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Understanding the coevolution of electricity markets and regulation

Busra Gencer [a,*], Erik Reimer Larsen [b], Ann van Ackere [a]

[a] University of Lausanne, Faculty of Business and Economics (HEC Lausanne), Quartier UNIL-Chamberonne, 1015 Lausanne, Switzerland
[b] Aarhus University, Department of Management, Fuglesangs Allé 4, DK - 8210, Aarhus V, Denmark

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ABSTRACT

Electricity markets are complex; they involve long lead-times, include feedbacks that are generally hard to interpret and are influenced by environmental concerns and political objectives. After liberalization, the markets moved from a monopoly situation with a single service provider and captive customers to competitive markets with multiple service providers. Foreseeing the consequences of regulatory decisions is thus becoming increasingly complicated for the regulator. However, understanding these is central to avoid mismatches between the markets and their regulation, which could result in unanticipated and costly long-term consequences.

In this paper we aim to provide a behavioural regulatory framework to help understand how electricity markets and their regulation can successfully coevolve. We identify four stages of market evolution, with their respective regulatory challenges. Next, we discuss several behavioural elements that affect electricity markets at the different stages. We then provide examples of regulatory failures at the different market stages, highlighting the role of the behavioural factors. We conclude with a general discussion of how this framework can contribute to addressing the challenges involved in regulating electricity markets.

1. Introduction

The move towards a liberalised and deregulated electricity sector over the last thirty years has significantly changed the nature of its regulation. While previously regulation was centred on regulating a monopoly, a relatively structured, though not necessarily simple task, the regulation of electricity markets is, paradoxically, much more complicated and complex. Whereas most other "free" markets require only occasional regulatory intervention, electricity markets have needed the constant attention of, in most cases, a designated regulator (Hunt, 2002). Rules have been tailored to the national conditions; they have required frequent amendments, and occasionally a complete overhaul. The need for these continuous regulatory changes results not only from the, often quite fast, development and maturing of electricity markets, their imperfect initial designs, and technological change, but also from the changing behaviour of the various stakeholders (consumers, generators, distributors and policymakers).

While some network industries, including electricity, telecom and rail, had an initial private phase (Parker, 1999), they were soon considered and treated as natural monopolies. When they became publicly owned or licenced, they were regulated as monopolies. Depending on the stage of development, regulation focussed on issues such as good coverage, adequate capacity, affordable prices, etc. (Hunt, 2002). In the seventies and eighties this natural monopoly status started to be questioned. In particular, the issue arose whether at least some of these utilities could operate more efficiently in a market-based setting. This led to the creation of competition in the telecom and electricity sectors (e.g. (Thatcher, 2004)). In the electricity sector, the first mover was Chile in the eighties (Watts and Ariztía, 2002), followed by Norway and England and Wales (Bye and Hope, 2005; Green and Zaccour, 1998). Thereafter the situation evolved quickly, with an increasing number of countries moving towards liberalization, and the EU mandating competition in 2000 (Jamasb and Pollitt, 2005). In what follows we focus on the electricity sector, but many of the arguments apply equally well to other network industries.

The process of deregulation of the electricity industry was initiated for different reasons in different jurisdictions. The main reason in Europe was a belief that the industry could be more efficient; competition should thus lead to lower electricity prices, making Europe more competitive. Another, more political, argument was used in England and Wales: state-involvement should be as limited as possible. In developing countries, it was often the lack of resources to finance the expansion of the industry that made deregulation necessary (Dyner and Larsen, 2001). Consequently, the initial conditions faced by countries starting

* Corresponding author.
E-mail addresses: busra.gencer@unil.ch (B. Gencer), erik.larsen@mgmt.au.dk (E.R. Larsen), ann.vanackere@unil.ch (A. van Ackere).

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the deregulation process varied widely in many respects. Examples include, but are not limited to, coverage (e.g., about 35% in Nigeria (Adenikinju, 2005), compared to (close to) 100% in most Western European countries), technology (e.g., Norway has close to 100% hydro (Energy and manufacturing., 2017) while Denmark has none), and reserve margin (e.g., 24% in England and Wales in 1990 (Bunn and Larsen, 1992), while Colombia had major blackouts before starting to deregulate in 1995 (Larsen et al., 2004)).

