# What drove down natural gas production in Argentina?

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**Abstract**

We address the causes behind the drop in natural gas production in Argentina since 2004, 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 absence of contractual renegotiation of concessions extensions. Results from a panel of the change in natural gas production in all areas between 2004 and 2009 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 and the role of renegotiations of concessions extensions. We find preliminary evidence that post 2007 renegotiations –which are associated with better price prospects- may have had an impact in correcting production decline in one leader firm. Other significant effects come from a negative impact of a change in the seasonality of production that in turn can be related to demand rationing and to price controls. Overall, the evidence suggests 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.

*JEL classification:* Q3; Q4

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*Keywords:* Natural gas; Production; Exhaustible resources; Argentina.

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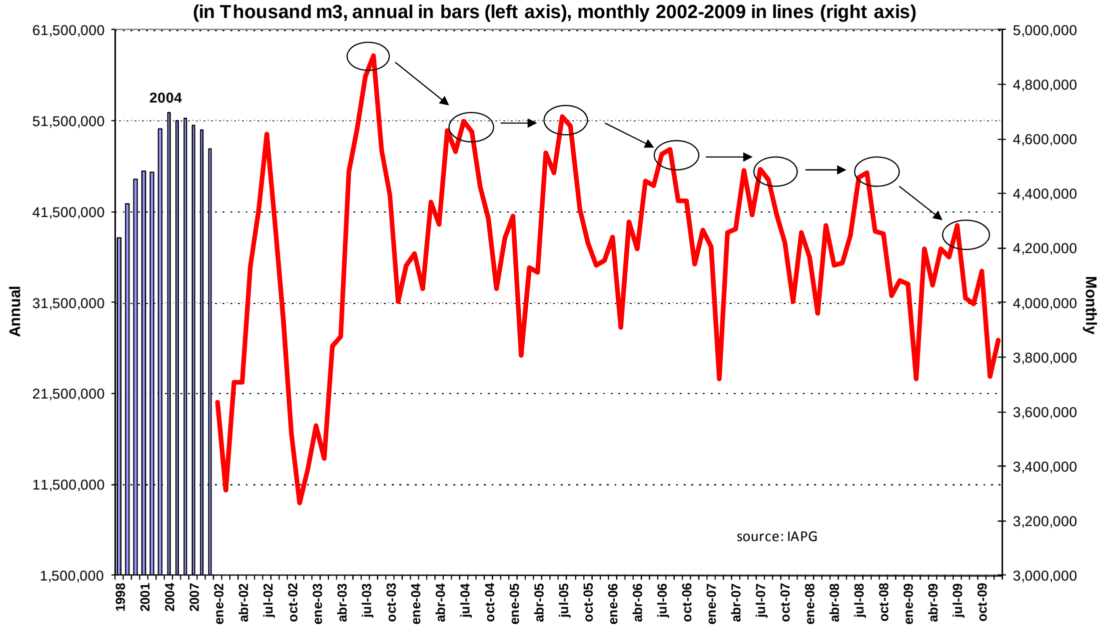
## 1. Introduction

Natural gas production in Argentina has experienced a seemingly bubble dynamics in the last 20 years, with a pronounced rise and fall separated by a peak in 2004. Figure 1 represents the dynamic of the aggregate natural gas production since 1998 with monthly dynamics from 2002 to 2009. Different hypothesis have been attempted to explain this phenomenon depending on the role attributed to firm behavior on the one hand and the regulatory environment on the other. To some observers, the culprit of the fall in production since 2004 is explained by the lack of investment efforts by large firms and in particular YPF. The alternative view allocates a central responsibility to the contractual disruption in natural gas markets created by an interventionist paradigm adopted since 2002. Variants of these 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 and the scant empirical support for these claims relies on casual observation, descriptive statistics or partial relationships that do not control for other effects.

