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Simulation for alternative regulations in the power-supply industry: lessons for California

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Abstract

This paper reviews the transformation of the electricity industry world-wide and examines the benefits that this has brought up to both generators and customers. It points to problems as well as to possible solutions for the sustainability of reforms, and establishes that under the uncertainty of the environment, the regulation has been making a rapid progress and it is expected that its evolution will continue for many more years.

We propose a non-standard System Dynamics approach for evaluating alternative regulation schemes. The objective consists on finding costs and benefits, as well as possible winners and losers. System dynamics allows also assessing the opportunity for the transformation process, as gradual implementation seems to be possible in an expanding market.

A specific regulation problem is undertaken to illustrate the proposed methodology. It shows how the capacity-charged element, which has been used for reliability purposes, might be changed for alternative schemes. The proposed transformations to the actual regime seem to overcome some of its drawbacks. Simulation results indicate that alternative regulation improves the general system behaviour.

1. Regulating the new electricity industries

The electricity industry initiated major transformations world-wide during the late eighties. The basic idea was to replace state-owned monopolies by open and competitive markets in those parts of the production-distribution chain where this was feasible. During the first years the experiment operated properly in some sectors, especially in the generation and sales to large customers. During the last years, competition reached the household sector with benefits to customers. These changes have prompted a new paradigm for the activities of trading, management and delivery of energy services to final customers as well as for regulation (Armstrong *et al.*, 1994).

Chile was the first country to move ahead along these lines. Few years later, the UK and Norway revolutionised the industry with major innovations with respect to market openness, privatisation schemes and regulation set-ups. The motivations for these reforms have not always been clear, as there was nothing explicitly wrong with this industry. Electricity was being delivered with no major problem. In many cases no significant additions in capacity were required, technology seem appropriate and no one thought that prices were incorrect. Furthermore, complains from customers were not a major issue.

Ideology, and the general economic thinking about industrial organisations, were perhaps the main driving forces behind reforms although other issues, such as dependency of coal in the UK, regional price differences in Norway and mismanagement in Latin America, have had important impacts as well. Also in some countries, the need for private investment was a motivation for de-regulating the electricity industry.

Both the evolution and the world-wide spread of the new industry paradigm have been very rapid. The UK has moved along its proposed timetable and is now initiating new regulatory adventures. The Norwegian model was exported with adaptations to Scandinavia, creating the Nord Pool. The European Union established directives, gradually opening the industry and East European countries are facilitating foreign investment. The majority of States in North America have undertaken profound reforms during the last five years while most Latin American countries have undertaken major reforms or are in the process of transforming their electricity industries. Australia and New Zealand have also moved in the direction of unbundling the industry. Nevertheless, most countries in Asia and Africa have made little progress in this direction.

Some benefits are already being perceived from these reforms, such as:

- Technology has evolved rapidly,
- Prices have dropped,
- Efficiency and industry productivity have increased,
- Management and regulators have rapidly evolved towards different paradigms.

Although it had produced benefits, the system is still far from reaching an equilibrium and major reforms are underway in many countries. Limitations in adaptation have created problems in New Zealand, Chile and California, where major outages and extremely high electricity prices have been observed. Furthermore, market power, price volatility and investment risk are creating problems in the industry with negative consequences for the guarantee of supply.

It is first argued in section two that the newly created markets urge for a new rounds of reforms because of the ever increasing complexity and uncertainty observed in the electricity industry. In section three we discuss some alternative methodologies for policy support, and in section four we propose a system dynamics platform for assessing those regulation alternatives. Section five applies the discussed methodology to the Colombian case, assuming two different regulation schemes. Finally, we provide some conclusions.

2. Complexity and uncertainty in the power industry

In a long-term view of the industry many issues arise which include demand satisfaction, ownership concentration, price volatility, technology development and regional and intra-continental trading. In particular, the electricity industry has turned highly uncertain with respect to the following factors (Dyner and Larsen, 2001):

Price: One of the largest volatilities observed in any industry (between 200 to almost 1000%).

Regulation: No regulation scheme seems capable of surviving over long periods.

Demand: Demand forecasting has become as uncertain as in most competitive industries. The focus has shifted from long-term forecast to strategies, for example with respect to:

i) Variations in market share
ii) Price predation or price skimming
iii) Segmentation
iv) Fusions and divestments

Externalities: No optimal expansion plan seems to be possible for the industry because of weather, regulation and demand uncertainties, as well as of environmental concerns.

