas demand and supply imbalance at the beginning of the sample period.

10. As production depends on available resources there is an effect of accumulated past production or diminished reserves on costs which is negative as it reflects lower productivity from exhaustion of the reservoir, which is implicit in our formulation. This relationship can be also affected by the management of the reservoir which may also depend on maintenance investment activities (i.e. area management investment will diminish the negative effect of cumulative past production on current production). We contemplated these effects in the model of an earlier version of this paper but are not included here as they play a secondary role and are not amenable to testing.

11. This simple model is written in a certainty-equivalent fashion and can accommodate uncertainty in either the cost of capital and/or in the discount rate. In the latter case see for example Bohn and Deacon (2000) where a risk (probability) of expropriation acts depressing the discount rate.

12. We have kept a simplified formulation and notation although the model can be written in alternative forms. We thank an anonymous referee for letting us notice this fact. Starting with reserves R_0 and assuming that investment efforts in period 0 and 1 adds reserves (in periods 1 and 2 respectively) through the functions $F_1(IE_0)$ and $F_2(IE_1)$ respectively then production levels in periods 0, 1 and 2 have to satisfy the restrictions $y_0 \le R_0$ (1); $y_1 \le R_1 = R_0 + F_1(IE) - y_0$ (2) and finally $y_2 = R_1 + F_2(IE_1) - y_1 = R_0 + F_1(IE_0) + F_2(IE_1) - y_0 - y_1$ (3). This last restriction holds as an equality and can be written as expression (2) above in the main text with $Y(IE_0,IE_1) = R_0 + F_1(IE_0) + F_2(IE_1)$. The explicit inclusion of the other restrictions on y_0 and y_1 is avoided because they are not choice variables or in the case of y_1 it is assumed to be non-binding.

costs are increasing, i.e. $C_1 = 0.5cy_1^2$; $C_2 = 0.5cy_2^2$, and investment costs depend on the cost of capital ρ_E and are also quadratic, i.e. $G_E(IE_1) = 0.5\rho_E IE_1^2$. In this setting, we have from first order conditions that supply in the current period can be written as,[13]

$$y_1^* = \delta_0 + \delta_1 R_1 \tag{3}$$

$$\text{where} \quad \delta_0 = \frac{p_1 - \beta\ p_2^e}{c.(1+\beta)} \tag{4}$$

$$\delta_1 = \frac{\beta}{(1+\beta)} \tag{5}$$

$$R_1 = \ Y(IE_0, IE_1) - y_0 \tag{6}$$

Expression (3) establishes a linear relationship between production and reserves R (see e.g. Medlock (2009)) and is a well known consequence of assuming quadratic costs (see e.g. Pickering (2008)). Given the cost parameter and the discount rate (c, β), the supply of natural gas in the current period will depend (positively) on current prices and (negatively) on discounted future prices as well as (negatively) on past cumulative production and (positively) on remaining reserves. Expressions (4) to (6) also shows that investment effort IE affects endogenously interacts with current and future production, because is part of a simultaneous decision problem. In expression (6) we notice that remaining reserves in (at the beginning of) the current period also depend on investment efforts in exploration in the past period. The official complaint in Argentina about lack of investment effort in the past as a driver of falling production is well captured by this effect.[14]

Alternatively, we can write (3) as (7) denoting a negative relationship between current production and aggregate past production, which again shows the link with the choice of investment effort IE_1.

$$y_1^* = \phi_0 - \phi_1 y_0 \tag{7}$$

$$\text{where} \quad \phi_0 = \frac{p_1 - \beta p_2^e + \beta\ c\ \ Y(IE_0, IE_1)}{c(1+\beta)} \tag{8}$$

$$\phi_1 = \frac{\beta}{(1+\beta)} \tag{9}$$

The other first order condition in the maximization problem written in (1) and (2) relates to the choice of investments in exploration IE_1 in the current period. Interior solutions from these first order conditions again for the quadratic specification are given by,

13. Expression (3) comes from the first order condition w.r.t. y_1 which is the simple arbitrage intertemporal condition $(p_1 - cy_1) - \beta(p^e{}_2 - cy_2) = 0$ and substituting for y_2. The firm chooses the intertemporal allocation of production across periods, which is simultaneously determined with the decision to invest in period 1 to have more resources and production in period 2 (see expression (10)).

