STUDYING BOOM-BUST CYCLES IN NATURAL GAS PRODUCTION ASSETS INVESTMENTS

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BIEE 11th Oxford Research Conference, 21-22 September 2016, Oxford, United Kingdom

Key words: natural gas markets, news investment-specific shocks, agent-based modeling, path-dependence, dynamic disequilibrium, irreversibility, boom-bust cycles.

Abstract

During the past decade, the global natural gas market has witnessed a series of critical upheavals: increasing market volatility, greater geopolitical risks, ever-growing hazardous market cycles,... In this disrupted environment, the use of models capable of representing the genuine dynamic of gas market fundamentals has become decisive for the gas industry to generate the most reliable long-term forecasts. However, conventional natural gas models usually neglect the effects of dynamic path-dependence and independent agent behaviors by assuming that the market stands in a permanent state of equilibrium.

The new model therefore aims at exploiting these two disregarded concepts to represent the natural gas market as an evolving and complex system. To this end, the new approach consists in building the dynamic path resulting from the progressive realization of the natural gas market with an advanced rolling optimization model.

In accordance with the principle of causality, the non-coordinated an irreversible investment decisions in natural gas production assets made by independent market players at a given date have a direct and structural impact on the market configuration over the following years. Associated with a thorough representation of the progressive depletion of existing natural gas resources, the model may lead to market conditions which deviate from equilibrium. More specifically, the model can exhibit endogenous boom-bust cycles characterized by a succession of oversized expansion periods followed by critical contraction periods.

The aim of this new rolling model is to help decision makers in the natural gas sector to better assess incoming risks and opportunities by providing them with the most likely market forecasts rather than with market forecasts fulfilling ideal but not realistic market conditions. Beyond this specific application, this innovative approach could be readily applied to oil or power fundamental models.

* The views expressed are those of the author and do not necessarily reflect the views of ENGIE.

Introduction

The objective of this effort is to initially build a framework that allows the observation of endogenous disequilibrium in Natural Gas (NG) markets. These phenomenon emerge as an endogenous consequence of the dynamic evolution of NG markets combined with the independence of market players and the irreversibility of their investment decisions.

In this respect, the first section describes the theoretical limitations of the current economic paradigm to address market disequilibrium. Then, the second and third sections respectively present the new theoretical solution and its technical implementation with an innovative simulation model. Finally, the last section provides the preliminary results of the model focusing on generating a series of Boom-Bust cycles in NG production assets investments.

1. Current theoretical limitations in addressing market disequilibrium

Context

Global NG markets have shown significant developments over the last couple of years. First of all, the emergence of shale gas in the United States has upset the historical panel of global NG market players. For decades, conventional NG reserves were indeed developed field by field with significant development periods. This paradigm is now over with the arrival of several thousand new US shale gas producers incrementing production capacities on a well by well basis at a much faster rate. Under pressure of this massive source of supply, the Henry Hub spot price recently hit historical lows and the country is now expected to become a major Liquefied Natural Gas (LNG) exporter in the coming years.

Furthermore, the secondary effects of the 2011 nuclear accident of Fukushima on NG markets have now reached their consequential climax. Initially, the immediate and mass substitution of nuclear power production by NG-fired power production boosted both Asian NG import prices and expected forward prices. As a consequence, a large series of investment decisions were made on the basis of optimistic medium-term forecasts to supply this newly-expected increase in LNG demand as seen from 2012-2013. Thus, most of these liquefaction plants will be commissioned in the coming years, adding to the already significant LNG supply from the US.

If we also consider the additional NG exports expected from Iran following the end of international sanctions as well as doubts on China increase in NG demand, global NG prices should remain low. If the combination of these events is particularly complex, at least one conclusion appears from this quick analysis: global NG markets are arguably out of a long-term equilibrium.

The aftermaths of this situation are severe: in the medium term, recent investments' profitability is directly threatened as revenues from NG are not sufficient to cover the full costs of capital. This concern appears in several regions around the world even in historical oil and gas producing countries such as e.g. Russia (Yamal LNG). As a result, major investment projects which have not yet been sanctioned are now postponed while waiting for better days to come. In the longer term, strong upward pressure on NG markets resulting from a combination of producing assets depletion and likely underinvestment cannot be excluded. For these reasons, the use of models capable to represent the genuine dynamic of NG markets fundamentals has become decisive for the NG industry to generate the most reliable long-term forecasts.

Limitations of the paradigm on market equilibrium

Most of commodity economic modeling systems rely on the assumption that a competitive market tends to an endogenous state of equilibrium. In this paradigm, demand and supply quantities of a commodity are both considered as functions of price and the market price is established through competition such that the volume bid and the volume asked are equalized. This market equilibrium is assumed to be stable and to occur at any time scale in such a manner that economic market players' plans are in equilibrium. This optimal approach results in the complete coordination of each market player decision to minimize costs and to maximize total welfare. By construction, this approach prevents the development of any endogenous market disequilibrium in general and the occurrence of business cycles in particular.