Technology: Last, but not least, major threats come from the fast evolution of technologies. Efficiency of combined cycle gas turbines, CCGT, has improved rapidly, making obsolete relatively new plants in less than eight years of use, when its financial life span was calculated to be around 15 years. Moreover, there seems to be rapid progress towards supply alternatives based on hydrogen cells, which might revolutionise the whole industry.

Against this background some research questions arise: Are the present market structures appropriate for industry development? If not, what market structures might be more appropriate for the progress of the industry? Will it be feasible to return to central planning?

We believe that it is not realistic to consider that the electricity industry may return to central-planning schemes in the near future, for political and financial considerations, as well as for technological reasons. There are challenges to overcome if the industry is to prosper; however, their discussion extends beyond this paper.

Imitation and learning across industries have done much for electricity. Consultants and researchers have managed to innovate within the new framework, but the development of the electricity market paradigm is still in an embryonic stage. Little has been accomplished in terms of convergence, but sensible alternative options are being examined in different countries and regions. Pool-based mechanisms and bilateral trading frameworks seem to be the most frequent alternatives for the short-term electricity markets; options and futures markets for the long-term; and ancillary markets for instant dispatch.

Electricity markets have called the attention of a number of scholars and consultants, who use a variety of tools for analysis. These tools include simulation and risk analysis techniques for investment purposes, optimisation approaches at the operational level, and both simulation and econometric techniques for the evaluation of regulation alternatives (Dyner and Larsen, 2001).

3. Complexity and regulation modelling: simulation Vs optimisation

From a regulatory perspective, the electricity industry has been dominated by uncertainties and the primer objective is to seek for stabilisation. Major reforms are underway but an incremental approach seems to be preferred, given the sunk costs of investment that are involved in the industry, the existing operation licenses, some rights that have been acquired by agents, and long-term contracts that are permanently agreed between different institutions.

Side effects of the reforms need close examination. General regulation frameworks call for adjustments to account for the specific characteristics of regions and for technological aspects. For example, strong winter and summer in the north hemisphere and tropical conditions in temperate climate cause demand differences. Similarly, seasonal variations in hydroelectricity generation are much higher than in thermoelectricity technologies, and while heating is probably best supplied via some sort of thermal energy, cooling may be better provided by electricity sources. Moreover, as weather affects hydroelectricity plants depending on the water source, the behaviour of Norway's system differs from Brazil, Chile or Colombia's.

Those particularities demand adjustments of the theoretical framework for regulation The design of industry needs to incorporate issues such as economies of scale, possible entry and exit barriers, market power, environmental limitations, technology availability, and demand characteristics.

When considering the industry as a whole, from the regulation point of view, the regulator's task is far from simple. The regulator needs to provide what the market lacks from. He should judge a balance between all stakeholders and has specially concerns for two of them: suppliers and customers. From a simplified view, he might pursue goals to attain such intensity in competition, that prices will reflect the incremental industry cost, with clear signals for effective system expansion to satisfy demand at competitive prices and good electricity quality. Under these conditions, the regulator often faces conflictive, but not multiple objectives. Even trying to approach the problem as one with multiple objectives, there will be difficulties related to uncertainty in prices, weather and technology, which would not allow to attain an optimal solution.

Alternatively, the regulator pursues long and short-term goals seeking for balancing the costs and benefits of the confronting agents. In such environment, learning from reality may, in some cases, be inappropriate and cause catastrophic effects for the system as a whole, given the long lags involved in this industry. Learning from models might help to assess likely consequences, and the policy maker may investigate alternatives to eliminate unwanted effects.

Modelling causality and delays turns important in practice to account for policy effects on the system and how it may need adjustments or re-enforcement to obtain the desired system behaviour and sometimes, to investigate if policies trigger instabilities, which may affect system performance. System dynamics, an approach that incorporate these elements has been successfully used for exploring different policy issues in the energy industry during the last decades (Naill, 1977; Naill, 1992; Ford, 1983; Ford, 1985; Ford 1990; Ford 1997; Bunn and Larsen 1992; Bunn *et al* 1993; Bunn and Larsen 1997; Bunn *et al* 1997; Dyner *et al*, 1995; Dyner and Bunn, 1997; Dyner 2000).

Trying alternative regulation schemes before implementation helps to understand issues with unknown outcomes. As feasible solutions may be infinite, a modelling platform (Dyner, 2000), like the one briefly described in the next section, may serve as a tool for policy support.

