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Modelling uncertainty in electricity markets for learning, policy and strategy

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ABSTRACT

Since the late 80s, the electricity industry has been sustaining important adjustments worldwide, changing from centrally planned systems, with government control, to open market schemes, where intense private participation is now taking place.

These markets exhibit major dynamics with respect to management, technology progress, consumer behaviour, industry configuration and government policy. In some countries, consumers have benefited from changes but in others they have suffered from the new market arrangements. At the company level, some have performed better than others and even some have gone bankrupt as the case of ENRON.

There are questions related to ill-defined policy assessment or company mismanagement. From the hindsight it can be argued that in all circumstances some modelling has been or could have been of help, particularly SD modelling.

In this paper we focus on the scope of SD modelling to the Latin American case, mainly Colombia, but also bring examples related to the UK. We report research that emphasize how modelling has taken an important role in “learning environments” as well as a support tool for decision-making and policy assessment.

Key words: System Dynamics, energy policy, modelling, electricity industry.

1 Introduction: Uncertainty in energy markets

Under the present uncertainty that electricity markets are experiencing, the challenge that market agents confront is for better understanding and “forecasting” of their system evolution and particularly the behaviour of some key variables. On the one hand, this is required for the purpose of risk management, company strategy and electricity trading, seeking for improvements in company performance. On the other hand, the market regulator needs to assess not only the risk involved in this activity but also the underlying profits of the industry, as well as the regulatory adjustments that might be necessary for achieving a balance between the benefits that need to be assign to producers and those to consumers.

In this environment, investors of physical assets are confronting an almost insurmountable task, as valuing generation facilities do not seem credible, because of the large implicit or explicit variance that involves any estimates. Buying power plants involves considerable risk and capacity building is turning an even more complex task. But there are opportunities and some agents are taking advantage of them. However, most every one is ill prepared in terms of the methodologies, tools and techniques that are required for the evaluation of the different alternatives that they might wish to consider.

Traders do not live under a calmer environment either as price volatility amounts to around 600% in some places, which compares with the long-term volatility of the financial markets of about 20% (Larsen *et al*., 2003). Under these conditions, when and how much to buy is not a simple question, given the intense competition existing in electricity markets and the possible substitution options open to the consumers.

Against this background, learning and decision-making becomes a challenge to investors, traders, strategists, policy makers and regulators in liberalised electricity markets (Dyner et al., 2000). This paper reports some of the research, based on SD modelling, that has been conducted on energy markets at the Institute for Systems and Decision Sciences at the Universidad Nacional de Colombia, during the last 10 years. The focus has been on building “learning environments” for strategy and policy assessment, regarding issues related to investment, trading and electricity regulation. In each case the underlying goal has been to test a dynamic hypothesis of system behaviour, within the framework of the particular problem that is being confronted.

2 SD modelling of complex electricity markets for policy and learning

Under central planning, previous to electricity deregulation, the most difficult task in the electricity sector was related to resource allocation. And, during those days, one of the most important issues for the rapid development of the electricity industry was capacity building and grid expansion to increasingly support high-demand growth. As most variables were though to be under control, classic OR, mainly optimisation techniques, were worldwide developed and used. However, under the present market condition, uncertainty plays a much more important role, and the different agents have to think about alternative tools to support the decision-making processes and their intended strategies (Gary and Larsen, 1998; Dyner and Larsen. 2001).

The challenge has also been to develop teaching environments to assist learning as the classic strategy and finance frameworks do not apply according to the well developed theoretical schemes that largely assume static conditions. In the present remarkably complex electricity systems, where circumstances vary more frequently and suddenly than in most markets, interactive and changing (far from static) frameworks need to be analysed, experienced and practiced. In this context, where far from equilibrium, simulation approaches, particularly SD based, have been considered because of its imbedded potential for contributing to the understanding of the system evolution for policy and strategy assessment (Dyner and Larsen, 2001).