This classical approach suffers from two important limitations which are closely linked. First, it neglects the effect of time or in other words, the physical principle of causality whereby the cause precedes the consequence. Indeed, in the classical endogenous equilibrium framework, the problem is equivalent to considering an omniscient global planner who makes the most relevant choices to minimize the global cost to satisfy the demand both in space and time. For example, a decrease in demand will result in an alternative static equilibrium by assuming that a competitive market generates by itself the necessary forces to return the system to equilibrium. Unfortunately, the dynamic path used by the system to move from the initial to the final states is not taken into account. That is to say, the path used by different market players to step forward in time by adapting their own situations to the new market conditions is considered as immediately solved, and of no consequence.

The second limitation is related to the high heterogeneity of market players: a commodity market brings together many different types of market players with different individual opportunities, constraints, motives and strategies at various time scales. For illustration, a commodity producer who expects to make an industrial investment profitable in the long term will not adjust its position to a decrease in the demand as easily as a commodity trader who can balance its positions on a highly liquid spot market. However, these market players are not interchangeable and both are required to ensure the effective functioning of the market.

In their preliminary works on supply shock propagation in the US natural gas market, Outkin et al. (2014) provide a synthetic review of some attempts which are emerging to challenge the paradigm of general and partial equilibrium. Among them, the approach to planning and optimization of energy networks by Beck et al. (2008) is of special interest as it focuses on the combination of a global optimization system with Agent-Based Modeling (ABM) tools to model the inherent complexity of an energy network development. Furthermore, Lee and Yao (2013) demonstrate the relevance of using ABM systems to model the endogenous penetration of technology in an evolving economic environment. Finally, Chappin et al. (2010) propose an innovative combination of equation based modeling and ABM modeling to exhibit the endogenous emergence of a spot market within the LNG market.

Beyond the debate on equilibrium within the market, many efforts have been underway to study the impact of news shocks on macroeconomic fluctuations on the basis of Beaudry et al. (2006) work. While providing evidence from forecast data to validate this concept, Miyamoto et al. (2014) define news shocks as information about future fundamentals that does not affect current fundamentals. When economic agents become aware of such forthcoming changes, they adjust their positions accordingly, and thus cause economic fluctuations on realized data. At this level, it has to be noticed that the physical succession of events over time is difficult to challenge. Furthermore, Fisher (2006) demonstrates that specific investment shocks drive the majority of macroeconomic business cycles. Benati (----) explores the combination of both concepts and concludes that news investment-specific shocks play the most important role to explain the succession of upward and downward macroeconomic fluctuations.

This paper: methodology, motivation and preliminary results

This paper presents the implementation of an innovative combination of ABM and system dynamics to explore the endogenous emergence of disequilibrium within the global NG market. Whereas the study of disturbances propagation generally focuses on the resilience of a market in the aftermath of exogenous shocks (eg. the increase in LNG demand following the 2011 Fukushima nuclear accident), the new approach aims at analyzing the endogenous trend generated by the NG market itself (eg. the reasons why the market currently moves toward a LNG liquefaction overcapacity on its own). These disequilibria appear as the consequence of the propagation of news investment-specific disturbances. These disturbances are endogenously generated by the imbrications at different time scales of non-reversible investment decisions made by independent market players with the maximum information available at a specified date. The main features which support this approach have been listed by Outkin et al. (2014). This paper relies on four of these features:

- **Non-equilibrium:** NG market has recently experienced major structural transformations. Several evolutions can be mentioned at this point like the emergence of US shale gas resources which upsets the worldwide NG supply, the further growth of the LNG supply from Australia with the commissioning of large-scale liquefaction plants such as Golar LNG (GLNG) or Australia Pacific LNG (APLNG)… As a result, the global NG market is apparently out of a long-term equilibrium.

- **Independence:** at a given date, economic agents make their decisions independently of one another with the willingness to beat the market. Nevertheless, an obvious link appears between all players *a posteriori* as every decision impacts the market during its implementation.
- **Path-dependence and emergence:** the market configuration at a given date ensues from the combination of all decisions made in the past. Thus, the market goes forward step by step and the evolution of the entire system traces a path which may exhibit emergence phenomena.
- **Heterogeneous time scales:** the evolution of a commodity market results from the interaction of different market players trying to fulfil objectives at different time horizons. Schematically, a trader focuses on his short term profits and losses whereas a NG producer has a special interest in the long term direction of the market.

Finally, the paper presents the preliminary results provided by this simulation system based on a limited dataset. It shows to which extent the combination of investment decisions in NG production assets made by independent players trigger endogenous news investment-specific shocks which will cause structural and endogenous disequilibrium to develop in the market. In particular, the simulation exhibits the emergence of boom-bust cycles properties characterized by a succession of oversized expansion periods followed by sudden and critical contraction periods.

2. Theoretical model

An step by step description of observed NG economic rules

This description consists in analyzing the NG market as the combination of two aspects which complement each other along the arrow of time.