4. System platforms for regulation assessment

Electricity systems depend upon their generation, transport and supply characteristics, possess underlying dominant structures and its behaviour is influenced by physical, technological and topological considerations. Other "softer" structural aspects such as institutions, policies and regulations have short-term effects on behaviour and long-term impact on the physical structure of the system, which reinforce or transform system evolution. Figure 1 indicates the main macro-structure dynamics of such electricity set-ups.

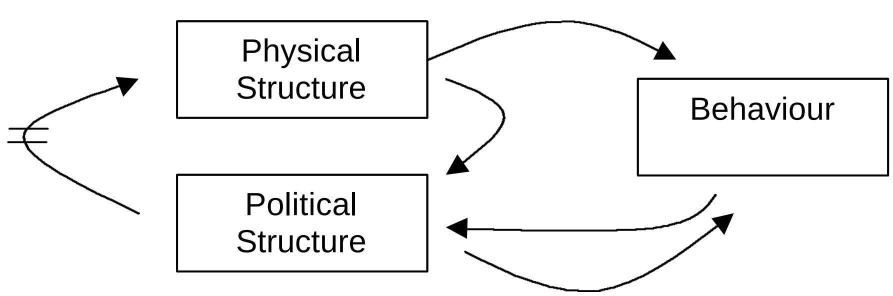


Figure 1. Macro-structure dynamics of electricity systems

In general, system dynamics modelling focuses on trying to understand how structure influence behaviour in terms of its dynamics (because of the difficulties in forecasting non-linearities and delays), instabilities (because of the interrelationships between variables and initial conditions) and counter-intuitive behaviour (because of the interrelationships between variables and delays).

In the case where long- and short-term issues play an important role, as discussed above, the system dynamics approach may undertake the path of modelling platforms (Dyner, 2000). In this case, one the basic components is the physical structure (which might be fairly complex) and which is either being transformed exogenously (not modelled) or endogenously (explicitly modelled).

Evolving regulation has dominated the electricity industry over a decade. We have a great number of changes, which involve theory development, good industry practice and continuous adjustments, much of it in the learning-by-doing approach.

A major shift towards a new round of reforms has signalled that no-natural and slow evolution will continue to happen in parts of the globe. Substantial changes in regulation are being prepared in many countries such as UK, California, and Colombia, and there is not clear outcome. Simulations may help to evaluate both alternative options to follow and likely system behaviour.

In this paper we examine alternative regulation schemes and evaluate and compare likely outcomes with respect to both historical data and future base line behaviour. The method applied for evaluating each alternative over time consists on trying to establish the evolution of the physical and topological structure, depending on the investment decisions with respect to capacity, which take into account the real options evaluation of projects menu. In this way, each alternative is assessed with respect to its reliability and price to customers, including volatility. In the next section, we illustrate with two examples some of the results provided by the simulation platform.

5. The case for regulating electricity in Colombia

The characteristics of the Colombian electricity industry are unique. It contains a large hydroelectricity share; a third of it depends on large reservoir capacity. Its domestic consumption pattern is very high, the household sector consumes over 45% of the total produced electricity sector, with little air conditioning or heating. The industry is also periodically affected by sever weather variations, which reduces water inflows into the system by up to 50%.

Furthermore, with plant configuration that depends on location and technology, and a transmission network that interconnects suppliers and customers, the Colombian electricity sector demands specific solutions, perhaps under the general framework that is being applied to other countries around the world.

Colombia has adopted a British-like scheme (Garcia and Dyner, 2000), and some variations were introduced to account for structural differences between both systems. The results of almost six years of operations are satisfactory in terms of:

- Price
- Guarantee of supply
- Technology evolution
- Management development

However, reductions in price volatility and benefits in the household sector are still to be observed. Furthermore, black clouds are ahead with respect to the “appropriate technology mix” which influences price volatility and guarantee of supply. Regulators have decided that time has arrived for reviewing the present regulation framework. The transition may not be smooth and some bumps might be in the way. Slightly bigger steps may now be required, incorporating schemes that have already been successful in similar industrial set-ups and also adopting ideas that have been experienced elsewhere.

One aspect of the Colombian system that bothers regulators, producers, trades and customers is the Niño, for which regulation rules have been established. These rules intend to control:

- The capacity payment for long-term system reliability, and
- The operational limits that are imposed on reservoirs to secure short-term reliability.