14. From expression (6) it is shown that remaining reserves comes from an identity that suggests that they depend on past investment efforts (affecting the total resource size Y) and on past production y_0.

$$IE_1^* = \frac{\beta}{\rho_E}[p_2^e - cy_2]\frac{\partial y_2}{\partial IE_1} \tag{10}$$

Investment in exploration, which only happens in period 1 in our model is a forward looking activity that depends on the ratio between the expected discounted cash flow $\beta(p_2{}^e - cy_2)$ and the cost of capital ρ_E. For this reason, and unlike the case of current production (which depends on reserves), exploration investment can become arbitrarily low or even zero (i.e. an interior solution as assumed in (10) is not even guaranteed) if the right hand side of (10) becomes too low or non-positive. Price expectations of sustained intervention in markets coupled with high capital costs risks (and expropriation risks, which eventually materialized in early 2012) and sunk investments may create a situation where investment becomes negligible (with only a symbolic amount due to contractual obligations to sustain concessions) and current production is positive and declining (given the absence of investment).[15] Our prior is that this is an ingredient of the sample we studied below that needs to be tested.

One query about the lack of incentives for investment voiced by some analysts in the Argentine case has been the shortening of the length of concessions and the need to avoid a last-period syndrome. Thus the call has been for an extension of concessions to overcome the sluggish behavior of investment and the drop in production. An extension of the concession can be seen as affecting the investment decision in (10) insofar as is equivalent to an increase in the discount factor β, implying higher investment. On the other hand, the effect on current production of a higher β is indeterminate (according to (3)). Thus, the quantitative effect of an extension of concessions in the production dynamics is an empirical question that needs to be tested.

To sum up, this section provides a simple framework that while capturing some stylized facts of the Argentine case serves for empirical modeling. Thus, in the next section we take the relationship between production and cumulative past production (or reserves) represented in (7) (or (3)) as the logical starting point in our empirical search for the determinants of natural gas production in Argentina, from which we explore the relevance of several control variables (basin effects, firm effects, concessions extension, demand effects, etc) related to the hypothesis or effects that have been mentioned in the introduction. It should be noted that the aim of this paper is to explain the factors behind the empirical observation of a sustained drop in natural gas production rather than to proceed to a structural estimation of the model used above, which only serves as a basic theoretical framework to organize our search. In fact, the basic equilibrium theory outlined in the previous model tell us nothing about the alternative specifications or functional forms (where the linear form of (3) is a rather restrictive one arising from also restrictive assumptions) and about alternative effects of other control variables (that nevertheless may be related to some of the variables of the basic model). So empirical modeling should also consider these limitations not as a nuisance but as something to be completed by the evidence from the data generation process.

3. EMPIRICAL MODELING

Our empirical analysis is based on a data on annual production of NG at the area level, after an effort to build our data set from detailed raw data provided by the *Instituto Argentino del*

15. In our model an increase in capital costs ρ_E due to higher risk reduces investment without any effect on current production. An alternative formulation of introducing uncertainty adjusting (reducing) the discount rate has the same effect but reduces current production. See Bohn and Deacon (2000) where investment (or capital invested per unit of resource) is negatively related to a risk of expropriation and positively related to future prices, but at the same time current production is positively related to the risk of expropriation.

Petróleo y el Gas (IAPG). This basic data was further evaluated and made consistent to allow a correct identification of the areas across years.[16] The original data comes from a panel of annual production by area from 1993 to 2013. Given that our objective in this paper was to study the drop since 2004, we use twelve consecutive years of production from 2002 to 2013, which in annual rates of change reduces the observations to 1298, representing 168 areas.[17] The data identifies the firm that operates the area (there is only one operator per area) and the basin in which is located.

We gathered, from the same source, data on proven reserves and were able to construct annual aggregate past production for all areas. While data on annual aggregate past production is very reliable, we found some revisions and therefore instability with the data on proven reserves.[18] We thus focus our empirical model on aggregate past production (as in (7)) rather than reserves (as in (3)). However, as in our testing we express both variables as a ratio in relation to total resources by area (Y in the notation used in the previous section), both definitions become related and we explore the sensitivity of results to both definitions. Cumulative past production (or remaining reserves) are according to the previous model a main variable so as to condition the equation on production performance.