This large diversity in starting points excludes the idea of the existence of a single model, applicable across all jurisdictions. However, the purpose of deregulation was similar across all markets: creating a sustainable system that guarantees an adequate level of supply to all parts of the nation, at the lowest possible cost, resulting in affordable prices for the end-users. But, as events since the beginning of electricity deregulation illustrate, this has far from always been the case. There have been, and still are, many failures, as markets continue to evolve. These market failures, due to regulatory problems, deserve attention as they often result in undesirable situations, embarrassing for regulatory authorities and policymakers alike (Larsen et al., 2004); fixing these problems is difficult, costly and cannot be done overnight. Failures in electricity markets can be critical for the broader economy: electricity rationing, unreliable supply and persistent blackouts negatively affect economic growth. Understanding the link between regulation and the market is necessary to create a forward-looking, proactive regulation, as opposed to constant fire-fighting to deal with undesirable outcomes.

Our focus here is on developing a framework that can help to create understanding of how regulation can and must coevolve with the market. The maturing of markets is a natural process, which results from interactions between the different market participants. By definition, the initial regulation of a newly created market is imperfect. The players will explore the regulatory framework, testing its boundaries and exploiting available loopholes, causing the market to evolve. Sooner or later regulatory intervention will be required to close the loopholes and keep the market on track to achieve its intended objectives. Regulation that is out of synch with the evolution of the market is bound to create significant challenges for market participants, including the regulator, possibly endangering security of supply at the national level. We discuss the main components of a forward-looking behavioural regulation that can keep up with the continuous evolution of the market.

The paper is structured as follows. After the literature review, we identify four stages of market evolution and review the regulatory challenges faced at each stage. Next we discuss three behavioural elements that affect electricity markets and link these to the market stages. We then present a selection of examples of regulatory failures in the light of this framework. We conclude with a general discussion of how this framework can contribute to addressing the challenges involved in regulating electricity markets.

2. Literature review

Regulation of utilities has been an area of interest for scholars across different disciplines, including law (Demsetz, 1968) and economics (Stigler, 1971; Peltzman, 1976; Joskow and Rose, 1987). Research has focused on the regulation of monopolies (Posner, 1969), as well as on the liberalization of utilities such as telecommunication, gas and electricity (Armstrong and Sappington, 2006). Sectors such as electricity, gas, railways and telecommunications, where the capital costs are high and demand can be met at the lowest cost by a single firm, are considered as natural monopolies (Baumol, 1977). In such sectors, under the ideal circumstances where the regulator is fully informed about all the aspects of the market, competition is not expected to improve market effectiveness in terms of price and quality of the service (Armstrong and Sappington, 2006). However, monopolies are often criticized because of their inefficiency (Demsetz, 1968; Winston, 1998). In the electricity context, liberalization is expected to address the shortcomings w.r.t. resource utilization and investment (Bye and Hope, 2005), while providing competition that leads to lower prices and more innovation (Joskow, 2008).

While most countries start deregulation of the electricity sector with the wholesale markets (Woo et al., 2003), they have opted for different timelines and types of regulation. In the U.K., transmission and distribution of electricity remained regulated, while generation was deregulated to increase competition by allowing market entry (Green and Newbery, 1992). The country introduced price-cap regulation, a new approach at that time (Dnes et al., 1998), which was expected to increase efficiency, regulatory predictability and transparency. However, this mechanism also resulted in incentives to reduce costs, which can lead to lower quality, as observed for instance in the context of telecommunications (Joskow, 1997).

When pursuing regulatory reform in electricity markets, regulators should not only ensure affordability of electricity, they should also guarantee security of supply. While, in theory, competitive market prices should induce an adequate investment level (Wolak et al., 2000), the inelasticity of short-term demand, price volatility and unsuitable market rules prevent prices from sending timely investment signals (Finon and Pignon, 2008), forcing regulators to step in. Additionally, long licensing processes (Woo, 2001) and uncertainty resulting from market reforms (Woo et al., 2003) have turned out to be significant barriers to entry. In recent years problems have been exacerbated by interventions to support renewables generation (Blazquez et al., 2018).

The characteristics of the market (e.g., technology mix and current market structure) and political aims should both have a role in the choice of the nature and type of regulation. As markets go through a restructuring process, their policy framework needs to be adjusted (Larsen et al., 2004). The characteristics of investors are also important when designing policy mechanisms: their perception of political, regulatory, financial and cultural risk is important to secure investments (Komendantova et al., 2012).