The first process involves all activities associated with the allocation of NG physical flows to satisfy demand at the least cost. These flows are allocated in the short term by considering a given and fixed set of production capacities and constraints such as e.g. transportation infrastructures and contracts which have been commissioned or entered into in the past. Since investment decisions are irreversible, these assets will be available in a configuration considered much earlier in the past to supply the NG market and so long as NG prices meet the variable cost of operation commonly known as the OPEX regime. Indeed, should prices fall so much that a given asset can no longer repay the debt obligations to the creditors, the asset will not be demolished. It will be put under administration and sold out at the value of its expected discounted cash flow given the depressed prices which will at the lowest be its OPEX regime. Only if prices fall structurally below the OPEX regime will the foreclosed capacity be mothballed or abandoned.

The second aspect of the NG market relates to investment dynamics which are based on medium and long term NG market forecasts. Most of NG market forecasts achieved at a year Y_i currently assume that the market is in a stable and static equilibrium. These forecasts are then massively used to supply a series of business plans studies, in particular, in NG production assets investments. These business plans mainly rely on the thorough examination of micro-economic indicators such as e.g. the Net Present Value (NPV) or the Internal Rate of Return (IRR). Assuming no capital rationing, two options are then possible for each business plan: either the business plan fulfils all financial constraints leading to an irreversible Final Investment Decision (FID) or the project is not validated. In the latter situation mentioned, the project remains in the developer's portfolio but it is postponed from year to year so long as the successive market forecasts are not favorable. It should be pointed out that any investment project aims at generating a positive margin by repaying at least all fixed and variable costs. For this reason, all projects submitted to an investment committee are tested against their full cost of production. All these investment decisions are made independently from each other by autonomous market players who try to maximize their own expected profit by relying on market forecasts as the best view of the future they may have during the year Y_i. The FID decisions in the real world are made even more binding due to the significant use of third party contracts and debt in the NG sector to build and finance projects development. Should prices collapse during a project's construction phase, contracts and loans made earlier with contractors and bankers are binding.

The aggregation of irreversible decisions in investing or postponing production projects generates news investment-specific shocks which appear throughout the proceeding of time and propagate within the market. In parallel, the flow allocation of the year Y_i leads to the physical depletion of some NG resources whereas some other resources have been postponed because they did not prove sufficient economic performance to be produced. In consequence, market players take into account these both achieved and forthcoming evolutions to adjust their own position accordingly as early as the year Y_{i+1}. In the current way to proceed, this will constitute the basis of a new static market forecast which will be used to invest in new production capacities,...

This short and pragmatic description of reality provides with two significant insights. Firstly, a dynamic market description is necessary to ensure a good understanding of the whole process. Again due to the principle of causality, series of events follow each other and the market configuration which will be available in 20 years will result from the specific path followed by the progressive realization of the market along these 20 years. Secondly, market players are independent and do not coordinate their investment decisions. For this reason, a system based on ABM is crucial to deliver a relevant market forecast.

Taking time into consideration

The first step consists in defining different levels of temporal projections within the model. For this purpose, the set of observed economic rules described above is represented through a 2 temporal dimensions prism: the first temporal dimension [0] is the actual realization of the market through the allocation of physical flows. The second temporal dimension [1] corresponds to the market forecast achieved by analysts at a given date from the temporal dimension [0] to evaluate investment opportunities. By nature of a forecast, nothing guarantees the achievement in reality (or in the temporal dimension [0]) of the market evolutions described within the temporal dimension [1].

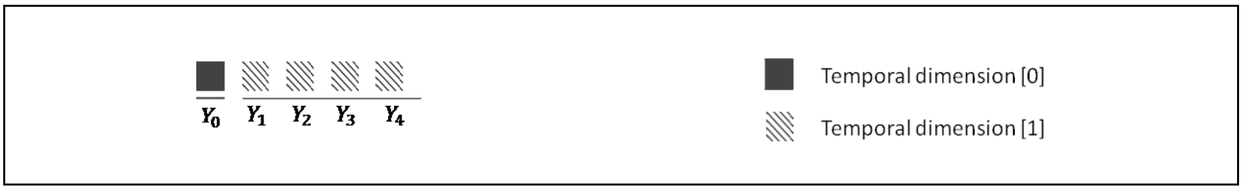


Figure 1 Conceptualization of observed economic rules within two temporal dimensions

The new approach aims at endogenising the observed economic rules by considering the imbrications of the above described two temporal dimensions into a third one [2]. In other word, the new model is based on a rolling system of endogenous forecasts [2] which will probably never be achieved within the temporal dimension [1]. In accordance with the description of observed economic rules, it has to be noticed that these forecasts assume a market equilibrium both in the short and long term.