As investment is an endogenous variable and a determinant of production performance we explicitly consider its behavior in our empirical modeling. We use a data set on the number of wells drilled per year for each of the 168 areas as from 1997. To cope with endogenous problems in our production equation we model investment behavior in a first stage below, where investment depends on variables suggested by the model of section 2. Investment (as well as production) depends on a price incentives indicator expressed as the gap between the price of imports of natural gas from Bolivia and domestic prices received by local producers, the cost of capital[19] and the observation of some special incentives schemes (called "Gas Plus") for additional production, at higher prices.[20] Other variables such as the observation of a renegotiation of area concessions (made between 2007 and 2010) are also included in our data set and in the empirical model.[21]

16. We had to perform a detailed analysis of the original data set provided by IAPG in order to make consistent the names of the areas across time, as denominations changed in many cases in the early 1990's due to new concessions and the privatization of YPF process.

17. Besides the work on the homogenization of data, and despite the fact that the sample selected is the right one to represent the "period of interventionism" defined in the analysis of section 2, there were several data limitations at this stage to the testing of a broad model for the large sample 1993–2013. For instance, key variables such as proven reserves or exploration efforts (new wells) are available after 1994, and the later variable comes in a different regional aggregation before 1997. This fact and the extension of the lag we use (3 to 6 years) to capture the effects of exploration efforts, reduces the sample employed.

18. Proven reserves data are estimates that may oscillate depending on considerations by firms on economically recoverable resources from a given reservoir and therefore depend on the economic environment and the influence of regulatory policies. Cumulative past production is instead a much objective and measurable variable.

19. We include a proxy of the cost of capital for Argentina as expressed by the spread of a reference sovereign bond over US Treasuries We also used sector specific data on the return on debt for private firms such as Petrobras Argentina.

20. Since 2008 the government implemented the Gas Plus incentive program that selected specific projects in about 40 areas so as to receive a higher price (about twice the average price) in exchange for higher production; see EIA (2012, pag.7). Not all the approved projects entered into a drilling phase or into production but, by the end of 2012, about 335 wells in 26 areas operated by about 13 firms in all basins in Argentina were part of this program. Most of them were located in the Neuquina basin.

21. All renegotiations dummies are included in the sample. Being able to distinguish between them we are capable to look for different cases in case some of them show to be significant. In particular this is the case of the Anticlinal Grande–Cerro Dragon area in the San Jorge Basin, which has been one of the most commented renegotiations.

To deal with effects attributed to firms or basins, we explicitly test for the additional effects due to the performance of YPF and Loma-La-Lata (the largest area in Argentina and operated by YPF). In addition, we include dummies for "large firms" and "medium firms" that capture the performance of firms different from the largest one (YPF) and that might have been subject to different expropriation risk.

Finally and although evidence from Figure 1 show that supply and demand behaved independently with net trade being the result (and therefore caused by both demand and supply), we account for possible demand shocks or interactions through GDP growth and an indicator of an (intra-year) shift in demand (towards the summer) that captures demand shocks due to cold winters.[22] While GDP growth may be expected to have a positive coefficient, the demand shift effect is expected to have a negative coefficient since it involves a bottleneck effect in the summer that detracts production capabilities. Table 1 summarizes the definition of variables.

The specification we adopt to study the drop in natural gas production between 2003 and 2013 is summarized in equation (12), while the investment equation modeled in the first stage is shown in equation (13). As the explanatory variable in equation (12), we take the logarithm of the ratio between production in t and production in t-1 in the area i, approximating the annual rate of change. The independent variables are the log of the ratio between accumulated past production and total resource endowment followed by the rest of variables and a set of controls defined below. In the case of investment we instrument it through equation (13) with numbers of wells drilled as the explained variable, cost of capital and price incentives and other controls (as the GASPLUS incentive program dummy) capturing across area variability.