First, SD modelling frameworks (Bunn and Larsen, 1992; Bunn, 1994; Bunn and Larsen, 1997; Dyner, 2000; Gary and Larsen, 2001) have played an important role for thinking, learning, policy and strategy support in deregulated electricity markets. Particularly our approach which considers System Dynamics Platforms has shown to be useful and effective, as it has been detected in our research that modelling of physical assets is not a trivial task. Modelling physical assets and market structures have in many occasions become common to different problem set-ups. From our experience, we have turned them into components, fairly large “archetypes”, of our models. In this way, they can be plugged and unplugged according to requirements. This model building approach has simplified our model-building task, and not only has helped us to keep consistency but also has allowed incremental improvements as new data becomes available and as validation has indicated. This approach fulfils modelling requisites with respect to modularity, transferability and transparency (Dyner, 2000).

Second Microworlds have been on demand for supporting teaching environments that use simulators in workshops. By using Microworlds the trainees can observe the dynamics of the different theoretical frameworks as in learning by doing (Argyris, 1985).

In this paper we illustrate a number of cases where SD modelling has been helpful. In some cases, modelling has taken the form of Microworlds for learning; while in others the form of simulators that have been used as a main tool for systems thinking for policy or for strategy support. In all cases the focus has been on the sorts of uncertainty that electricity markets suffer. In the following sections we examine issues related to electricity generation, trading and regulation. In this sense we provide a number of examples of how SD has been used in complex electricity environments, illustrating only a very limited list of the vast potential of SD in this field.

3 Modelling electricity generation for learning, policy and strategy

The power generation industry, under competitive markets, has drawn the attention of SD modellers to address issues related to capacity building. This research that has been pioneered by Bunn and Larsen (1992) has been followed by Dyner (1995), Gary and Larsen (2000), and Ford (1997, 1999), as well as by others that have not yet reported widely their findings. In this paper, we provide evidence from our findings, pointing out some of the dominant dynamics and the role that SD might play for managing uncertainty in electricity markets.

3.1 *Microworlds* for learning about power investment opportunities in Latin American markets

Based on our experience of building Microworls for learning about capacity investment in Colombia, our group has extended this approach, in terms of our thinking frameworks, for modelling the electricity industry of neighbouring countries that live under similar development conditions and industry set-ups, namely Ecuador, Panama and Peru (Smith *et al*, 2001). This microworld was based on an earlier model developed for the Colombian electricity market (Arango et al, 2002).

Investment in capacity is a complicated issue. It is difficult to provide medium-term estimates for profits, returns or operational costs, as in most places it has turned very difficult to assess when (during the year) plants will be running. In this environment dispatching a generation plant depends on a number of uncontrollable variables, including weather factors and competitors bidding strategies as well as network congestion and the regulatory risk of changing the market rules. In these circumstances, Microworlds have proven to be of help to understand and analyse investments in these new electricity markets.

3.2 *The Wind energy component of electricity markets:*

The experience of our group on model-building has been an asset for evaluating related ideas to investigate the likely complementarities between wind and hydro-electricity. Operationally, it is not a trivial question to answer. When thinking of a plant portfolio for a company, it is not simple to specify the real advantage, if any, of holding hydro, thermo and wind plants. Market liability for not meeting electricity supply contracts is always a possibility, and supply opportunities when prices are at a peak levels are often observed.

How much capacity should be build of each technology? Where, how and under what circumstances an agent should invest in capacity and what sort of capacity? The answer to these questions, are by no means simple pieces of work for newcomers to the field. The problem is broad and there does not seem to be a straightforward close answer for the client. Here, we are also investigating the potential penetration of an unknown technology in the Colombian electricity market - wind energy - seeking opportunities for a particular agent.

Building wind-energy parks, as part of the diversification strategy for power generation, opens new possibilities. As initial research suggests, there is statistical evidence about complementarities between wind and hydro electricity, especially when water is needed most: during dry weather conditions. However, it is not a trivial fact as to what can be the advantage drawn from this circumstances for a particular company. Again, issues related to grid topology, which create system restriction for plant dispatch, as well as company strategies, contract portfolio for electricity supply of the different agents and the changing regulatory environment, makes it difficult for assessing the potential benefits of wind power.