**Figure 1**
**Argentina: Natural Gas production 1998 - 2009**
**(in Thousand m3, annual in bars (left axis), monthly 2002-2009 in lines (right axis)**




The aim of this paper is to contribute to the identification of the factors behind the post 2003 drop. The importance of clarifying the relative role of the above competing hypotheses is not a minor one. From a positive perspective it helps to better understand factors behind natural gas production dynamics in Argentina and the future path of conventional natural gas production. At a normative level, it may clarify some aspects of the current energy policy debate, provide some evidence that may be useful for the resolution of disputes in litigation processes around

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contractual breaks and finally it may help at assessing the urgency behind the move towards non conventional gas development at higher prices.[1]

The structure of the paper is the following. In section 2 we sketch a simple supply model of a non renewable natural resource that allow us to derive an optimal supply from a producer that is constrained by regulated prices and is facing a depletion process (as reserves fall) that raises production costs (i.e. decreases productivity). This simple model gives us some guide 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 139 areas between 2004 and 2009-, 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 changes in the seasonality of demand 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[2] 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.[3] 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 an oversimplification that 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.[4]

We assume three periods, where the current period of interventionism ("1") is preceded by a previous or past period ("0", of more normal market behavior) and a future period ("2") that depends on expected prices. Past period values are exogenous factors that are taken as given in the

[1] See Navajas (2010) for an account of performance and policy options in the Argentine energy sector.

[2] See for instance Heal and Dasgupta (1979); Krautkraemer (1998); Krautkraemer and Toman (2003) and Medlock (2009)

[3] See Wells (1992) for thorough critical survey of these strategies.

[4] Since 2002 prices have been controlled and kept very low in real terms and in relation to import values (see for example Cont et al. (2009)). Demand has been growing fast and above domestic supply and has been covered by imports or rationing of some (industrial) customers in cold winters. Price expectations have remained dominated by the interventionist market regime (which has also intervened on contracts between private parties to redirect quantities to serve regulated segments) and expectations on precise price changes in such a regime have been difficult to form. Even recent announcements in December 2010 concerning new pricing rules for unconventional gas discoveries are blurred by pervasive potential temporal inconsistencies in the regulation of energy markets.

optimization which considers only effects in the present and in the future. Natural gas resources are (up to exploration efforts driven by investment $IE_1$, that have an impact in the next period) fixed and given by Y. Aggregate production across the three periods will necessarily add up to the resource size, i.e., $Y=y_0+y_1+y_2$. Prices of natural gas at the wellhead are represented by the vector $(p_0,p_1,p_2^e)$, 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.[5] Prices are assumed the same across areas of production, which fits into actual conditions. Cost functions associated with production of natural gas depend on current and past (accumulated) production: $C_0=C_0(y_0)$; $C_1=C_1(y_1,yo)$; $C_2=C_2(y_2,y_0+y_1)$. The effect of accumulated past production is negative (up to management of the reservoir that depends on investment *IM*) as it reflects lower productivity from exhaustion of the reservoir (an effect that cannot be reverted but only diminished by *IM*). Both investment spending enters into total costs as $G_E(IE)$ and $G_M(IM)$.

Given this setting, a firm (under competition) in charge of a production area in the current period 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)

$$\{y_1, IE_1, IM_1\} \arg\max \Pi = [p_1.y_1 - C_1(y_1, y_0, IM_1)] + \beta.[p_2^e.y_2 - C_2(y_2, y_0 + y_1, IE_1, IM_1)] - - G_E(IE_1) - G_M(IM_1) \qquad (1)$$

subject to $Y = y_0 + y_1 + y_2 \qquad (2)$

where β is the discount rate applied to period 2 profits. We are assuming that costs depend on past exploration investment (through its effect on production and therefore on –nonlinear- costs) and on area management investment.[6] We are further assuming that the firm will not make any management investment in period 2. The firm of course chooses only $y_1$ as this also determines $y_2$ through the resource constraint (2).

Dealing with problem (1) for the case of quadratic costs of production and investment turns out in a simple representation of the supply function. We assume that $C_1=0.5.c.y_1^2+0.5.\hat{c}(IM).y_0^2$ ; $C_2=0.5.c.y_2^2+0.5.\hat{c}(IM).(y_0+y_1)^2$; $G_E(IE)=0.5.\rho_E.IE^2$; $G_M(IM)= 0.5.\rho_M.IM^2$. We assume that marginal cost are increasing in current and past production with different parameters ($c$ and $\hat{c}$, which depend on management investment, with $\hat{c}$'<0, i.e. more management investment reduces costs of production by diminishing the negative effect of cumulative production). Investment marginal costs are also increasing in investment effort with different parameters ($\rho_E$ and $\rho_M$). In this setting, supply in the current period can be written as

[5] 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), Navajas (2006) and FIEL (2007, 2008 and 2009) for accounts of the natural gas demand supply imbalance during the sample period.