$$\log\left(\frac{y_{it}}{y_{i,t-1}}\right) = \beta_0 + \beta_1 \log\left(\frac{y_{0,it}}{Y_{it}}\right) + \beta_2 IE_{i[t-6,t-3]} + \beta_3 \log(PG_t) + \beta_4 B_i + \beta_5 YPF_i + \beta_6 LLL_i \tag{12}$$

$$+ \beta_7 LF_i + \beta_8 MF_i + \beta_9 \log(GDP_t/GDP_{t-1}) + \beta_{10} DEMSHIFT_{it} + \beta_{11} RENEG_{it} + \hat{u}_{it}$$

$$IE_{i[t-6,t-3]} = \alpha_0 + \alpha_1 \log\left(\frac{y_{0,it}}{Y_{it}}\right) + \ldots + \alpha_{10} RENEG_{it} + \alpha_{11} CP_t + \alpha_{12} GASPLUS_{it} + \hat{v}_{it} \tag{13}$$

Where ("log" means natural logarithm in (12) and (13))
$\log(y_{it}/y_{i,t-1})$: Growth rate of area i production in year t.
$y_{0,t}$: cumulative past production in area i in year t.
$Y_{it} = y_{0,it} + R_{it}$: resource size in area i in year t.
R_{it}: remaining proven reserves in area i in year t
IE_{it}: exploration investment effort in area i from $t-3$ to $t-6$.
PG_t: Price gap between imported natural gas and domestic.
B_i: dummies for the basin in which the area is located (Austral, San Jorge, NOA).

22. This is so because a shift of demand towards the summer has occur in some years, as rationed users in the manufacturing sector moved demand to the months where first-served users (residential and commercial) were not active or had very low demand. The same effect was observed for thermal electricity generators, as (cheaper, or price controlled) natural gas was available in the summer to avoid use of more expensive liquid fuels. For some observers, this change in the seasonal pattern of the demand for natural gas had both a cause and a consequence. The cause was the price repressed regime that led to a strong excess demand scenario particularly visible in cold winters. The consequence was that summer production tasks in the fields or areas—directed at preparing the areas for the winters—suffered from this shift in demand. Our estimates below tend to confirm that the seasonal shift in demand had a negative effect on production performance.

YPF_i: dummy for YPF (LLL excluded).
LLL_i: dummy for Loma de la Lata area.
LF_i: dummy if the area is operated[23] by a large (top 5) firm (YPF excluded).
MF_i: dummy if the area is operated by a medium (top 10) firm (top 5 excluded).
$\log(GDP_t/GDP_{t-1})$: Annual growth of GDP in year t.
$DEMSHIFT_{it}$: A shift of production to the summer in area i in year t.
$RENEG_{it}$: a step dummy for areas after a renegotiation (extension) of a concession.
CP_t: weight average cost of capital in year t.
$GASPLUS_{it}$: dummy if the area has projects included in the GASPLUS incentive program.

Expected coefficients are $\beta_1 < 0$, $\beta_2 > 0$, $\beta_3 < 0$ (all according the model of section 2), $\beta_4 = \beta_5 = \beta_6 = 0$ (because our prior is that the drop in production is not explained neither by basins or firms), $\beta_7 = \beta_8 = 0$ (if there were no differential behavior regarding the size of the firms), $\beta_9 = 0$ (because we argue that demand effects are not relevant to explain production dynamics in our sample), $\beta_{10} < 0$ (because we expect demand shifts be detrimental to productive effort as they congest production preparation for the winter, made in the summer), and β_{11} is indeterminate according the model in section 2.

Table 1: Definitions and Sources of Variables

Coefficient	Variable	Definition	Source
	Production of natural gas	Quantities in thousands of m^3	IAPG
β_1	Cumulative production	Production between 1991 and $t-1$	IAPG
β_1	Remaining proven Reserves	Quantities in thousands of m^3 at the beginning of the year	IAPG
β_1	Resource size	Sum of cumulative production and remaining proven reserves	IAPG
β_2	Exploration	Number of exploration and advanced NG wells drilled between $t-6$ and $t-3$	IAPG
β_3	Pricing gap with Bolivian imports	Price gap between imported natural gas and domestic	Own elaboration
β_4	Austral	Binary variable, $=1$ when the area is located in Austral basin	IAPG
β_4	San Jorge	Binary variable, $=1$ when the area is located in San Jorge basin	IAPG
β_4	Noroeste	Binary variable, $=1$ when the area is located in Noroeste basin	IAPG
β_5	YPF	Binary variable, $=1$ when the area is operated by YPF (LLL excluded)	IAPG
β_6	Loma La Lata (LLL)	Binary variable, $=1$ when the area is Loma La Lata	IAPG
β_7	Leaders	Binary variable, $=1$ when the area is operated by a large (top 5, YPF excluded) firm	IAPG

(continued)

23. Results presented in Section 4 remain if we define firms as "majority shareholder" rather than "operators" in our sample. As some of the firms that operate the areas are not the majority shareholder this distinction may create doubts about actual incentives. However, results indicate that there is no sensitivity to this redefinition.