At a general level, there have been questions related to investments under uncertainty. The basic problem consists on deciding when to invest and what module (when modular plants are being considered) to be built. The Real Option theory has addressed this problem, using however very simple Winner Processes that do not resemble the prices observed in the electricity industry in countries such as Colombia. Undergoing research within our group aims to make connections between more general forms of Real Options and SD, seeking to incorporate this into our modelling of the new electricity market set-ups.

In all models that we have developed, the basic logic that drives investment opportunities is driven by finding when and which plants will be most required. This depends on the technology and the type of investment. Once the system has been identified, the investment dynamics that is being tested follows the general causality shown in Figure 1. It can be appreciated that, as the system margin decreases (the difference between supply and demand), electricity price increases. On the one hand as prices increases and as other conditions are present (e.g. agents foresee acceptable returns for their investments) there are incentives for capacity building, which in the long run implies that more capacity is built, widening the system margin, which in turn reduces electricity price. On the other hand, as prices increases, demand decreases, and the system margin is reduced, leadings to higher prices.

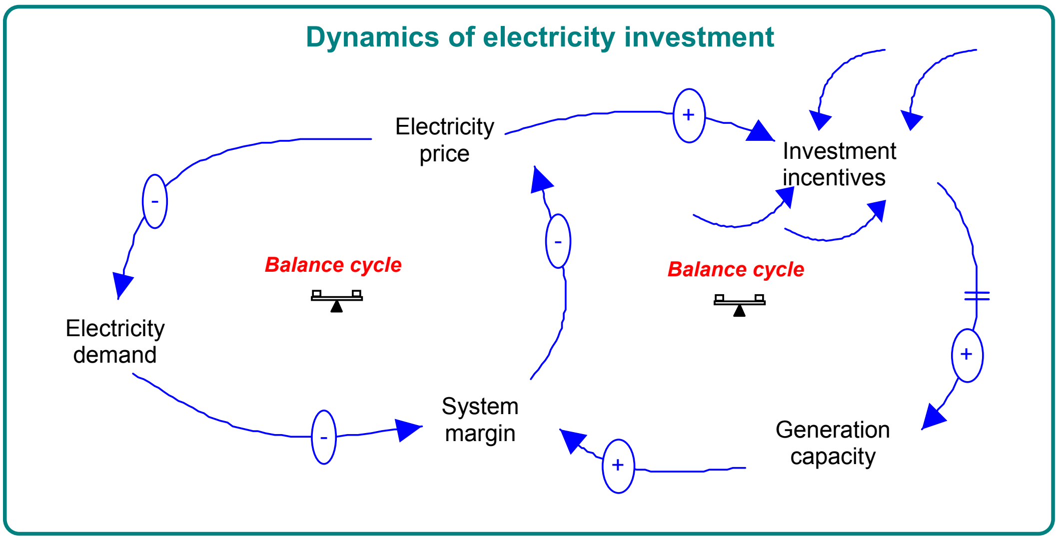


Figure 1 Investment dynamics

Understanding incentives could be almost as difficult to modellers as it is to investors. While electricity price is one of the most important variables to this effect, what investors would like to know is what prices will be available when new plants start operations. But incentives also depend on the evolution of demand and supply and also on some other exogenous variables, which are highly uncertain. The problem about specifying investment functions in deregulated electricity markets has been discussed by a number of authors (Bunn and Larsen, 1992; Ford, 1999; Dyner and Larsen, 2001; IEA, 1999; and others) and is not a concluded matter yet.

In each particular application, researchers need to carefully examine local and global conditions to be able to specify the appropriate investment function as illustrated in figure 2. For the Colombian case, which is similar to other Latin American countries, some elements that are particularly important include Capacity Charge (incentive defined by the regulator), hydrological conditions, grid restrictions, and so on.