Each country has its own characteristics that need to be considered when deregulating its electricity market (Larsen and Bunn, 1999). Not taking into account individual characteristics creates a mismatch between markets and regulation, which leads to failure and need for change. When such changes lead to increased regulatory control, Vogel (1996) refers to such situations as “reregulation”; he argues that in industrial countries, deregulation is a combination of liberalization and reregulation, which may sound contradictory. The experience from different countries shows that in electricity markets regulatory change often occurs with a considerable lag: in Chile the lack of policy interventions led to blackouts (Fischer and Galetovic, 2001) while in the U.K. major regulatory adjustments took place 10 years after deregulation (Helm, 2003).

The mismatch between markets and their regulation is not unique to the electricity sector. In order not to fail, regulation should evolve with the market, especially in fast-changing markets (Fukuyama, 2008) and in contexts where scientific and technological innovations pose policy challenges (Howlett and Newman, 2013). This is the case in electricity markets, where the introduction of renewable energy resources leads to a need for major policy changes.

3. A conceptual framework of the evolution of electricity markets

In this section we propose a conceptual framework for the evolution of deregulated electricity markets. We identify four stages (monopoly, wholesale regulation, retail competition and reregulation) which, in our opinion, provide a generic view of the evolution of electricity markets and discuss the characteristics and challenges of each. These are based on what we have observed over the last three decades in connection with deregulation in electricity markets. While we could have chosen a more fine-grained model, i.e., more stages, we believe that these four stages capture the main issues and that a finer grained model would not contribute significantly to the understanding. It is also important to

point out that the stage labelled "reregulation" may not be the final step. It is easy to imagine, for instance, a future in which the issue of efficient storage has been solved, leading to a reduced need for regulatory intervention to insure adequate capacity investments. While chronologically this would be a fifth stage, our model captures this by moving "backwards" to retail competition.

These four stages can briefly be described as follows:

- *Monopoly*. The stage before deregulation, characterised by the absence of competition.
- *Wholesale competition.* Often the first stage of deregulation. Large electricity users (mainly distributors and companies in energy-intensive industries) can buy electricity directly from the generators, either in a spot market or from an electricity broker (Hunt, 2002).
- *Retail competition.* All consumers can choose from whom to buy their electricity, i.e., a free market (Hunt, 2002).
- *Reregulation.* Markets may reach a point where, due to internal or external factors, things start to go wrong and the regulator is forced to intervene to induce or prevent certain behaviours by market participants.

It is important to point out that not all countries follow this sequence. For instance, several countries moved from wholesale competition to reregulation without implementing retail competition. One example is California, which had only reached the wholesale competition stage before reregulation occurred after the crisis (Weare, 2003). Similarly, Colombia has never intended to introduce retail competition, and has reregulated in recent years (Olaya et al., 2016). Ecuador moved from wholesale competition back to a monopolistic system (Ponce-Jara et al., 2018).

Table 1 provides an overview the different stages and their characteristics. For each stage, we outline the key market characteristics, the main regulatory aim and some of the problems that have been observed at that stage of deregulation over the last thirty years.

4. Elements of a behavioural view

The difficulties encountered by electricity regulators result to a large extend from behavioural elements that exert a significant influence on the characteristics of the required regulation, as well as on its outcome, thereby affecting the performance of the sector as a whole. They are not new, but had little or no impact before deregulation. It is these factors that have caused regulatory measures to lead to unexpected consequences, surprising the regulator (Larsen and Bunn, 1999). Such unanticipated effects, together with another distinguishing feature of the electricity sector - our society cannot function without electricity - have forced regulators and policymakers to frequently adjust the regulatory framework in minor or major ways. This has created a high degree of uncertainty around the long-term profitability of the sector, affecting its attractiveness and leading to inadequate levels of new investments. In what follows we discuss three elements that we consider to be the main areas of concern from a regulatory point of view (Larsen and Bunn, 1999). While our focus is on electricity, a number of these elements are also relevant for other utilities.