Table 1: Definitions and Sources of Variables *(continued)*

Coefficient	Variable	Definition	Source
β_8	Medium firms	Binary variable, = 1 when the area is operated by a medium (top 10, top 5 excluded) firm	IAPG
β_9	Rate of growth	Rate of growth of GDP	INDEC/Congress
β_{10}	Demand Shift	Quotient between monthly average summer production (January, February and March) and monthly maximun production in the year	IAPG
β_{11}	Renegotiations	Binary variable, = 1 when the extension of the area has been renegotiated	IAPG
α_{11}	CP	Yearly cost of capital in Argentina	Damoradan Online; BCRA; Mecon
α_{12}	Gas Plus	Binary variable, = 1 when the area has projects included in the Gas Plus incentive program	IAPG

4. RESULTS

We estimate (12) and (13) as a pooling model for 1298 observations covering changes in production for 168 areas between 2003 and 2013. Tables 2 and 3 report the main results. Results of testing the production equation (12) with OLS and 2SLS are reported in Table 2 in columns (1) to (4). The investment equation (13) which is instrumented in a first stage for the previous 2SLS is reported in Table 3. Variables coefficients are shown in rows.

Table 2 report results of the production equation (12) in the first two columns and repeat the estimation using remaining reserves instead of aggregate cumulative past production in the last two columns. The results show no major difference between OLS and 2SLS estimation procedures. Our main explanatory variable to condition production performance in our reference model of section 2, namely cumulative past production or remaining reserves, is significant in all specifications. The constant term—which in our specification (given the chosen dummies) represents the supply behavior of small firms in the Neuquina Basin that have not renegotiated concessions—is significant and positive showing that small firms less subjected to expropriation risks have had a better production performance. Investment effort does not show up as a significant determinant in our sample, even after a proper instrumentation. Instead, there are other three significant variables in the empirical model. The first is the "medium size firms" variable reflecting the fact that their performance was also superior to large firms due to being less exposed to expropriation risks. The second is the "demand shift" variable that captures a shift in demand (i.e. a less peaked demand with a shift towards the summer) due to abnormal industrial demand rationing during the winter, which in turn is a by-product of the disequilibrium caused by the intervention during the sample. The third is the (positive) renegotiation effect of one important area (Cerro Dragón) performed in 2007. These effects survive to across the regressions that either use cumulative past production or remaining reserves although are sensitive to OLS or 2SLS estimation.

While there are no differences between OLS and 2SLS procedures, the latter is important insofar as it allows looking at the investment performance equation (13). This is shown in Table 3. The role of prices in the performance of investment is captured in general (at 5% confidence) by the price gap between domestic and border prices (which is a time dependent variable similar for all areas) and across areas by the strong significant effect of the GASPLUS dummy. Our cost of capital variable (again time varying and similar for all firms, i.e. not capturing different expropriation

Table 2: Regression Results for Production Performance, Equation (12)