With respect to the capacity payment, not many agents are satisfied with the present arrangement. Rewards are based on an optimisation program with an objective function that agents do not share and that the public do not know, do not understand and do not care for. As a result of this, some are losing and some are gaining but most seem unhappy. The ones that are losing are also seeing that their total revenues are falling. The ones whose performance is improving with respect to the capacity payment see that this is insufficient to survive within the present industry arrangement.

Two coinciding factors affect the industry at the present time, a large fall in demand and a very heavy rainy season, which creates a situation that has never been observed in the recent history of the Colombian electricity industry. The present excess-capacity drives prices down and discourages thermoelectricity plants, and may have unfavourable long-term consequences, as thermoelectric plants may not seem viable now, but may be required for the next Niño.

Against this background, consultants and researchers have been called for to examine the most troublesome issues affecting the system. A number of considerations have been made and the rules related to the security of supply are first in the agenda. Several alternative solutions have resulted from discussions with specialists. Some are what has been called administrative and other are market-oriented solutions, meaning that the former are fairly interventionists and the latter more market oriented.

At the outset five different alternatives were examined and two further solutions are being evaluated at present. The first ones include availability payment, seasonal biding, technology thresholds, reserve payments, and options market. The former solutions being considered are: an entirely liberalised market and several regional pools (two or three).

The alternatives need to be evaluated and simulations may help in this respect. It will be possible to assess the regulation effect on signals for capacity installation, system reliability, technological performance of plants with same technology, and price trends. In this sense, will it be possible to evaluate who are the beneficiaries and who the losers?

Figure 2 shows the general causal loop diagram. All components of the model are the same for all alternatives, except those that are consequences of the regulation and the bidding exercise. The system operation is the most important factor that is common to all alternatives, except when the pool mechanism varies. The hydrology scenarios are also shared by all alternatives. Price and regulation provide a delayed signal for investors.

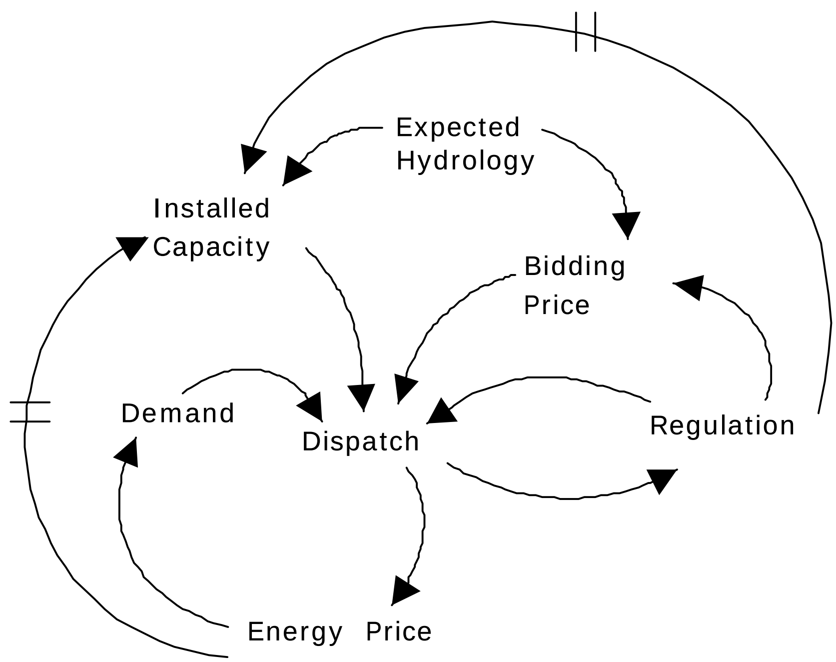


Figure 2. General causal diagram for evaluating regulation alternatives

As stated above, an availability payment and an options market are used in this paper to illustrate the discussed methodology. These alternative regulation schemes will be explained in the following sections.

5.1 Availability payment

The idea with an availability payment regulation is to reward plants for being available now, in spite of not being dispatch, as they may be needed in the future, during the dry periods, and even more so during the Niño season. That is, short-term reliability contributes to long-term reliability and should provide the appropriate signal for investment.

Figure 3 indicates how the scheme operates. When business as usual in the Colombian pool, after the daily plant bid for dispatch, they are ordered according to merit: cheaper plants are preferred over the more expensive ones and used for electricity production up to the point where demand is satisfied. The regulator establishes a threshold beyond the plants required for dispatch, indicating which plants will also be rewarded.