4.1. Feedback and long-term commitment

Feedback is a critical element in most social and economic systems, rendering them difficult to manage and control (Morecroft, 2007). The interaction between feedback and delays is one of the main factors creating the dynamics in the electricity industry. While feedback without delays would not constitute a problem, the electricity sector is characterised by very long lags. We can distinguish between two different processes: (i) feedback between the regulator and the market participants and (ii) long-term investment cycles due to the long construction times and lifespans that characterise in particular thermal, nuclear and hydro investments. To further complicate matters, these two feedback processes also interact; in particular, the regulatory feedback process influence the investment process.

Markets take several years to adapt to regulatory changes. Regulators in turn require significant time to evaluate whether the markets' evolution resolves the problems targeted by the regulatory interventions. If not, or if new problems appear, further regulatory change may be required, and so on. While there are occasional major regulatory overhauls, regulation tends to be fine-tuned by a constant stream of small changes, e.g., adjustments of the England and Wales market remain very frequent (OFGEM, 2018). The consequences of any change materialise over many years, even decades, taking a long time to become visible to the market participants, regulators and policymakers. It is difficult for regulators to learn in such markets: the potentially long time between decisions and outcomes makes the identification of the effects of one specific change impossible; the interaction of successive changes makes it difficult to understand the consequences for the market of any single one. Consequently, regulators are hesitant to implement large-scale reforms. This is illustrated for instance by the fact that the England and Wales regulator took ten years to decide on a fundamental change of the initial price formation mechanism (Helm, 2003).

It can take up to ten years to construct a large hydro power plant, three years to put a CCGT plant into operations and a similar order of magnitude for run-of-river hydro and larger wind parks. Additionally, assets of the electricity sector have traditionally been characterised by a long lifespan: power stations are generally built to last at least thirty to forty years, grids even longer, implying that these investment decisions are not taken overnight and affect the market for several decades. While the life-span of renewable technologies is shorter (e.g., 20–25 years for PV (Kannan and Turton, 2012)), this remains significant compared to the length of a regulatory cycle. Before deregulation, the electricity sector was centrally controlled, and in most cases large operations research models were used for planning. After deregulation the newly created markets began to behave like most other capital intensive industries: capacity cycles were observed in many countries, leading to periods of excess capacity followed by periods of concern about the capacity margin. Examples include England and Wales and California ((Ford, 1999), (Arango and Larsen, 2011)).

The complexity is increased by the interaction between short- and long-term technologies and the need to achieve an adequate generation portfolio by balancing, e.g., investments in thermal and renewable generation capacity. Renewables have a relatively short construction time and are often subsidised, leading to a rapid growth over the last decade in many countries, e.g., in Denmark (IEA, 2018a) and Germany (IEA, 2018b). As renewables have low variable costs, this rapid growth has rendered many CCGT plants uneconomical, even relatively new ones, thereby reducing their generation and leading to mothballing and premature closing. However, these thermal generators are required when renewable generation is limited due unfavourable weather conditions, leading to concerns among regulators about capacity shortages at critical times, as is the case for instance in Belgium (ELIA, 2016) and England and Wales (OFGEM, 2015).

This combination of feedback and delays affects both the regulator and the market participants. Indeed, the speed and magnitude of the market participants' reaction to regulatory change often exceed the regulator's anticipation, forcing further change. A better understanding of the effect of feedback and delays, particularly by regulators and policymakers, can reduce the occurrence of unanticipated undesirable

Table 1
Summary of different market stages.

	Monopoly	Wholesale Competition	Retail Competition	Reregulation
Characteristics	One national or regional supplier No competition Regulated prices Long-term capacity planning	Wholesale market with multiple suppliers Price determined by supply and demand for large consumer Regulated price for small consumers	Competition in all parts of the market except transmission Price determined by supply and demand for all consumers	Competition in most parts of the market – but capacity determined by regulator Price determined by supply and demand for all consumer
Regulation aims	Ensure capacity adequacy, cost recovery, access and affordability Reach environmental targets	Ensure sufficient investments Prevent market power and collusion in wholesale market Ensure equal access to market Protect regulated customers Reach environmental targets	Ensure sufficient investments Prevent market power and collusion Reach environmental targets	Ensure sufficient investments, adequate capacity mix and security of supply Prevent market power and collusion Reach environmental targets
Typical Problems	Overcapacity (Developed countries) Lack of investments (Developing countries) Relatively high prices Inefficient management	Market power Exploitation of regulated customers Disconnection between regulated price and wholesale price Uncertainty about - long-term development and stability of the market - implementation of the rules	Market power Lack of investments Price volatility Increasing uncertainty about - long-term development and stability of the market - implementation of the rules	Lack of thermal capacity Distortion of competition due to subsidies for thermal and renewable generation Increasing prices Increasing volatility Regulator has significant control over the market Public opinion influences policy decisions

outcomes.[1]