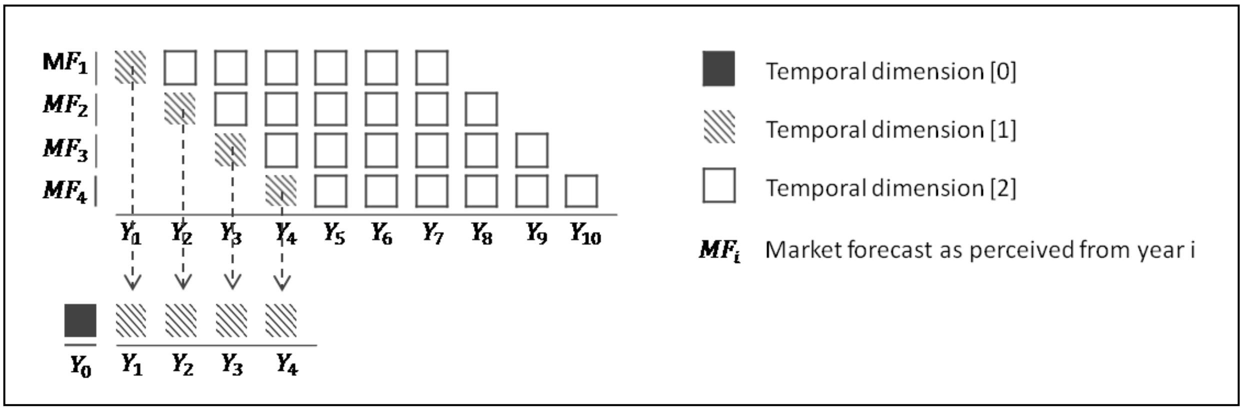


Figure 2 Imbrications of observed economic rules within an additional temporal dimension

The model then increments time forward one year after another in the temporal dimension [1] and for each step, the model generates a medium-term forecast in the temporal dimension [2]. These forthcoming evolutions then lead market players to adjust their positions from the following year in dimension [1]. By doing so, their decisions impact the market configuration over the following years both from the temporal dimensions [1] and [2] and a specific path emerges from the market simulation. In other words, news shocks take the form of the implication of medium-term forecasts generated in the temporal dimension [2]. Finally, the forecast as seen from the time space [0] is obtained through the concatenation of all steps on the path followed within the temporal dimension [1].

This being said, it is now possible to better represent the three temporal dimensions by positioning ourselves in an expected temporal dimension [-1], or in a word, extract ourselves from the imbrications of temporal dimensions and take the helicopter view as summarized below. Hopefully, it will be the task of actual NG analysts in the coming years should they use this type of model.

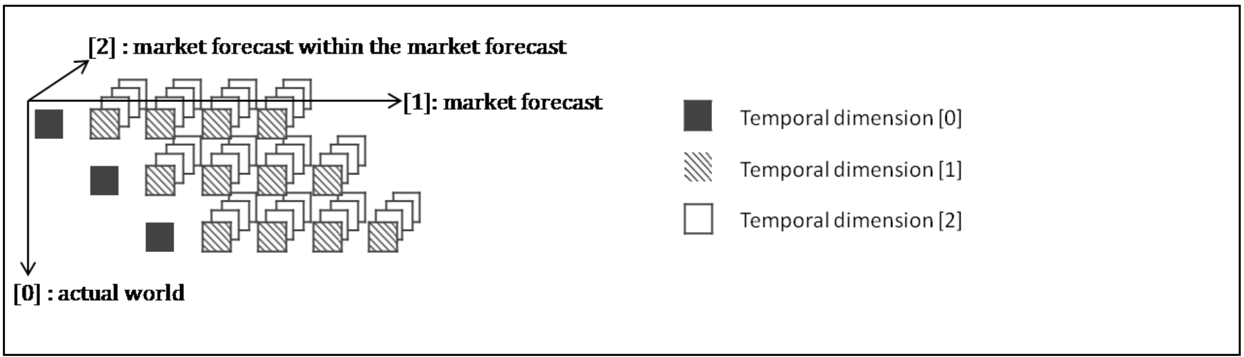


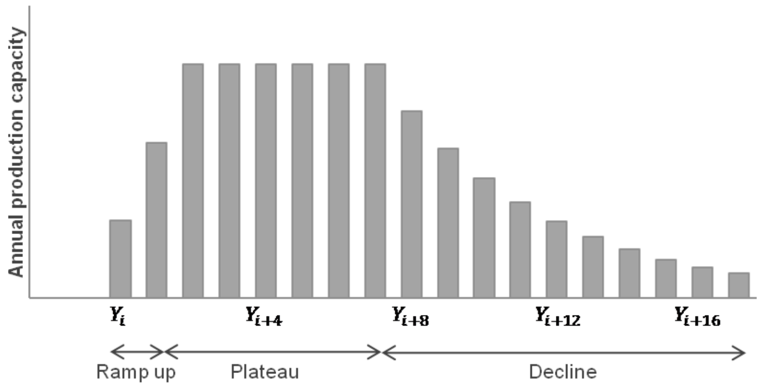
Figure 3 Temporal imbrications matrix as perceived from the temporal dimension [-1], a.k.a. 'helicopter view'

In this paper, the approach is limited to a representation of time in three dimensions. More precisely, the model remains relevant in forecasting market evolutions so long as its user exploits exactly one temporal dimension more than other market players do.

Which choices for which economic agents?

Within the timeframe presented above, the simulation model endogenously generates different types of market evolutions to dynamically move from the market configuration as seen from the year Y_i to the market configuration as seen from the year Y_{i+1}.