[6] Thus, in period 1 *Y* is only affected by exploration investment effort in period 0 ($IE_0$), while investment effort in period 1 only affects the size of the resource in period 2.

$$y_1^* = \delta_0 + \delta_1.R_1 \qquad (3)$$

where $$\delta_0 = \frac{p_1 - \beta.p_2^e - \beta.\hat{c}(IM_1^*)y_0}{c.(1+\beta) + \beta.\hat{c}(IM_1^*)} \qquad (4)$$

$$\delta_1 = \frac{\beta.\mathrm{c}}{c.(1+\beta) + \beta.\hat{c}(IM_1^*)} \qquad (5)$$

$$R_1(IE_0) = Y(IE_0) - \mathrm{y}_0 \qquad (6)$$

Expression (3) establishes a linear relationship between production and reserves R (see for instance Medlock (2009)) and is a well known consequence of assuming quadratic costs (see for instance Pickering (2008)). Given cost parameters and the discount rate (c, $\hat{c}$ ,β), the supply of natural gas in the current period will depend (positively) on current and (negatively) on discounted future prices as well as (negatively) on past cumulative production and (positively) on remaining reserves. Expressions (4) to (6) also show the channels where investment efforts *IE* and *IM* affect current and future production. In expression (6) we notice that remaining reserves in (at the beginning of) the current period depend on investment efforts in exploration in the past period. The complaint about lack of investment effort in the past as a driver of falling production is captured by this effect.[7] Meanwhile, expressions (4) and (5) show that area management investment in the current period will diminish the negative effect of cumulative past production on current production.

Alternatively, given that $R_1=Y-y_0$ we can write (3) as (7) denoting a negative relationship between current production and aggregate past production. This formulation is slightly different to (3) since $y_0$ does not directly depends on past investment effort ($IE_0$) as in the case of remaining reserves in period 1, $R_1$.

$$y_1^* = \phi_0 - \phi_1.y_0 \qquad (7)$$

where $$\phi_0 = \frac{p_1 - \beta.p_2^e + \beta.c.Y(IE_0)}{c.(1+\beta) + \beta.\hat{c}(IM_1^*)} \qquad (8)$$

$$\phi_1 = \frac{\beta.(\mathrm{c} + \hat{c}(IM_1^*))}{c.(1+\beta) + \beta.\hat{c}(IM_1^*)} \qquad (9)$$

The other first order conditions in the maximization problem written in (1) and (2) relate with the choice of investments in exploration $IE_1$ and area management $IM_1$ in the current period. The former will have an impact in the future period while the latter will impact in the current one. Interior solutions from these first order conditions are given by

[7] From expression (6) it is shown that remaining reserves comes from an identity that suggest that they depend on past investment efforts (affecting the total resource size *Y*) and on past production $y_0$.

$$IE_1^* = \frac{\beta}{\rho_E}.[p_2^e - c.y_2)].y_2^{'} \qquad (10)$$

$$IM_1^* = \frac{-0.5.\hat{c}'}{\rho_M}.[y_0^2 + \beta.(y_0 + y_1^*)^2] \qquad (11)$$

Investment in exploration *IE* is a forward looking activity that depends on the ratio between the expected discounted cash flow $\beta.(p_2^e\text{-}c.y_2)$ and the cost of capital $\rho_E$. An extension of the concession can be seen as affecting this decision. Seen as an equivalent of an increase in the discount factor $\beta$, an extension of the concession implies a higher investment in exploration (an in area management investment $I_M$, see(11)), and a higher future production. On the other hand, the effect on current production is indeterminate as a higher $\beta$ reduces current production (according to (3)) but it also increases investment management which in turn reduces the drop in production caused by cumulative past production.