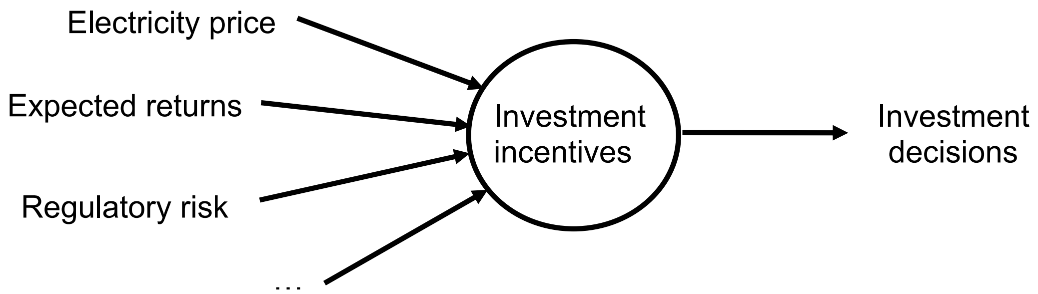


Figure 2 Investment incentives

Figure 3 provides a simple example that illustrates this point with respect to investment incentives. As the gap between supply and demand narrows (the system margin is reduced), new power comes in place (for the simulation provided, significant capacity is in place by the year 2009). But is it the same to invest in CCGTs (Combine-Cycle Gas fired Turbines), hydroelectricity or wind-based power? Of course not, and this depends on the incentives and threats that agents observe and confront, such as low system margin, time for building new capacity and market uncertainties; and also with respect to other particular aspects of the technology, such as efficiency and environmental restrictions.

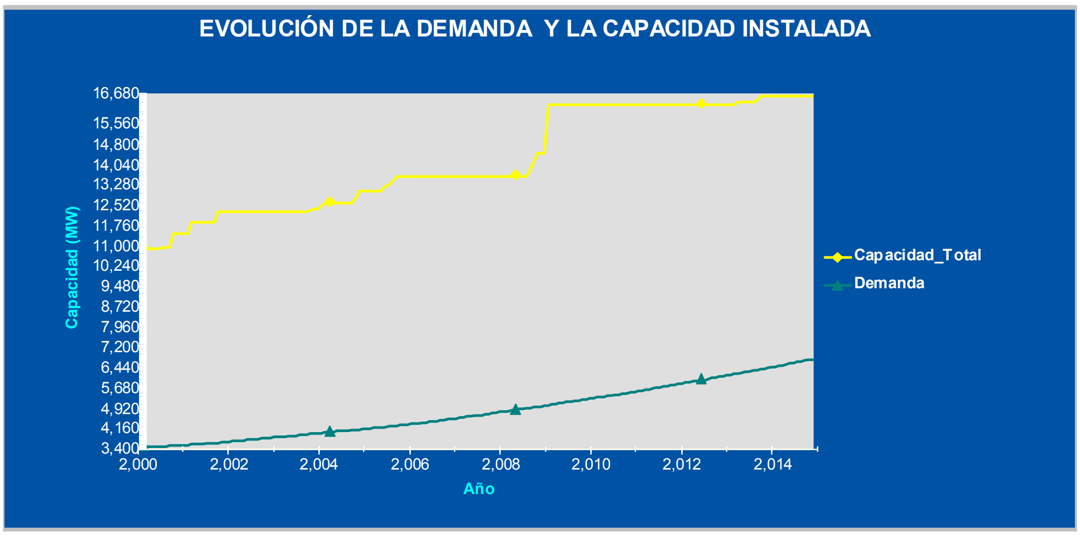


Figure 3 Typical simulation results for capacity additions when investment incentives "work appropriately"

In this section we have addressed problems of power additions to energy systems and have shown the basic dynamics that have been tested in these circumstances. The typical observed behaviour is cycles of capacity excesses and shortages as has been shown in Bunn and Larsen (1992), Bunn (1994), Ford (1999) and Gary and Larsen (1998). The basic dynamic hypotheses have been specified in our research according to the fundaments indicated by Homer and Oliva (2001). Our research has proven useful for better understanding the complexity of investment in electricity markets, showing its applicability to learning, policy and strategy in these markets. Furthermore, this is not exclusive to the cited cases and might be helpful in many other circumstances.