- **Market evolutions occurring in the temporal dimension [1]**: they are achieved by players operating NG production assets which were already invested in the past. This means that no change can be made as to the availability and capacity of the asset in the present due to the consequential irreversibility of an investment decision. The model takes into account an accurate representation of producing asset in terms of production capacities and variable production costs to get the most realistic modeling of NG fundamentals. In particular, the production profile of a NG asset is specific and irregular in time which is of substantial interest to capture the true dynamic of the sector.



$$\sum_{full\ life\ cycle} Production\ capacities = Recoverable\ reserve$$

Figure 4 NG schematic production profile

Within temporal dimension [1], it is assumed that the flow allocation is efficient to satisfy the NG demand at the global least cost. This assumption is realistic due to the worldwide increasing development of NG trading as well as the steady progress of LNG trade which boosts the interconnection of active regions in the NG sector. At the end of any given year, two options are available for each production asset:

1. **The production asset has produced no NG during the past year Y_i in the temporal dimension [1].** In this case, the unused amount of NG is postponed by one year forward, generating a transformation of the whole production profile over the following years.

2. **The production asset has produced NG during the past year Y_i in the temporal dimension [1].** In this case, the production profile does not change over the following years within the following medium-term market forecast.

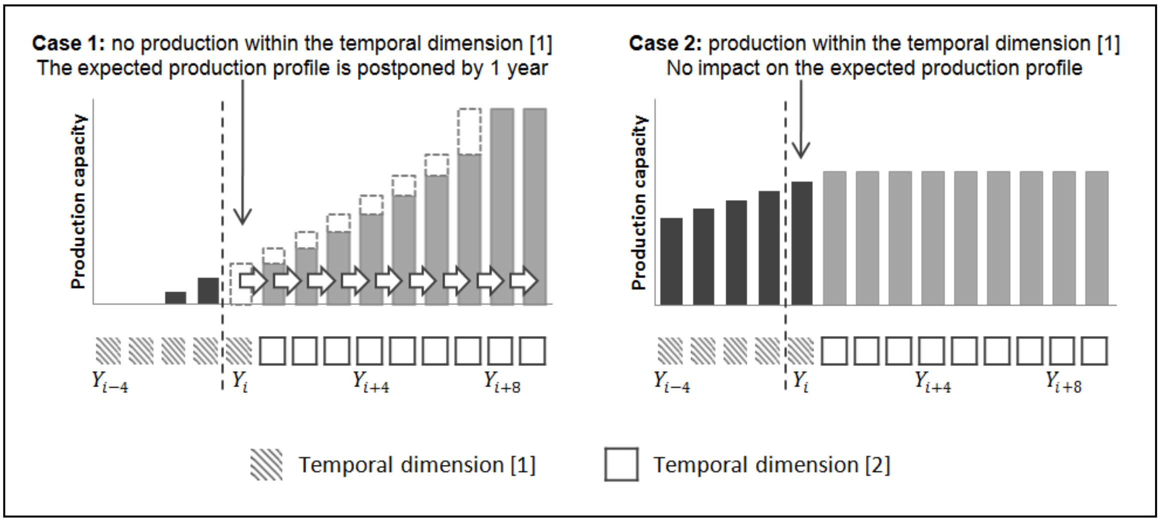


Figure 5 Dynamic depletion of producing assets within the temporal dimension [1]

By doing so, the model insures the consistency between NG recoverable reserves and the sum of all production capacities while allowing a dynamic representation of resources depletion.

- **Market evolutions occurring in the temporal dimension [2]**: these evolutions are linked to players assessing investment opportunities in production assets within the model. The choice of investing or not is made by the model on the basis of microeconomic indicators as a realist investment committee would. This evaluation combines the key characteristics of the production asset in terms of costs (CAPEX, OPEX, taxes) and technical aspects (NG production profile, NG reserves) with the static market price forecasted within the medium-term forecast market prices generated in the temporal dimension [2] to estimate NG expected revenues. For each asset, the model is currently able to study the assessment of a primary and three secondary indicators identified as reference indicators for assessing an investment by Brealey et al. (2013):

1. **Primary indicator:** the net present value (NVP).
2. **Secondary indicator:** the internal rate of return (IRR).
3. **Secondary indicator:** the profitability index (PI).
4. **Secondary indicator:** the payback period (PP).

These indicators are then compared with criteria which represent the decision rules of the projects portfolio manager. These criteria may vary from one actor to another. The conclusion is then Boolean:

1. **At least one investment criterion is not validated:** in this case, the project remains in the portfolio but it is postponed by one year. The investment will be assessed again the following year upon considering the updated medium-term market forecasts of the temporal dimension [2] generated in Y_{i+1}. As long as the investment is not validated, the project is postponed and will only appear in market forecast of the temporal dimension [2]. Consistently with the investment criteria aiming at recovering the full costs over the full life cycle of the project, the asset is assessed against its full cost of production within the temporal dimension [2].

2. **The microeconomic evaluation validates all investment criteria:** in this case, the investment decision is irreversibly sanctioned. As soon as the period between the FID date and the asset commissioning date has elapsed in the temporal dimension [1], the production capacity of this project becomes subject to the short term market evolutions occurring within the temporal dimension [1]. It has to be noticed that the completion period varies from asset to asset depending from their size and their environment, from a few months for a shale well to a decade for large Russian fields.