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, concession' extension, seasonal effects, etc) related to the hypothesis or effects that have been mentioned in the introduction. On the other hand, we acknowledge that the basic equilibrium theory outlined in the previous model tell us nothing about the likely dynamics (where (7) or (3) are static or equilibrium relationship), 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 shortcomings.

## 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 Petróleo y el Gas (IAPG). This basic data was further evaluated and made consistent to allow a correct identification of the areas across years.[8] The original data comes from a panel of annual production by area from 1993 to 2009, with 2880 observations distributed in 282 areas. Given that our objective in this paper was to study the drop since 2004, we use eight consecutive years of production from 2003 to 2009, which in annual rates of change reduces the observations to 640, representing 139 areas.[9] The data identifies the firm that operates the area (there is only one operator per area) and the basin in which is located.

We also 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

[8] 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.

[9] Besides the work on the homogeneization 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 1993-2009. 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.

is very reliable, we found several changes and instability with the data on proven reserves[10]. We thus decided to use in our empirical model 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. We nevertheless explore the sensitivity of results to using reserves instead of cumulative past production. We have further identified within our panel if the area has renegotiated the extension of the concession and if it has been associated with an export contract.[11] We also gather data on exploration (number of wells drilled per year) for each basin as from 1997 which we include to proxy exploration investment effort. Finally we constructed an indicator of the change in production seasonality (towards the summer) from the log of a ratio between the average monthly production during the summer and the maximum monthly production for the same year[12]. Table 1summarizes the definition of variables.

The specification we adopt to study the drop in natural gas production between 2004 and 2009 is summarized in equation (12). As the explanatory variable, 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 and a set of controls defined below:

$$\log(\frac{y_{it}}{y_{i,t-1}}) = \alpha_0 + \alpha_1.\log(\frac{y_{0,it}}{Y_{it}}) + \alpha_4.IE_{it} + \alpha_1.B_i + \alpha_2.SF_i + \alpha_3.LLL_i + \alpha_4.LF_i + \alpha_5 ER_i +$$

$$+ \alpha_6.EX_i + \alpha_7.SEAS_{it} + \hat{u}_{it} \qquad (12)$$

where

$y_{it}$, $y_{i,t-1}$ : 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.

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

[11] We made a careful estimation of renegotiations and export contracts by area using information from official resolutions (INFOLEG), newspapers and sources from the sector. We considered only resolutions that refer to (or identify) production areas, and leave uncovered those that refer to basins (given the impossibility to allocate it to specific areas within the basin). Thus there may be a potential (but small) omission error from our estimation.

[12] As mentioned before, the change in seasonality meant a shift of demand towards the summer, as many potentially (and effectively) rationed users in the manufacturing sector moved demand to the months where first-served users (residential and commercial) were not active or had 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. In other words, the shift in demand could be seen as a shock that negatively affects productivity (for a given investment effort in production maintenance *IM* in the notation of the model of section 2). Some observers doubted on the empirical merit of this last explanation (while accepting that there was a shift in demand, possibly related to rationing in the winter). Our estimates below tend to confirm that the shift in demand had a negative effect on production performance.

$R_{it}$ : remaining proven reserves in area i in year t

$IE_{it}$ : exploration investment effort in area i in year t.

$B_i$ : dummies for the basin in which the area is located (Austral, San Jorge, NOA).

$SF_i$: vector of specific leader producers (YPF, TOTAL, PAE).

$LLL_i$: dummy for Loma de la Lata area.

$LF_i$: dummy if the area is operated[13] by a large (top 9) firm.

$ER_i$: dummy if "i" has renegotiated the extension of the concession (before or as from 2007).

$EX_i$: dummy if "i" has participated in export contracts.

$SEAS_{it}$: Seasonal (summer) effect of area i in year t.