4.2. Stakeholders

When electricity was a monopoly business, there were a small number of influential stakeholders, i.e., the regulator, the monopoly firm(s) and possibly the policymakers; consumers only had a limited indirect influence via any pressure they could exert on policymakers. Deregulation has brought a drastic change: while each jurisdiction still only has one regulator, there are nowadays many competing generation and distribution companies, the financial sector has become a major player with new actors, like brokers, entering the market, and large (if not all) consumers can change provider (Larsen and Bunn, 1999). The influence of the existing stakeholders has also changed as a consequence of deregulation, e.g., electricity companies can decide on and influence prices. Table 2 compares the main stakeholders before and after deregulation, and their changing role. In this table we do not distinguish between wholesale and retail competition stages to avoid unnecessary repetition.

The interaction between these different stakeholders, whose incentives and motivations are rarely aligned, is a major contributing factor to the evolution of the market and the regulation of the sector (Hancher and Moran, 1989). There have been instances where the regulator did not anticipate the impact of new stakeholders. This was most likely the case in England and Wales, after the creation of the wholesale market. Here the regulator used RPI-x regulation with the distribution companies to protect the regulated retail customers. After the negotiations in 1994, where the investment needs were established and the parameter x was negotiated, distribution companies suddenly started to increase the salaries of their senior management and one company offered to pay its shareholders an extraordinary dividend of £ 560 million to prevent a takeover. This use of revenues was totally unanticipated, and unacceptable to the regulator: the money was intended for investments in infrastructure. This eventual prompted the regulator to reopen the negotiation with all the distribution companies (Pallett, 1998).

[1] Various methods have been used to increase awareness and enhance understanding of these complexities. System Dynamics simulation models in particular have been used successfully to capture the key interactions between the different feedback processes and the long-term commitment of investments (Morecroft, 2007).

Table 2
Stakeholders before and after deregulation, illustrating their changing roles.

Stakeholder	Monopoly	Deregulation
Policymakers	The general framework	The general framework
Regulator	Price, investment, rules, oversight	Rules, oversight, investment incentives
Incumbent Electricity Company	Investment	Investments, pricing, lobbying
Shareholders	Limited if any (depending on the jurisdiction)	Standard shareholder rights
Financial Markets	Lending – but often government backed	Commercial lending, standard performance criteria
New Entrants[a]	N/A	"threat" of acquisitions
Brokers	N/A	Competition
Industrial Consumers	N/A	Change supplier, lobbying
Retail Consumers	N/A	Change supplier, prosumer, short term storage

[a] Energy companies as well as companies from other sectors entering the electricity sector.

4.3. Attitudinal factors

Considering attitudinal factors is essential to be able to understand how markets and regulation evolve, as these non-economic factors influence the stakeholders' decisions. The design of regulatory frameworks often rests on two hypotheses. First, it is assumed that stakeholders will behave in a rational way, ignoring well-known cognitive biases. For instance, customers will forego the more energy-efficient appliance, which would be the most economical in the long-run, in favour of one with a lower price-tag (time-preference (Frederick et al., 2002)). Similarly, the rational expectation that customers will systematically choose the lowest-cost provider ignores the inherent inertia in people's decision making (status quo bias (Kahneman et al., 1991)).

A second assumption is that stakeholders will interpret the legislation as intended by the regulator. But it is in the companies' interest to exploit every possible loophole, pushing the rules to their limits. More generally, it is often overlooked that stakeholders will focus on their immediate, short-term interest, rather than on the longer-term, general interest. This applies to both policymakers and market participants. For instance, policymakers may be influenced by their desire to promote

their career prospects, leading to decisions such as requiring excess generation capacity to avoid the embarrassment of a blackout or keeping a specific plant in operation to protect local employment, if not outright to corruption. Such an attitude is illustrated for instance by the coal contracts Powergen and National Power were endowed with in 1990. These were clearly driven by political motives (supporting the mining sector), rather than by an intention to make the electricity sector more efficient (Helm, 2003). Such behaviours can be enhanced in the presence of NIMBY attitudes ("Not In My Back Yard"). A well-known example is the opposition to the North-South high-voltage line in Germany (Steinbach, 2013).