	White SD			
2003–2013	Equation (12)		With Remain Reserves	
Dependent variable: $\ln(prod_t) - \ln(prod_{t-1})$	OLS	2SLS	OLS	2SLS
1. Constant	0.52**	0.52**	0.84**	0.84**
2. Cumulative past production	−0.16**	−0.16**		
3. Remain Reserves			0.08**	0.08**
4. Number of Wells Drilled	0.01	0.01	0.00	0.02
5. Pricing gap with Bolivian imports	0.00	0.00	0.00	0.00
6. Basin				
a. Austral	−0.01	−0.01	−0.03	−0.02
b. San Jorge	−0.06	−0.05	−0.06	−0.05
c. NOA	−0.18	−0.18	−0.18	−0.18
7. YPF	0.07	0.07	0.04	0.04
a. YPF 2012–2013	0.03	0.03	0.04	0.04
8. Loma La Lata Area	0.02	−0.04	0.04	−0.08
9. Leader Firms	0.04	0.04	0.05	0.05
10. Medium Firms	0.10*	0.09*	0.08*	0.08 +
11. Rate of growth	−1.04	−1.05	−1.01	−1.04
12. Demand Shift	−0.72**	−0.72**	−0.82**	−0.83**
13. Renegotiations	−0.04	−0.04	−0.07*	−0.08*
a. Anticlinal Grande–Cerro Dragón	0.13**	0.09	0.14**	0.05
13. Year dummies				
a. 2003	Yes	Yes	Yes	Yes
b. 2009	Yes	Yes	Yes	Yes
14. Others dummies				
a. San Jorge 2011–2012–2013	Yes	Yes	Yes	Yes
b. NOA 2011	Yes	Yes	Yes	Yes
Observations	1298	1298	1298	1298
R squared	0.16	0.16	0.13	0.12

Note: + significant at 10%;* significant at 5%; ** significant at 1%.

risks) does not show up as significant. Thus, price incentives have been behind the observed low equilibrium concerning investment decisions.

An important result shown in Tables 2 and 3 is that other often mentioned area-specific or firm specific reasons for the decline in natural gas production are non-significant, with some differences observed in the case of investment performance. For example the "YPF effect" and the "Loma la Lata effect", both made responsible in many allegations steaming from casual observation based on descriptive non conditioned statistics of production performance do not appear as significant controlling for other variables. What the results tell us is that, while very important, the drop in production observed for YPF and Loma La Lata are not abnormal or dissimilar with respect to other areas or firms pointing to a common rather than a particular process. On the other hand, evidence from the estimated coefficients in the investment performance equation does indicate a subnormal investment effort of YPF outside (but not inside) Loma La Lata.[24]

24. The dummies report in Table 3 for Large (excluding YPF) and Medium firms show that they have had a better investment effort performance than YPF, but this does not apply to the Loma La Lata area.

Table 3: Regression Results for Investment Performance, Equation (13)

2003–2013	Without White SD		White SD	
Dependent variable: Number of Wells Drilled	Production	Reserves	Production	Reserves
1. Constant	0.78	0.69	0.78	0.69
2. Cumulative past production	0.08		0.08**	
3. Remain Reserves		0.05		0.05 +
4. Pricing gap with Bolivian imports	−0.16*	−0.15*	−0.16*	−0.15*
5. Basin				
a. Austral	−0.20 +	−0.19	−0.20 +	−0.19 +
b. San Jorge	−0.39**	−0.41**	−0.39**	−0.41**
c. NOA	−0.03	−0.03	−0.03	−0.03
6. YPF	−0.13	−0.09	−0.13 +	−0.09
a. YPF 2012–2013	0.12	0.11	0.12	0.11
7. Loma La Lata Area	6.87**	6.88**	6.87**	6.88**
8. Leader Firms	0.46**	0.43**	0.46**	0.43**
9. Medium Firms	0.36**	0.37**	0.36**	0.37**
10. Rate of growth	2.32	2.32	2.32	2.32
11. Demand Shift	0.17	0.27	0.17	0.27*
12. Renegotiations	0.19	0.21 +	0.19	0.21
a. Anticlinal Grande–Cerro Dragón	4.02**	4.02**	4.02**	4.02**
13. WACC	−5.37	−5.34	−5.37	−5.34
14. Gas Plus	1.11**	1.11**	1.11**	1.11**
15. Year dummies				
a. 2003	Yes	Yes	Yes	Yes
b. 2009	Yes	Yes	Yes	Yes
16. Others dummies				
a. San Jorge 2011–2012–2013	Yes	Yes	Yes	Yes
b. NOA 2011	Yes	Yes	Yes	Yes
Observations	1298	1298	1298	1298
R squared	0.31	0.31	0.31	0.31

Note: + significant at 10%;* significant at 5%; ** significant at 1%.