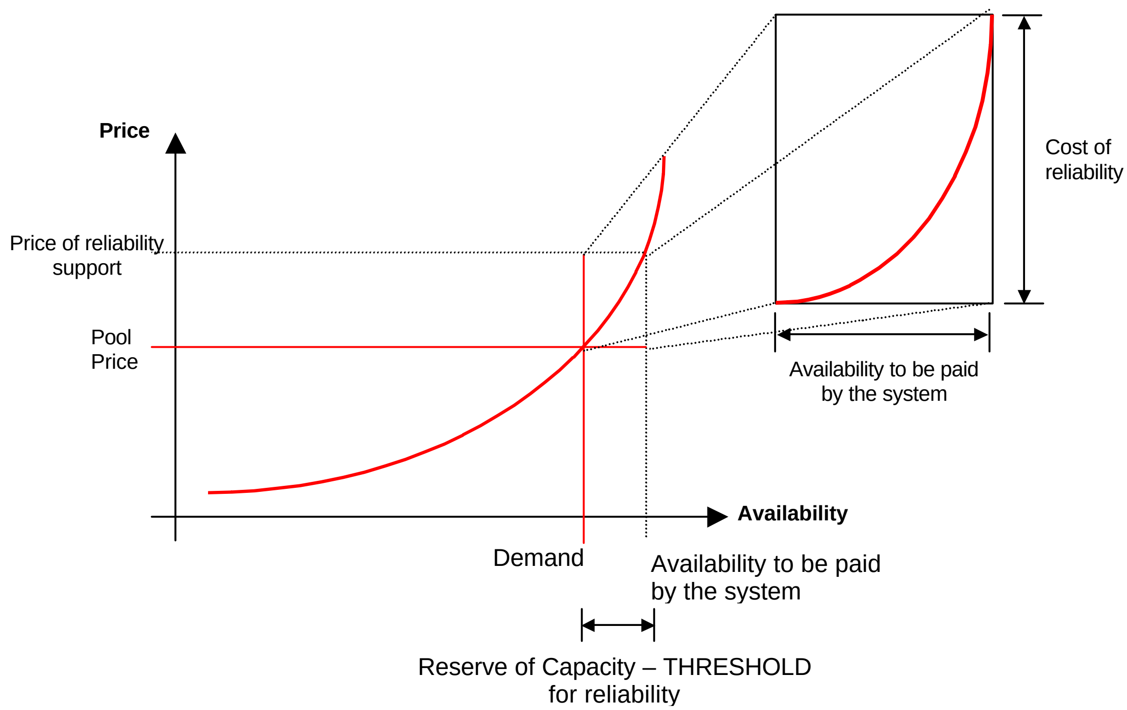
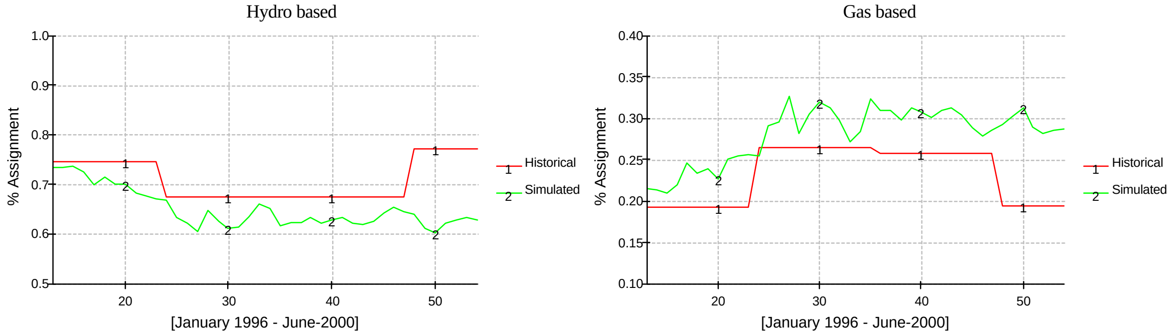


Figure 3. Availability payment up to an established threshold

Figure 4 shows both simulation results of what would have happened if the scheme had been applied during the previous years and also the historical market behaviour for hydropower technologies (4a) and gas fired plants (4b). In this case a threshold of 30%, over the demanded electricity, has been used. As can be observed, gas-fired plants will benefit at the expense of hydroelectricity plants that possess large reservoirs.



(a) (b)

Figure 4. Percentage of rewards to hydropower technologies and gas fired plants

Figure 5 shows the percentage distribution reward for availability payment, according to technology, in the case where critical hydrology is present. As can be observed, Thermoelectric plants will come close to the hydroelectric ones, under this scenario.