4 Modelling electricity trading for learning

Electricity trading is not a much less risky activity than the one related to investing on power generation. Although it has been argued that Enron went bankrupt for its bad investments in physical assets and not for its commercial activities, the risk involved in electricity trading is enormous compared with almost any other activity, as price volatility (a measures risk) is much larger than in most industries (even ten times higher than market indexes). In the electricity sector, understanding price dynamics becomes a challenge and may turn to be a factor contributing to competitive advantage for those who work on it. In this sense, decisions related to: when to buy and what sort of contracts to endorse, as well as how to undertake sales, are not well understood by the sales work-force, managers or specialists in this industry. This is the case as the electricity business is similar to no other business, as it involves very cumbersome rules only understood by highly specialised analysts in the field.

4.1ENERBIZ Microworlds

With the challenge of helping managers for better understanding electricity markets, and for building abilities and capacities in relation to strategic thinking and risk management, the Energy Institute, at the Universidad Nacional de Colombia, and Interconexión Eléctrica S.A., decided to develop learning environments - supported on SD models - for teaching and learning about electricity trading.

The basic influence diagram that represents the basic dynamics of electricity trading is shown in Figure 4. As may be observed, as traders sell electricity they have to decide where, when and how much electricity to acquire from the market. Depending on profits, traders invest in marketing, IT and other activities to improve their competitive advantage which feed backs over sales.

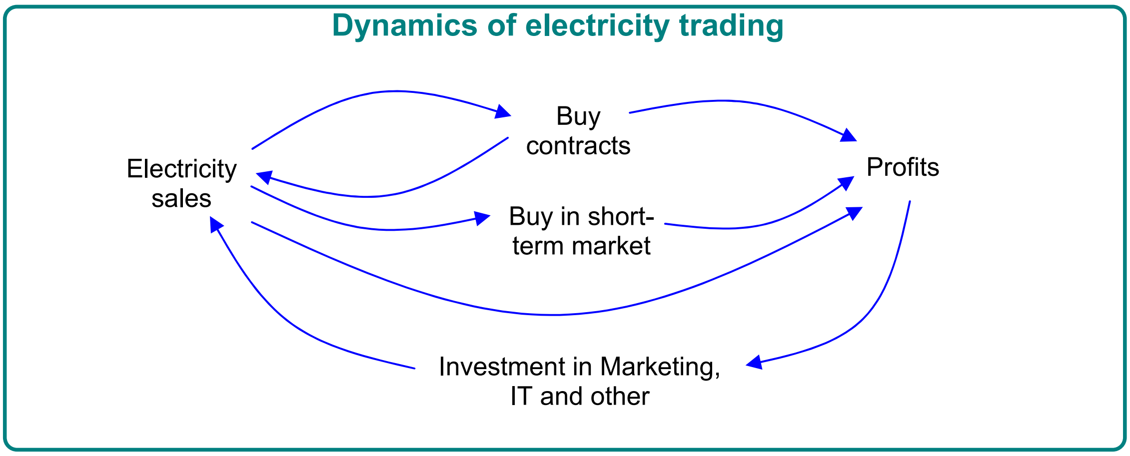


Figure 4. Basic dynamics of electricity trading

Can the understanding of this general dynamics be of any help? If the answer is positive: how much? and in what context? Our intent has been the specification of instruments for supporting learning environments. This has constituted an important line of research for our Institute over the last four years. Three different versions of Microworlds (Enerbiz I, II and III) have been developed intending to address different aspects of the electricity trading activity. The first two aim to assist workshops about corporate strategy and finance and the third about negotiation strategies - the specification of each of the models that support the Microworlds can be reviewed in Dyner et al (1998, 2000), Franco et al (2000, 2001), and Ochoa et al (2002). Questions related to market efficiency, best trader practices, risk electricity management, strategies on competitive advantages as well as negotiation strategies might also be addressed with the support of Enerbiz´ microworlds. Figure 5 shows some of the interfaces and typical results that can be obtained.