Our estimations also allow us to test for another often mentioned—particularly in the energy business community—effect for natural gas production drop in Argentina, namely the (absence of) renegotiation of concessions extensions.[25] In the simple model of section 2 extensions may be seen as enlarging the horizon of decisions and (for given a discount rate) may increase the marginal benefit of investment and production in the future. But this inter-temporal allocation of production effort makes the effect on current production ambiguous. In our results in Table 2, the renegotiation dummies effect on the rate of change of natural gas production are in general non-significant, except for the Anticlinal Grande–Cerro Dragon area. Thus, our results suggest that this area was underperforming until it renegotiated its concession in 2007, to become more dynamic after that year. A similar result is confirmed in the investment performance equation in Table 3.

25. Most of the concessions of areas in Argentina were granted by the federal government, dated from the deregulation and privatization of the early 90s and its time horizon was not approaching a last period. Even so they were judged as prone to be extended by the new concession authorities (Provinces) that emerged from the implementation of a constitutional reform in the mid 90s. Thus, a few areas (including the largest one Loma de la Lata) extended its concession period before 2007 and some more did so since 2007.

Finally another important testing is to see whether the nationalization of YPF has changed the performance behavior of the firm. While there is ample evidence that this is happening in Argentina our results do not capture such change, perhaps due to the frequency (annual) of our sample. YPF started in 2013 to perform better than the rest of the sector and this has happened amidst strong government support both in terms of incentives for additional production and access to hard currency.[26] Mirroring this improvement was a deterioration of the performance of other large firms leading to an extension of the drop in aggregate production in the two years after nationalization. The results do not allow us to capture such change and instead suggest that at an aggregate level the depressed-incentives regime that originated after the 2002 had not been reversed in 2013.

5. CONCLUSIONS

The main result of this paper is that the drop in natural gas production experienced by Argentina can indeed be modeled from a basic standard theory approach, which is the natural setting to start exploring the significance of other often cited explanations attributed to firms, areas, renegotiation of concessions. The role of past investment is considered in our framework and although it is endogenously determined it can nevertheless suggest a similar explanation. Our results are clear enough on the scant evidence in favor of firm-specific or area-specific effects that may suggest abnormal behavior and on the relative low power on production dynamics on renegotiations-without-economic-signals. The investment performance reinforces the evidence that is pretty much consistent with the deleterious effect of very low price signals on an already mature conventional gas pattern. Past investment efforts are present insofar as they determine the dimension of the natural gas resource base at the beginning of an interventionist era that is still in place. Whatever the mismatch between forecasted and accomplished required investments in the years previous to the interventionist era, the fierce control of prices and market transactions validated ex-post any over-conservative attitude towards investment in the natural gas upstream. The results are robust to the YPF nationalization decision of 2012, showing that the central features of our empirical model did not suffer from that change. With our sample ending in 2013 we cannot detect a change in the relative performance of YFP vis à vis the rest of the firms that reflects the changed incentives after nationalization. The recent move towards non-conventional gas with substantially higher prices is a central part of this incipient change.

We think that while the results of this paper are already robust enough to contribute to the understanding of the causes behind the drop in natural gas production in the 2000s in Argentina, they have also opened suggested lines of research to improve the modeling of production performance in recent years. One has to do with the interpretation of the observed phenomena in Argentina

26. At the beginning of 2013 the government proposed a new incentive scheme to firms so as to pay differential prices for the production of natural gas above an agreed declining path, with prices substantially above those regulated in recent years. The advantage of YPF was twofold in terms of being the first to sign such an agreement and being in a favorable position to overcome doubts about the time inconsistency of such proposal (given that natural gas prices paid by customers remained at very low levels and those higher prices offered to firms would depend on government subsidies). Another advantage of YPF was the preferential access to foreign currency, in a macroeconomic regime were firms have no open access and are constrained by hard capital controls to make external payments (including dividends). One fundamental reason behind these advantages has to do with the blurred separation between regulators and YPF, as energy authorities are members of the board, receive fees for their participation and show themselves completely side by side with the executive branch of the firm.

as a process related to a foretold nationalization/expropriation. A more detailed analysis of the decision and performance before and after the expropriation decisions and the asymmetric behavior of YPF and other large firms may be accomplished using the framework and testing the predictions of models such as that of Bohn and Deacon (2000). A second line has to do with the interpretation of this process as part of a political equilibrium (such as that modeled in Kawamura, 2013). Finally another promising line is to model the restoration of price signals in 2013 as part of a transition to unconventional resources, understood as a technical change in the sector that may redefine future resources.

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