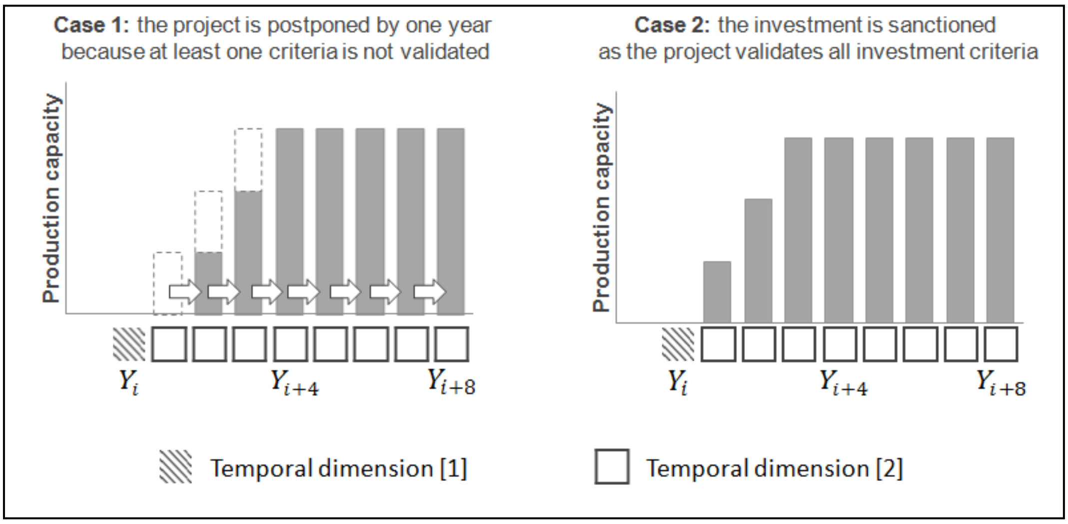


Figure 6 Dynamic representation of investment

Considering that market players make choices at a given date by looking forward at news investment-specific shocks propagation, a macro-supply development plan therefore emerges from micro-economic foundations combining realistic analytical accounting and corporate finance. All investment opportunities are evaluated independently one from another as market players make their decisions in a non-concerted manner.

3. Technical description of the simulation model

The new approach is based on the use of an existing global NG fundamental model which represents NG markets with a series of nodes associated with static NG supply and/or demand curves. Nodes are interlinked together with transmission infrastructures including both pipes and LNG chain (liquefaction, shipping and regasification). Each production and transmission infrastructure asset is associated with relevant costs. The model then optimizes NG flows allocation to satisfy the demand of each node at the global least cost by using a Mix-Integer Linear Program (MILP). The market price of each consumption node is then defined as the marginal cost of supply of the given node. In accordance with the observed NG economic rules described above, this traditional model is used to generate medium-term forecasts assuming a static equilibrium over the time horizon.

Year by year running within the temporal dimension [1], the outputs from the optimization model are read and subsequently analyzed by a Python program. This program first focuses on the possible non-utilization of producing assets to consequently postpone their production profile by one year. The program then analyses each node's NG price forecast to feed-in production assets business plans which will be evaluated for FID. The inputs of the following run by the optimization model are then totally reconfigured according to theses analyses.

4. Preliminary results on the emergence of Boom-Bust cycles

Understanding Boom-Bust cycles dynamics

Various justifications have been investigated to understand and explain Boom-Bust cycles, that is to say in the present case, periods in which NG prices rise and then crash. Such behaviors are usually assumed to require a combination of temporal and social myopic behaviors. According to Rey (2014), the temporal dimension of myopic behavior is presented as the *a priori* limitation in estimating the long-term consequences of short-term decisions whereas the social myopic behavior is described as the *a priori* knowledge limitation of decisional entities in a decentralized market. Together, these concepts result in a non-optimal organization of the market and thus in market disequilibrium.

We believe another fundamental aspect is at play here. For this purpose, an analogy with the observer effect commonly used in physics is of special relevance. It occurs when observation cannot be achieved without affecting the system. By analogy in the above described new approach on NG markets modeling, the system physical evolution is described within the temporal dimension [1] whereas observations relate to the market forecasts in dimension [2]. Thus, any observation of current market conditions by a player part of the game will alter his expectations, hence his decisions (whether to invest or postpone the project) which will in turn alter the market. This causality loop binds the sequential succession of observations, the consequential evolution of expectations, the investment decisions, and finally the impact on the market. It is impossible to build a model free from this causality loop unless making chicken and egg type assumptions as to which player plays first. As a consequence, a fundamental property of this model is that market players can either know the state of the market or know which investment decisions they will make but no both at the same time. The awesome powers of this property are demultiplied as the number of nodes, players and project increases.