These attitudinal factors are absent in most theoretical models. However, capturing the cognitive biases, the self-interest of stakeholders, political objectives and (over)reactions to incentives is crucial for understanding the evolution and development of the market, and thereby their regulation.

5. Examples of problematic interactions between markets and their regulation

In this section we use the framework developed above to analyse a number of instances where regulation and markets have not worked optimally together and learn from these failures. The cases were selected to illustrate different forms of malfunctioning, at different stages of deregulation.

5.1. Monopoly

In a monopoly, severe disruptions of the electricity system, leading to blackouts, are a major embarrassment for any government. In the absence of tight budgets, regulators can easily reduce this risk to close to zero by building significant levels of excess generation capacity and redundancy in the grid. This strategy seems to have been followed in Western Europe: at the time of deregulation, most countries had significant overcapacity, e.g., more than 24% reserve margin in the England and Wales market (Roques et al., 2005). In a world with captive customers and no competition there was little or no awareness of the price-impact of such excess capacity: the lights stayed on and few complained. After deregulation the target reserve margin was lowered to 20% (Roques et al., 2005), reflecting a change in attitudes, in particular the motivation of the stakeholders.

Developing countries faced a very different situation: population growth and an increase in per capita electricity consumption created a need for major investments. But the combination of political pressure to keep tariffs affordable and difficulties in reducing the unpaid share of electricity consumption (euphemistically referred to as "non-technical losses", which could exceed 25 percent of consumption), deprived electricity companies of the resources required for capacity expansion. The resulting electricity shortages led to repeated, occasionally major, blackouts (e.g., in Colombia (Larsen et al., 2004)) or, worse, to extremely frequent blackouts (e.g., in Nigeria (Amobi, 2007)). This is another illustration of the role of attitudinal factors: limited efforts to ensure payment and artificially low prices out of fear of political unrest led to capacity shortages.

Another example for monopolies relates to the USA, where the standard price regulation guaranteed a certain rate-of-return on actual investments (Gilbert and Kahn, 1996). This created unanticipated incentive problems, as cost-overruns led to higher profits. This is illustrated, among others, by the case of several nuclear plants in the USA, where actual construction costs exceeded budgeted ones by a factor of five or more. For instance, the Clinton plant, budgeted at USD 534 million, ended up costing 3.13 billion (McCallion, 1995). This example illustrates the exploitation of a regulatory system intended to provide a fair profit to the company, leading to excessively expensive electricity for the consumer.

5.2. Wholesale competition

The period following deregulation is a time of major uncertainty for all the stakeholders. Regulators are discovering whether or not the newly designed regulatory framework achieves its objectives, companies are unsure as to what is actually allowed in this new environment and the customers who have access to this new "free" market are inexperienced in dealing with its inherent uncertainty and the resulting risks (Larsen and Bunn, 1999). At this early stage usually only a wholesale market is established. This implies that, at least in principle, all market participants are well-informed professionals: generators, distribution companies and large consumers. Still, over the years problems have occurred even in these early stages of liberalization.

Shortly after deregulation in 1992, London Electricity (LE) established a retail chain selling all types of electrical appliances. But, being unfamiliar with the retail sector, they failed to control their costs. For instance, selecting prime locations for shops resulted in high rent. The situation was made worse by disappointing sales levels. LE incurred a UKP 10 million loss in 1993, the year before the retail chain was sold. Other UK regional electricity companies set up similar operations, with equally disappointing results (The Independent, 1995). These initiatives also led to complaints from other retailers, who claimed that the electricity companies subsidised their retail chains by up to UKP 250 million a year; if these claims are correct, the captive consumers footed the bill for these adventures (The Independent, 1995). In retrospect, these failures are not surprising: they illustrate that companies used to operating in a monopolistic environment have neither the capabilities nor the experience to enter the retail market (or competitive markets in general) and, most importantly, are unaware of their shortcomings.