**Table 1**

**Definition and source of variables**

| Variable | Definition | Source |
|---|---|---|
| *Production of natural gas* | Quantities in thousand of m3. | IAPG |
| *Cumulative production* | Production between 1991 and t-1. | IAPG |
| *Resource size* | Sum between cumulative production and remaining proven reserves. | IAPG |
| *Exploration* | Number of exploration finished gas wells between t-6 and t-3. | IAPG |
| *Summer average production* | Average monthly production during the summer (January, February and March). | IAPG |
| *Maximun production* | Maximun monthly production in the year. | IAPG |
| *Austral* | Binary variable, =1 when the area is located in Austral basin. | IAPG |
| *San Jorge* | Binary variable, =1 when the area is located in San Jorge basin. | IAPG |
| *Noroeste* | Binary variable, =1 when the area is located in Noroeste basin. | IAPG |
| *YPF* | Binary variable, =1 when the area is operated by YPF (LLL excluded). | IAPG |
| *Total Austral* | Binary variable, =1 when the area is operated by Total Austral. | IAPG |
| *PAE* | Binary variable, =1 when the area is operated by Pan American Energy. | IAPG |
| *Loma La Lata (LLL)* | Binary variable, =1 when the area is Loma La Lata. | IAPG |
| *Top 9 firms* | Binary variable, =1 when the area is operated by a large (top 9, YPF excluded) firm. | IAPG |
| *Extension before 2007* | Binary variable, =1 when the extension of the area has been renegotiated before 2007. | Own Estimates; INFOLEG |
| *Extension from 2007 (post 2007)* | Binary variable, =1 when the extension of the area has been renegotiated between 2007 and 2009. | Own Estimates |
| *Exports contracts* | Binary variable, =1 when the area has participated in exports contracts. | Own Estimates; INFOLEG |

We estimate (12) as a pooling model for 640 observations covering changes in production for 139 areas between 2004 and 2009. Table 2 shows some descriptive statistics of the main variables. The first panel shows statistics of basic data in 2004 and 2009 of daily annual production (in thousand cubic meters), cumulative past production, seasonal (summer) ratio and number of wells explored. There was a clear drop in production between these years, while cumulative production as a percentage of total resources went up. The seasonal effect shows a shift to summer production which is demand-driven as industrial production became rationed in

[13] Results presented in Section 4 (Table 3) remain if we define firms as "majority shareholder" rather than "operators" in our simple. 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.

the winter. Finally numbers of new wells drilled (so called finished) for exploration shows an already very low activity in 2004 (with substantially less than 1 new well per area per year) which was even lower in 2009. The dummy variables column shows the percentage of total observations covered by the dummy and inform on certain characteristics of the variables.

**Table 2**
**Descriptive Statistics**

| | | *Variables* | | | |
|---|---|---|---|---|---|
| | | Daily Anual Production (in Th. M3) | Cumulative Production share in total resource | Seasonal (summer) Ratio[1] | Exploration (bet. t 6 and t-3) |
| **2004** | | | | | |
| | Obs | 92 | 92 | 92 | 92 |
| | Mean | 1549 | 0.53 | 0.82 | 0.29 |
| | Median | 204 | 0.56 | 0.87 | 0.00 |
| | St. Dev. | 4246 | 0.25 | 0.17 | 0.83 |
| | Max. | 35564 | 0.97 | 1.00 | 5.00 |
| | Min. | 0.56 | 0.00 | 0.19 | 0.00 |
| **2009** | | | | | |
| | Obs | 125 | 125 | 125 | 125 |
| | Mean | 1056 | 0.60 | 0.84 | 0.22 |
| | Median | 88 | 0.65 | 0.89 | 0.00 |
| | St. Dev. | 2808 | 0.26 | 0.17 | 0.85 |
| | Max. | 20847 | 1.00 | 1.00 | 6.00 |
| | Min. | 0.06 | 0.02 | 0.09 | 0.00 |
| | | *Dummy variables share in sample (%)* | | | |
| | Austral | 15.3% | | | |
| | San Jorge | 23.8% | | | |
| | Noroeste | 6.7% | | | |
| | YPF | 18.8% | | | |
| | Total Austral | 2.8% | | | |
| | PAE | 7.2% | | | |
| | Loma La Lata | 0.9% | | | |
| | Top 9 firms | 45.0% | | | |
| | Extension before 2007 | 1.9% | | | |
| | Extension after 2007 | 4.8% | | | |
| | Exportation | 12.2% | | | |

1/ Monthly average summer production (Jan, Feb,Mar)$_t$ / Monthly maximun production$_t$

## 4. Discussion of results

Results of testing equation (12) are reported in Table 3 in columns (1) to (5). The sensitivity of results to using remaining reserves as an independent variables is shown in columns (6) to (9). Variables coefficients and p-values are shown in rows while the columns show different simplifications on the initial equation. Column (1) shows the unrestricted version of equation (12).Column (2) and (3) are simplifications of the initial model that eliminates non-significant variables. Column (4) tests for interactions between basin, firm-specific and renegotiation extension dummies and the slope of the effect of cumulative past production; and column (5) is a final simplification. Meanwhile, columns (6) to (9) repeat the same procedure in the case we use remaining reserves instead of cumulative past production as an explanatory variable.