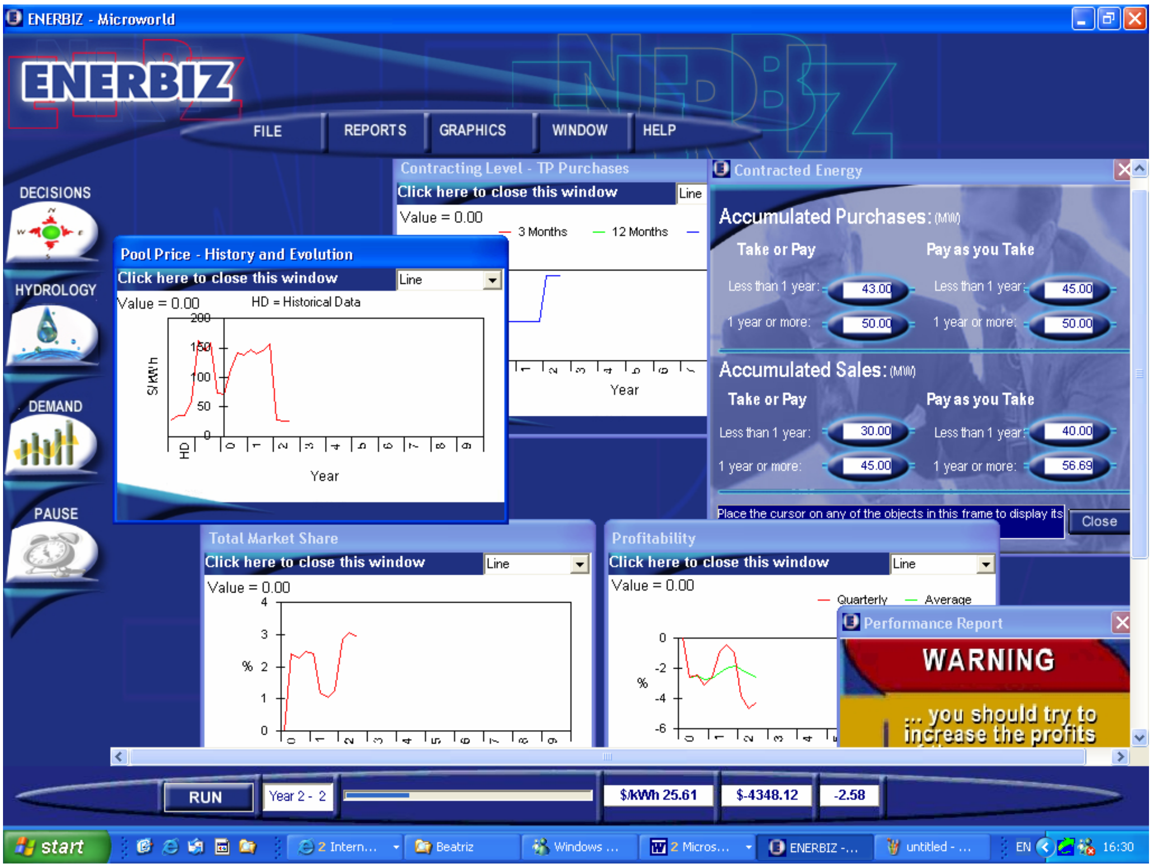


Figure 5 English version of Enerbiz. Some features and typical results

It is important to note that these Microworlds have been useful for purposes different from the ones that motivated their development. Enerbiz has been used: to present the Colombian electricity market, in courses about contracts liquidation, to promote the development of new related products, among others. Initial evidence show that these Microworlds have been a contributing factor to learning about electricity trading (Ochoa, 2002), yet more research is required on this line.