Staying with the England and Wales market, there were strong indications that the two main electricity companies started to test the boundaries of what it was possible to "get away with" in the second and third year after deregulation. Electricity prices increased significantly over that period, and there were suspicions, but no proof, that this resulted from these companies successfully signalling to each other through their bids to the pool. After the regulator threatened to change the bidding process prices fell; it is generally assumed that this (credible) threat was sufficient to eliminate this form of collusion (The Independent, 1992). This example illustrates how participants are tempted to test the boundaries in a newly deregulated market, forcing the regulator to step in.

Another well-known example is the crisis in California in 2000–2001, where the combination of a number of independent factors led to an electricity shortage and blackouts, with prices rising from $36/MWh in 1999 to $166/MWh in 2000 (Harvey and Hogan, 2000). These factors included natural events (weather patterns in the northwest of the USA), regulatory issues (slow approval of new generation projects), and behavioural aspects (possible manipulation of the system by Enron, rapidly growing demand in California). A monopolist or a fully deregulated market might have been able to cope with this situation, but at that time only the wholesale market was deregulated in California. While the generating companies benefitted from the high prices, distributors were caught in the middle, buying electricity at high prices in the deregulated wholesale market, and selling at low, regulated prices in the retail market (Borenstein, 2002). This led to a crisis, with one of the largest distributors failing: the government had to step in and subsidise the industry. The share of the cost of this crisis borne by the taxpayer is estimated to be in the 40 to 45 billion USD range (Weare, 2003). This example illustrates how essential it is that the regulator and the market participants understand the underlying market structure and its impact on market behaviour, particularly during a transition: rectifying an inappropriate design can be extremely costly.

While competitive electricity markets are designed to remedy inefficiencies in monopolies, they often create their own inefficiencies. In Switzerland, where only the wholesale market is deregulated, some distributors have a large captive market of small domestic customers.

The regulated price paid by captive customers being significantly above the market price, these distributors can cross-subsidise between large and small consumers (Le Temps, 2017). Such a market distortion can only occur in the presence of wholesale competition without retail competition, i.e., when small customers cannot change supplier. This is a clear example of regulatory failure since one of the objectives of the regulation in competitive markets is to protect the weaker captive customers (Borenstein et al., 1999).

5.3. Retail competition

As deregulated wholesale markets mature and the retail market is added, concerns evolve. While in the initial stages the focus was on "will the system work?", i.e., can shortages and blackouts be avoided, attention turns to identifying what adjustments are required to improve market functioning. In this stage the focus is on the behaviour and the dynamics of the market. Market power becomes a central issue: how can the regulator prevent companies from manipulating the market? Companies will always look for ways to legally exploit the market structure to their advantage.

There are many indications of market participants having successfully exerted market power in this stage in different parts of the world, but hard proofs are rare. The limited number of generators seems to have led to market power problems in the England and Wales market during the initial liberalization stages (Wolfram, 1999) and in California during the electricity crisis in 2000 (Wolak, 2003). There have been signs of market power and strategic behaviour during peak hours in the German market (Müsgens, 2006). The absence of excess generation capacity in India's deregulated market also points to companies having market power (Shukla and Thampy, 2011).

Regulators were aware of the dangers of excessive market power when developing the initial regulations, and devoted significant efforts to limiting this risk. Still, the large number of instances where market power has been suspected indicates they have failed on many occasions. While different contextual factors can explain part of these market power problems, a common contributing factor is the discrepancy between expected and actual behaviour of market participants.

The initial England and Wales regulation (1990) did not allow for vertical integration between a generator and a distributor. The objective was to insure a sufficient level of competition: distribution companies were forced to buy all their electricity either through contracts or in the spot market. However, the regulator soon realised that with only three main generating companies the level of competition was insufficient in this segment (Joskow, 2009). 1999 saw a major regulatory change: National Power was allowed to acquire a distribution company on the condition that it reduced its share of generation (Codognet et al., 2003). In this example the regulator realised that the initial design would not create a sufficient level of competition in the market, exacerbating the risk of companies being able to exert market power. Rectifying this step required a major change of the initially planned market structure: lifting the ban on vertical integration. This illustrates the time lag between understanding the consequences of regulatory designs and implementing the required adjustments.