The first results in column (1) of Table 1 show the relevance of the main explanatory variable reflecting the cumulative past production effect. The constant, which we interpret as capturing a combination of the depressed-price regime effect and past investment effort, is also significant at 1%. Other less significant effects are firm-specific effects (capturing a larger drop than that explained by the model in the case of the firm PAE) and the seasonal summer effect, i.e. a shift in demand due to abnormal industrial demand rationing during the winter, which is also a by-product of the depressed-price regime. All these effects (except for PAE which has a very interesting interplay with the renegotiation effect) survive to across the regressions reported in Table 3.

A very important result reported in Table 3 is that once the above mentioned effects (which can be derived from simple first principles of supply behavior) are modeled, other often mentioned reasons for the decline in natural gas production become non-significant. Chiefly among them are "past investment effort", "Loma de la Lata effect" and the "YPF effect", which have been made responsible in many allegations steaming from casual observation to more elaborated descriptive statistics. What the results tell us is that, while very important, the "collapse" in the Loma de la Lata area can be explained by past production dynamics and price effects. Of course these effects have to do with "insufficient investment" to sustain production along the observed sample (or even before). This is what the analysis of section 2 suggests. However, the empirical finding is that these effects are not dissimilar for Loma de la Lata or YPF with respect to other areas or firms. In other words, the firm or area has not been describing an "abnormal" production path.

Another often mentioned –particularly in the energy business community- effect for natural gas production drop in Argentina is the (absence of) renegotiation of concessions extensions, which do not allow mobilization of resources as the end period approaches.[14] In the simple model of section 2 extensions enlarge 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 3, the renegotiation dummies effect on the rate of change of natural gas production are non-significant, both for extensions granted before or after 2007. The reason for the separation between both periods is that after 2008, renegotiation may interact with new incentive schemes for "new" natural gas production –the so called Gas-Plus scheme-that come with higher prices, closer to scarcity or border (imports) prices. In other words, while pre-2007 renegotiations can be regarded as extensions-without-price-signals (or rather with bad price signals) in the sense that they were mere extensions of contracts in an otherwise repressed price regime, the post 2007 renegotiations are a bit different, since they co-existed with recently established incentive schemes that recognize that "new" gas could receive a higher price.

Results reported in column (1) of Table 3 show that both renegotiation dummies are non-significant. Nevertheless, the post 2007 renegotiation dummy has a significant interaction with the cumulative past production effect, which is reported in column (4) of Table 3. It informs that for those areas that renegotiated the extension of contracts after 2007, the negative effect of past cumulative production on current production diminishes (i.e. becomes less negative) implying that renegotiations after 2007 have had an impact, even if this result will have to be confirmed with a larger sample that include more years. Another relatively significant effect that arises in column (4) results is a San Jorge basin effect, again reducing the rate of drop of production. Further, the inclusion of both (renegotiation after 2007 and San Jorge) dummies turn into non-significant the PAE effect, which is unsurprising given that this firm operates mainly in San Jorge and has renegotiated its extension after 2007. Thus, our results suggest that PAE was underperforming until it renegotiated its concession in 2007, to become more dynamic after that year.[15]

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[14] 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, as Table 2 indicates, a few areas (including the largest one Loma de la Lata) extended its concession period before 2007 and some more did so since 2007.