4.2 Microworld for the UK electricity market

The UK introduced new trading arrangements for its electricity industry in 2001. With the intention of better understanding the underlying market, perhaps the most advanced worldwide, we built a prototype of a Microworld for this market. We initially explored its likely strengths and weaknesses and now intend to undertake research to explore which elements could be of use to the Colombian electricity market.

The Microworld is intended to be capable of showing market efficiencies and trading opportunities and, in this sense, the value that this market might add to the present Colombian electricity arrangements. Part of the assessment that might be carried out will include the examination of possible inefficiencies of the market, difficulties in terms of the support that might be required by financial markets and some liquidity aspects.

Figure 6 shows some of the features of the Microworld, under construction, for the UK electricity market.

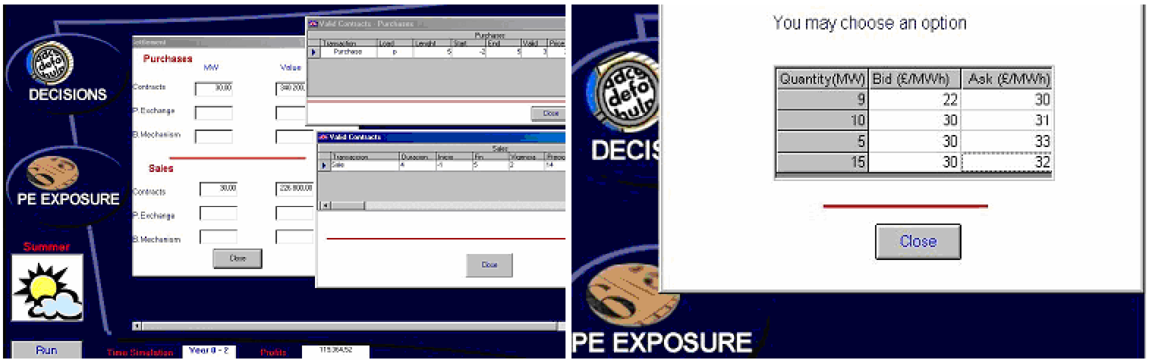


Figure 6. Aspects of the Microworld for the UK system.

The case of the Microworlds for supporting learning environments, illustrated here for electricity trading, has initially shown its adequacy for the assessment of the basic principles that may drive electricity trading. In particular it has shown to be of great value to test the logic of the business and particularly with respect to learning strategic and risk management frameworks under very dynamic conditions. Experiments conducted with the help of over 200 participants, initially indicate the usefulness of these Microworlds to assist learning about electricity trading (Dyner et al, 2002)

5 Modelling electricity uncertainty for assessing market Regulation

As well as market risk, industry agents and regulators have started considering regulatory risk. Changes in regulation might not only introduce more uncertainty to the electricity industry but might also induce higher volatility if these are not carefully undertaken. In this paper we examine research that has been carried out by our Institute with respect to this topic (Dyner et al, 2001)

In this case, as illustrated in Figure 7, models might be of important value for assessing the likely influence of the different regulatory set-ups over the agents' behaviour, and at the same time for evaluating how these influences the physical structure of technology composition, which directly effects system behaviour (volatility induced or prices). With this modelling approach it might be possible to help regulators assessing their intents and also for appraising their implementation strategies. As theoretical frameworks do not provide sufficient arguments to this end, it seems useful to evaluate regulatory initiatives, via simulation, before implementing them.