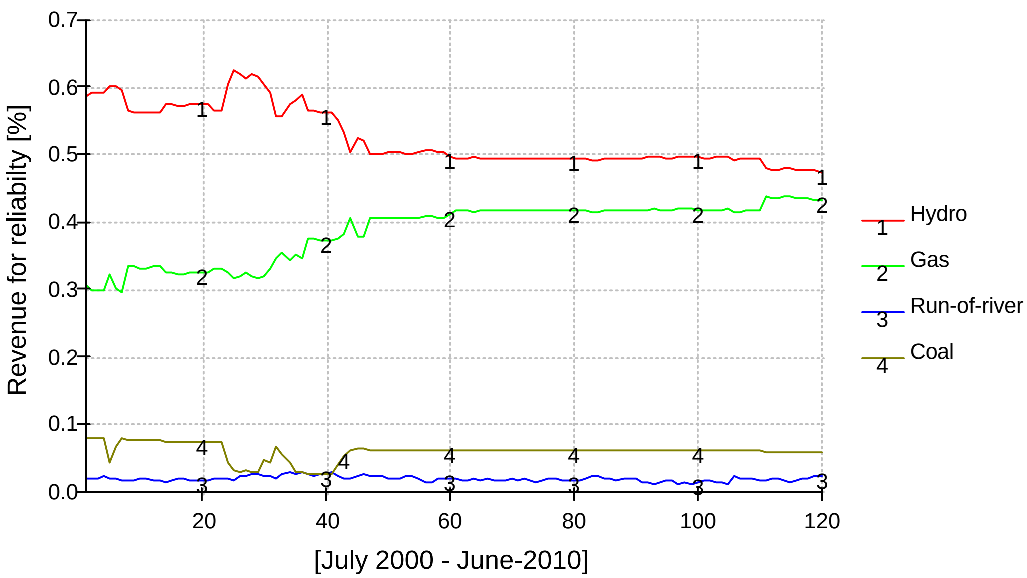


Figure 5. Simulation of market split revenues according to technology.

5.2 An options market

A less administrative solution to the problem of security of supply is one based on standard financial instruments designed for financial markets. The idea is to create instruments intended to protect buyers from a sudden increase in price, at the expense of premium, which the buyer pays monthly.

In this case, each generator has to find how to conform a portfolio of plants to guarantee power supply to its customers. In this manner, the market will find the appropriate technology mix that reduces the probability of electricity blackouts.

Table 1. Scenarios for premium and striking price

Case	Premium [US$/MW]	Striking price [US$/MW]
Base	15	55
X	10	65
Y	20	45

Electricity price is obtained according to:

EP = PR + [min(PP,SP) - CC],

Where: EP: Electricity price [US$/MW]
PR: Premium [US$/MW]
PP: Pool Price [US$/MW]
SP: Striking price [US$/MW]
CC: Capacity charge [US$/MW]

Figure 6 shows both historical behaviour of the average electricity price during each month, for the period 1996-2000, and simulation results during the same period in the case that the options market were in operation instead of the capacity charge.

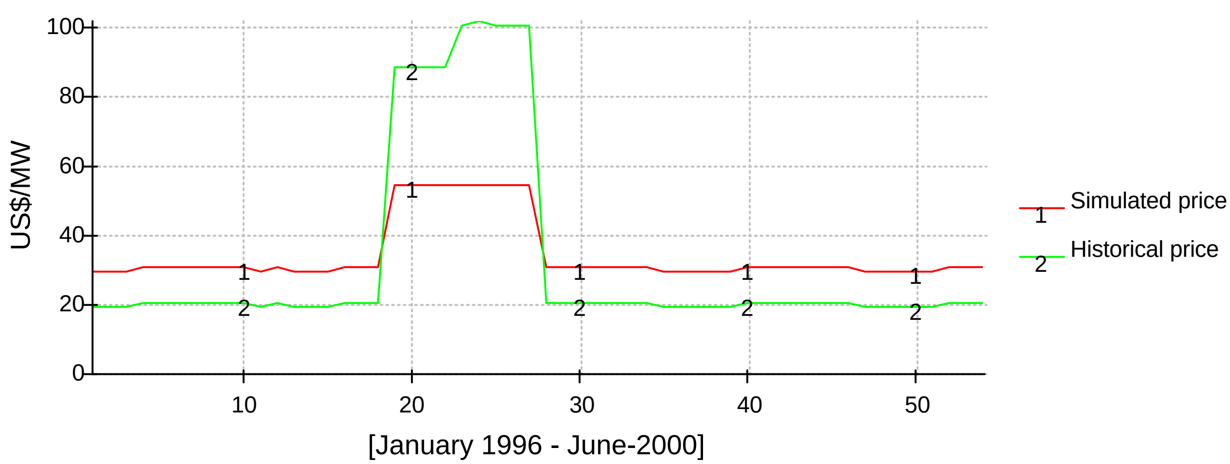


Figure 6. Electricity price. Historical behaviour and simulation of an option market