[15] The reason for concentrating our attention in PAE was driven by our interest to examine the robustness of the significant negative effect on production initially observed for that firm (see variable 6.c in Table

**Table 3**
**Regression Results**

| | Pooled OLS with White SD | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Equation (12) | | | | | With Remain Reserves | | | |
| **Dependent variable: $\ln(prod_t) - \ln(prod_{t-1})$** | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| **1. Constant** | -0.218 | -0.245 | -0.215 | -0.201 | -0.19 | 0.081 | 0.044 | 0.057 | 0.084 |
| | (0.001)** | (0.000)** | (0.000)** | (0.000)** | (0.000)** | -0.149 | (0.384) | (0.208) | (0.050)* |
| **2. Cumulative past production[1]** | -0.209 | -0.209 | -0.205 | -0.261 | -0.262 | | | | |
| | (0.000)** | (0.000)** | (0.000)** | (0.000)** | (0.000)** | | | | |
| **3. Remain Reserves[2]** | | | | | | 0.127 | 0.126 | 0.118 | 0.1 |
| | | | | | | (0.000)** | (0.000)** | (0.000)** | (0.001)** |
| **4. Exploration Investment** | 0.005 | | | | | -0.008 | | | |
| | (0.728) | | | | | (0.567) | | | |
| **5. Basin** | | | | | | | | | |
| a. Austral | -0.011 | | | | | -0.026 | | | |
| | (0.853) | | | | | (0.682) | | | |
| b. San Jorge | -0.037 | | | | | -0.055 | | | |
| | (0.443) | | | | | (0.249) | | | |
| c. NOA | -0.14 | | | | | -0.149 | | | |
| | (0.306) | | | | | (0.271) | | | |
| **6. Leader Firm** | | | | | | | | | |
| a. YPF[3] | 0.06 | 0.077 | | | | 0.044 | 0.065 | | |
| | (0.308) | (0.191) | | | | (0.436) | (0.259) | | |
| b. Total Austral | -0.042 | -0.023 | | | | -0.077 | -0.054 | | |
| | (0.798) | (0.580) | | | | (0.671) | (0.267) | | |
| c. PAE | -0.153 | -0.163 | -0.159 | -0.023 | | -0.052 | -0.087 | | |
| | (0.055)+ | (0.038)* | (0.037)* | (0.762) | | (0.394) | (0.149) | | |
| **7. Loma La Lata Area** | -0.05 | 0.03 | | | | -0.072 | -0.033 | | |
| | (0.772) | (0.508) | | | | (0.664) | (0.434) | | |
| **8. Top 9 firms[4]** | 0.09 | 0.104 | 0.076 | 0.025 | | 0.077 | 0.089 | 0.051 | |
| | (0.156) | (0.034)* | (0.035)* | (0.543) | | (0.229) | (0.075)+ | (0.149) | |
| **9. Renegotiated extensión of concession** | | | | | | | | | |
| a. Pre 2007 | 0.047 | | | | | 0.001 | | | |
| | (0.657) | | | | | (0.995) | | | |
| b. Post 2007 | 0.051 | | | | | 0.012 | | | |
| | (0.441) | | | | | (0.850) | | | |
| **10. Export Contracts** | 0.004 | | | | | 0.009 | | | |
| | (0.980) | | | | | (0.961) | | | |
| **11. Seasonal (summer) change[5]** | -0.218 | -0.222 | -0.222 | -0.222 | -0.221 | -0.261 | -0.264 | -0.263 | -0.248 |
| | (0.071)+ | (0.066)+ | (0.062)+ | (0.046)* | (0.047)* | (0.033)* | (0.031)* | (0.029)* | (0.040)* |
| **12. Multiplicative dummies with CPP or RR (2)** | | | | | | | | | |
| a. LLL | | | | -0.022 | 0.023 | | | | 0.165 |
| | | | | (0.871) | (0.832) | | | | (0.073)+ |
| b. YPF[3] | | | | 0.134 | 0.14 | | | | -0.011 |
| | | | | (0.106) | (0.081)+ | | | | (0.697) |
| c. Total Austral | | | | 0.067 | 0.053 | | | | 0.043 |
| | | | | (0.375) | (0.493) | | | | (0.335) |
| d. PAE | | | | 0.082 | 0.082 | | | | -0.003 |
| | | | | (0.278) | (0.148) | | | | (0.937) |
| e. Austral Basin | | | | -0.075 | -0.076 | | | | 0.052 |
| | | | | (0.559) | (0.549) | | | | (0.083)+ |
| f. San Jorge Basin | | | | 0.131 | 0.137 | | | | 0.02 |
| | | | | (0.067)+ | (0.045)* | | | | (0.608) |
| g. NOA Basin | | | | 0.035 | 0.039 | | | | 0.159 |
| | | | | (0.673) | (0.637) | | | | (0.073)+ |
| h. Renegotiated Extensions | | | | | | | | | |
| i. Pre 2007 | | | | 0.118 | 0.095 | | | | -0.088 |
| | | | | (0.210) | (0.285) | | | | (0.319) |
| ii. Post 2007 | | | | 0.155 | 0.147 | | | | -0.062 |
| | | | | (0.060)+ | (0.076)+ | | | | (0.122) |
| **13. Renegotiated Extension After 2007 *PAE** | | | | 0.393 | 0.382 | | | | 0.015 |
| | | | | (0.001)** | (0.000)** | | | | (0.893) |
| **Observations** | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 |
| **R squared** | 0.169 | 0.164 | 0.161 | 0.204 | 0.204 | 0.103 | 0.098 | 0.094 | 0.109 |