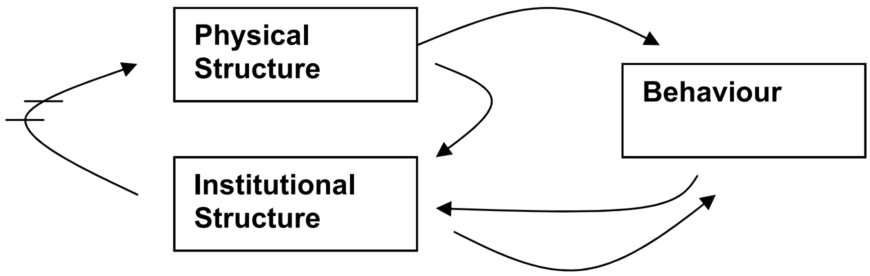
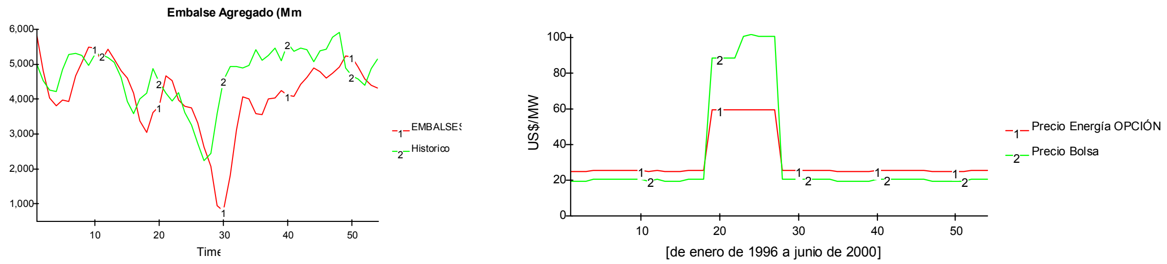


Figure 7 Important influences to be considered when simulating for regulatory assessment

In this particular case, models have been used to test alternative regulation to the capacity payment scheme that was introduced in Colombia in 1996. This, however, has shown weaknesses and alternative regulations have been suggested. The theoretical discussion around this issue provides insufficient grounds for the regulator to undertake any action, given the complexities involved. To prove this assertion just take into consideration what went on in California during 2001.

Figure 8 (A and B) ahead shows the historic behaviour (in green) and simulation results (in red) of certain variables, when two alternative policies are in place. In the first case, it is appreciated that there is better use of water (agents can dispose more of it) at a small risk, and in the second case pool price is lower under an alternative regulatory scheme. Both schemes will favour more thermoelectricity in the system, making it more reliable and smoothing prices.



A B

Figure 8 Simulation results of alternative regulation. Green shows historic behaviour and red simulation result

In this case we have tested policies for alternative regulation of electricity markets. Other regulatory schemes have been analysed by the Energy Institute and other consultants in Colombia. We have drawn some lesson that might be useful for policy purposes and have checked the validity of the system dynamics frameworks. These schemes might be easily extended to other industries that have been under deregulation such as communications and air transport.

Conclusions

We have undertaken modelling for managing uncertainty and for learning about the dynamics of electricity markets. This has shown useful in the cases exhibited here and by no means limited to them or to the particular circumstances that have been studied. The general approach indicated in this paper can be followed and applied elsewhere, but always observing the assumptions and limitations in each case where intended to pursue.

The focus has been the Colombian electricity markets, and some ideas have been extended to modelling other Latin American markets for the purpose of building learning environments. One case shows how the general framework of research has helped to build Microworlds for a completely different market, but with the intention of drawing lessons to the Colombian electricity system.

The idea in all circumstances exhibited here has been the dynamic-testing of all frameworks and the insights that might be drawn for the particular purposes that have been conjectured.

Finally, as we have been researching about modelling approaches for the new electricity arrangements that are taking place worldwide, we are making contributions with respect to the support of policy and strategy assessment, as well as in providing tools and instruments for learning environments. We are also intending to provide help, via our systems thinking-system dynamics approach, for developing insights about the electricity industry and a general way of thinking about electricity markets.

We have influenced policy makers, strategist, analysts, and part of the academic community in Colombia. Our research has also considered other Latin American markets and the UK electricity market, intending to assess the validity of our approach under uncertain and dynamic conditions. We hope that some of our ideas might be of use elsewhere.

Acknowledgments

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