It can be appreciated that an options market manages to spread rewards to producers, reducing peaking prices during periods of low water influx, such as during the Niño periods. Customers will also benefit for the same reason. Pool price volatility is reduced as can be appreciated in Figure 7.

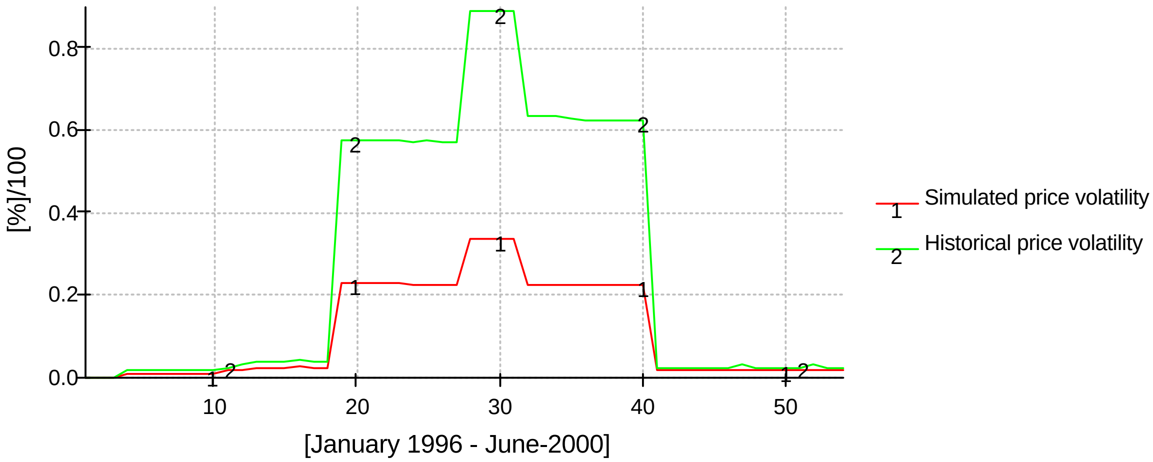


Figure 7. Volatility during the period 1996-2000. Historical vs options market simulation

Figure 8 shows the cumulative costs of historical trading at pool prices and those that would have been obtained if an options market had been operating. It can be observed that both alternatives produce similar results in the long-run.

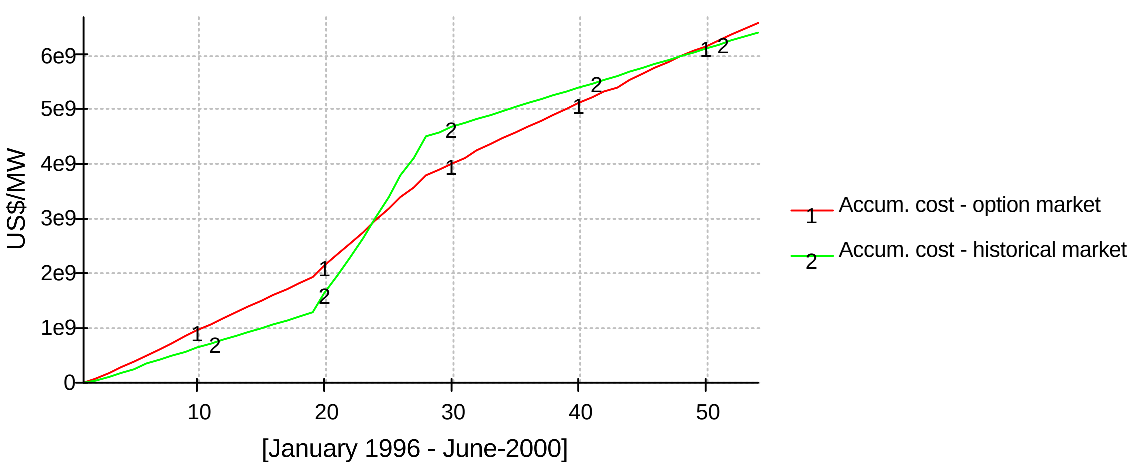
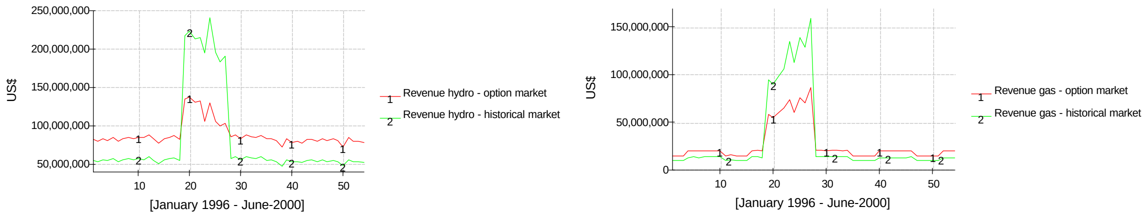