p values in parentheses
+ significant at 10%; * significant at 5%; ** significant at 1%
1/ {ln (Cumulative Production)$_t$ - ln (Total Resource)$_t$}
2/ {ln (Remain Reserves)$_t$ - ln (Total Resource)$_t$}
3/ Excludes LLL.
4/ Excludes YPF (LLL included).

The right-hand side panel of Table 3, from columns (6) to (9), replicates the estimation procedure by using remaining reserves instead of cumulative past production.[16] We observed

3). We have found that this effect disappears when the interaction of PAE with the renegotiation variable is considered (see variable13 in Table 3).

[16] We also examined the potential for a system model where reserves depend on past investment exploration effort, but found no evidence in favor of such specification.

that even though the overall adjustment is less satisfactory (with $R^2$ significantly lower) the main results of the empirical model remain. Reserves and the seasonal (summer) effect are strongly significant while exploration investment, basin or specific firm (including Loma de la Lata) and renegotiation of extensions effects are non-significant. Post 2007 renegotiations do not enter either as before when consider interactively with one of the leaders (PAE), which does not describe a heterogeneous behavior as in the previous specification. The interactive dummies with reserves (represented in 12 and in column (9)) are also bit different but mostly non-significant. The constant becomes slightly significant at 5% in the last simplified equation in column (9).[17]

## 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 and the role of past investment. Our results do not allow a complete screening of the relative merits of past (pre-interventionism) investment performance and current (post interventionism) price controls, but they 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. Overall the evidence is pretty much consistent with the deleterious effect of very low price signals on an already mature conventional gas pattern. Of course, 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. But 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. Looking from a different angle, the results of this paper suggest that we cannot expect good news from natural gas production performance in the near future, as the features of our empirical model become more dominant. The recent move towards non conventional gas with higher prices is –despite regulatory shortcomings- an obliged strategy for Argentina.

We think that while the results of this paper are already robust enough to contribute to the understanding of, or avoid confusions on, the causes behind the drop in natural gas production in the 2000s in Argentina, they have also opened suggested lines of research to improve our modeling of production performance. On such avenue is to enlarge the period of study to better capture and understand the natural gas production bubble experienced by Argentina in the last 25 years and the reasons for the seemingly mismatch between exploration efforts and demand growth, a fact anticipated by a World Bank report in 1990[18]. Another one looks into the future and should be devoted to modeling and testing the effects of the introduction of new incentive schemes for new unconventional gas, understood as a technical change in the sector that may redefine future resources or at least reduce the foretold decline of existing ones.

[17] All these basic results –except the non-significance of the exploration investment (variable 4) and of the Top 9 firms (variable 8) - remain if the second model is tested as a panel Random effect model, which is suggested as the appropriate model by an LM test at a 5% confidence in the model of column (9), although this disappears in the case of the models of columns (6), (7) and (8). One drawback of these models is that exploration investment has a wrong sign (negative) on its effect on production.

[18] See World Bank (1990) and the quotation discussed in Navajas (2006).

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