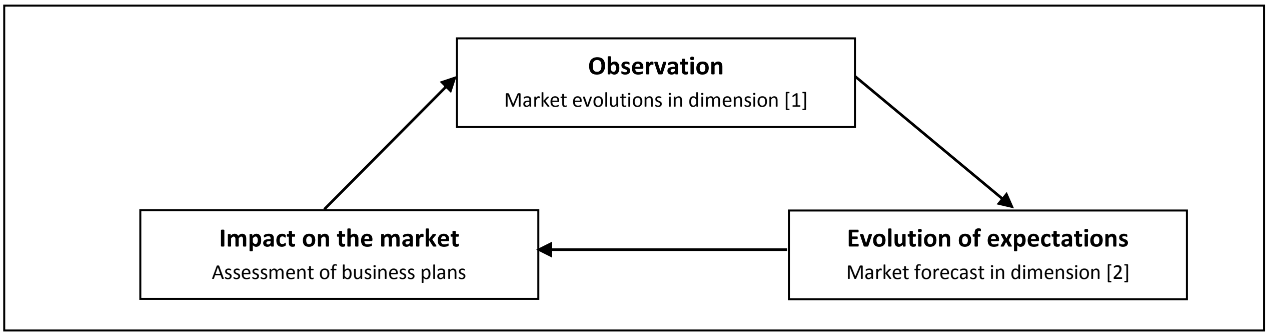


Figure 7 The causality loop

It has to be noticed that the hereby proposed framework assumes no *a priori* social myopic behavior as described above. There is no limitation of knowledge linked to a narrower visibility of the entire system as all market players share the same forecast. Nevertheless, as suggested above, a partial knowledge frontier emerges from the independence of market players making their investment decisions in a non-concerted manner. By construction, the temporal dimension of myopic behavior is effective through the causality loop.

Objectives and assumptions of the simulation

The objectives of this preliminary simulation is to observe the dynamics of a series of boom-bust cycles within a theoretical and limited dataset. The simulation test is based on an isolated node associated with a NG demand curve and a series of NG production assets.

- The NG demand is static, steadily increasing.

- The production capacities as perceived from the year Y_0 are split into two groups: the first group includes all production assets which were sanctioned in the past and which are immediately available within the temporal dimension [1]. The second group includes a series of forthcoming production assets which are available for investment within the temporal dimension [2].

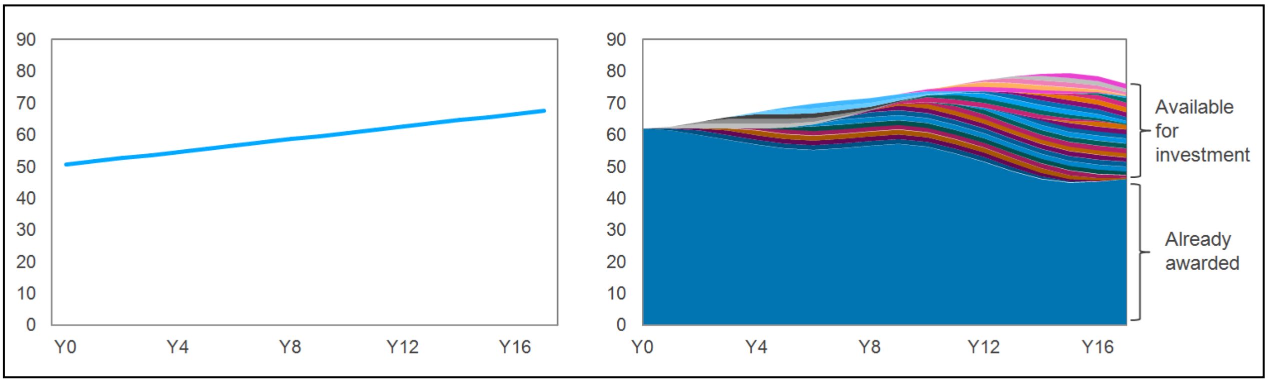


Figure 8 Assumptions on NG demand (left) and NG production capacities (right) as seen from year Y0 (bcm/y)

The simulation model is then launched over a 18 year-long period in the temporal dimension [1] coupled with a series of 20 year-long forecasts in the temporal dimension [2]. In this first simulation, we consider a strictly positive NPV as the minimal constraint to sanction an investment.

Results

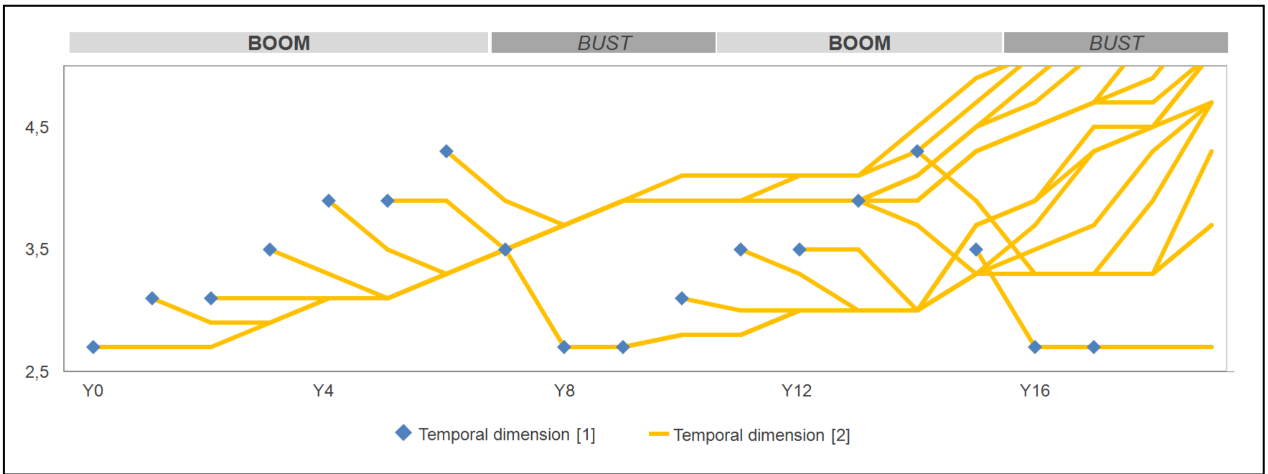


Figure 9 Results on NG prices ($/MMBtu)