Figure 8. Cumulative system costs at pool price (historical and with options market)

Figure 9 shows revenues of generators according to technology, if the options market had been in operation and historical behaviour. It can be observed that the historic tendency does not change and also that some compensation may have occurred between hydro and thermoelectricity plants.



(a) (b)

Figure 9. Revenues for plant, according to technology ((a) is hydro based; and (b) is gas based). Historical against options market.

Finally, Figure 10 shows that the expected future price evolution, under critical conditions, operates basically as was illustrated with historical data. Volatility is largely reduced, company revenues are more evenly distributed, and average prices are slightly lower.

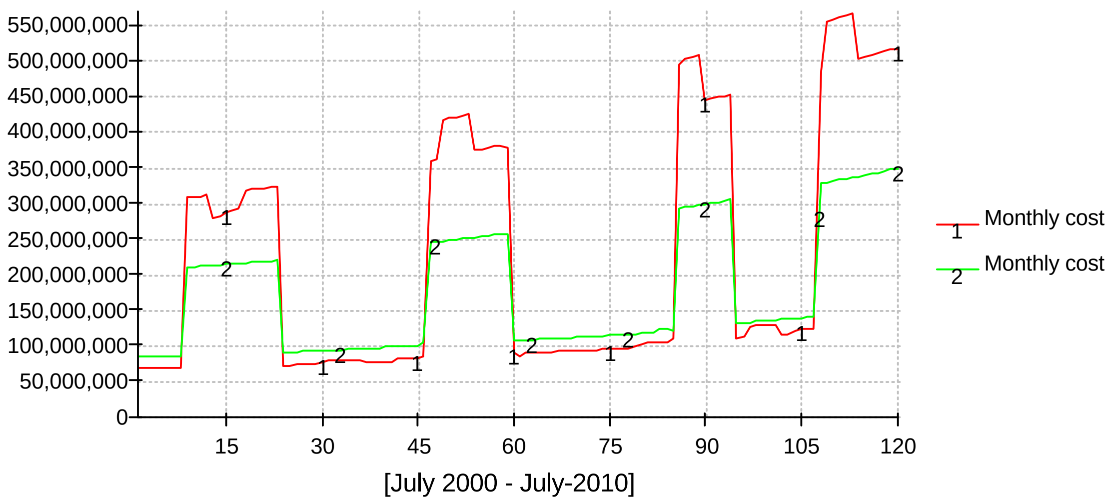


Figure 10. Simulation of the future price evolution under a critical hydrology scenario

Other regulation alternatives have been examined and evaluated. Given the focus of the paper, which is basically methodological, the authors believe that the above examples illustrate the approach, without going into further detail.

6. Conclusions

This papers shows how a System Dynamics approach, which takes the form of platforms for policy evaluation, may support the regulator's assessment of alternative schemes before implementation. This can overcome some the problems that theory and a oversimplified approaches pose.

Simulation results show that the system behaviour may be improved by introducing modifications to schemes in operation, eliminating the capacity charged, and putting in place one of the alternatives being examined. Further research is required for the selection process.

In almost all cases price system uncertainties are drastically reduced, which benefits both customers and investors. In some cases, volatilities are reduced up to 40%. Furthermore, even under the most critical scenarios, little blackouts were observed.

Although the schemes that have been explored above do not apply to other regions or countries, lesson can be extracted from the general methodology exhibited in this paper, using SD, for the assessment of alternative regulation before implementation elsewhere – California, among others.

Acknowledgements

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