The output of the model shows two boom-bust cycles in the temporal dimension [1]. Within the 7 first years of this temporal dimension, most of available production projects are postponed year by year because the successive NG price forecasts of the temporal dimension [2] are not high enough to sanction these investments. For this reason, the NG demand of the temporal dimension [1] has to be satisfied with supply sources which were sanctioned in the past but which present a higher cost of use. As a consequence, the NG prices of the following years within the temporal dimension [1] are systematically higher than previously expected. This dynamic is strengthened over time with the progressive depletion of the NG resources used within the temporal dimension [1]. In other words, the system runs in under-capacity regime, progressively generating the Boom effect corresponding to an increase in NG prices due to a lack of investment.

The market forecast generated from the year Y_6 reaches record levels in comparison with the previous ones. This optimistic view of future then attracts investors and all production projects which were postponed until then are suddenly sanctioned. Upon entering into service, those newly-commissioned capacities force the NG price to collapse as the market of the temporal dimension [1] is suddenly provided with abundant production capacities with low variable costs of using. This first wave of investments causes a contraction period which corresponds to the Bust phenomenon. These depressed market conditions then result in a freeze of investments in new production assets which drives prices up again, thus leading the market to a new Boom-Bust cycle etc. The results on NG production assets investments and use are in line with observed prices and industry behavior. In particular, the two waves of sanctioned investments are clearly visible.

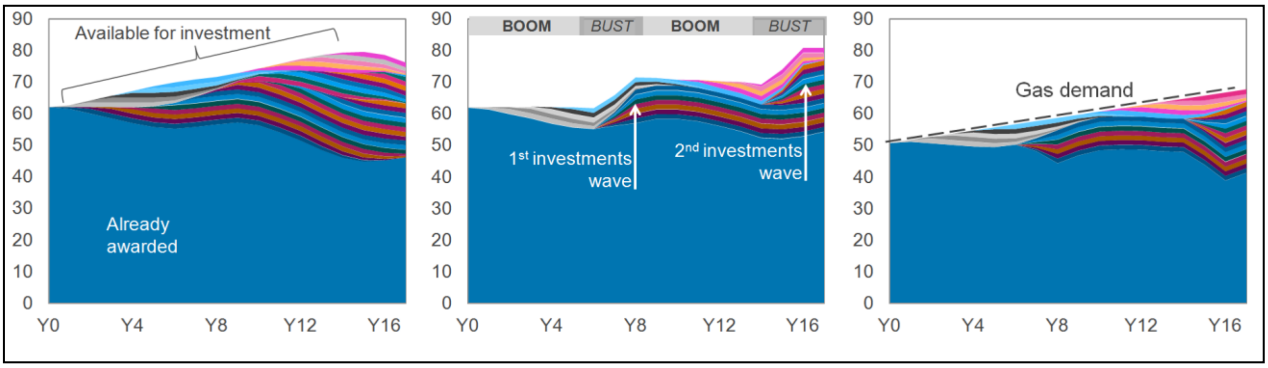


Figure 10 NG production capacities as seen from year Y0 (left)
awarded production capacities in dimension[1] (center)
physical flows allocation in the temporal dimension [1] (right)

Conclusions and next steps

This paper highlights the relevance of merging agent-based modeling with dynamic market modeling in order to represent the genuine dynamics of NG market fundamentals. In this respect, we demonstrate the possibility of endogenous market disequilibria emergence from the temporal imbrications of irreversible investment decisions made by independent market players on the basis of micro-economic foundations. The preliminary results of the simulation models show the occurrence of Boom-Bust cycles which are characterized by a succession of oversized expansion periods followed by critical contraction periods.

Additional works have already been completed to pursue this new path. These developments include the dynamic modeling of the price elasticity of NG demand, the dynamic modeling of market power of strategic NG producers and the dynamic modeling of investments in NG transportation infrastructures (pipes and LNG). On top of the above, other development works have been undertaken such as the study of exogenous shocks propagating within the simulation model, the adaptation of this new framework to other commodity markets (power, oil) and finally, the simultaneous combination of such commodity models (multi-energy demand, power, oil, NG).

Acknowledgment

The author is grateful to Jean-Baptiste Dubreuil, Benoît Dal Ferro, Roman Simcik, Adrien Soudan, Andreas Ehrenmann and Audrey Giffard for their helpful comments and insightful feedback on this work and this paper.

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