Colombia allowed vertical integration from the start, and created a competitive market by mandating that distribution companies buy at least 40% of the electricity they sold from another generator (Larsen et al., 2004). But the newly liberalised market ran into trouble in 1999 as a major economic crisis led to lower electricity demand: the resulting overcapacity resulted in lower prices, creating serious financial problems for several companies (Larsen et al., 2004). However, the Colombian regulator successfully managed this challenge by repeatedly adapting the capacity mechanism (Olaya et al., 2016). This timely intervention allowed the market to recover and attract new investments.

As the market continues to mature, the initial problems have been sorted out, and the market has demonstrated its ability to deliver electricity. The mature market functions well until changes in the environment create a need for further adaptation. For electricity markets, the sharp increase in environmental concerns provided such an external shock: governments suddenly started to support investment in renewable generation on a large scale with unexpected consequences. One example is the strong increase of PV generation in Denmark until 2012, forcing the authorities to abolish the subsidies much sooner than initially intended (Enkhardt, 2012). Such overreaction creates cycles, as has been observed in many industries, including the electricity sector (Bunn and Larsen, 1992; OFGEM, 2013; European Commission, 2016). This has led to a situation combining on the one hand overcapacity (leading to a collapse in prices) and on the other hand an inappropriate capacity mix (lack of investment in and premature closing of unprofitable thermal peak generators). The uncertainty resulting from the frequent, difficult to predict, policy changes has reduced investments in non-renewables, resulting in a need for capacity mechanisms, as argued by, among others, the regulator of the England and Wales market (OFGEM, 2013). This concern is shared by the regulators of a large number of countries, including Sweden, Germany, and New Zealand, all of which have introduced capacity payments in recent years, often in the form of capacity auctions (Blazquez et al., 2018; Liu and Wezel, 2015). The fundamental problem is: how can one balance a market where one part (renewables) is (heavily) subsidised, while another part (among others, thermal peak-units) is expected to be competitive without subsidies? This may turn out to be simply impossible, which would explain why we increasingly observe subsidies being extended to other technologies. This is another example of a problem that has taken a long time to develop and even longer to be recognised. And it will take a long time to fix. Most importantly, if the regulator is not extremely careful in defining and implementing corrective measures, these may lead to other, equally problematic, issues in the future.

It should be noted that the number of companies varies significantly across jurisdictions, from a handful in England and Wales or France (too few to create a competitive market (Helm, 2003)) to hundreds in Denmark and Germany (Eurostat, 2018. http://ec., 2018). Economics and strategy textbooks would predict that in electricity, which is essentially a commodity business, deregulation should lead to concentration over time, i.e., a smaller number of larger companies. However, there is evidence that this is far from being the case in general; both the initial conditions and the evolution differ significantly across countries, in certain instances in the opposite direction of that predicted by economic theory. For instance, in Germany the number of companies did not decline after deregulation, it actually increased slightly, with the small companies surviving, the large national actors expanding, and the regional companies declining (Liu and Wezel, 2015). Denmark has seen a very different evolution, with a high degree of consolidation, and a state-owned company becoming the major player. The EU and the OECD have actually expressed concerns over this development (Annual Report. 2005., 2005). These examples illustrate that deregulation can result in very different outcomes concerning, e.g., the number of market participation and the evolution of market power. For instance, in Denmark the regulatory framework failed to prevent the increasing market power of a national champion.

So far we have focused on single jurisdictions. A complicating factor is the existence of cross-border trade between neighbouring markets with different, possibly incompatible, regulations. The design of these cross-border markets is the outcome of inter-governmental negotiations. However, as few, if any, countries would consider handing over control of something as essential as electricity, there is no supra-national regulator; this is a source of conflict and problems. For instance, regulators are tempted to put the blame for major blackouts on neighbouring countries; this was indeed initially the case for the 2003 blackout in Italy (BBC, 2003), although it was later acknowledged that the true cause was a combination of the weather and human error (UCTE, 2004). Tensions also arise when countries accuse each other of unfair trading practices, including subsidies. For instance, Germany is periodically flooding the central European market with electricity, putting pressure on

neighbouring countries' prices and the profitability of their generators, with the German consumers subsidising consumers in these neighbouring countries (Reuters, 2015). This illustrates that when markets expand beyond their national boundaries, problems become even more complex; developing a comprehensive and fair regulation is essential to ensure that this evolution is beneficial, in particular for the small consumer.

5.4. Reregulation

The evolution over the last decade can best be described as a form of reregulation, where the control of the industry is slowly reverting back to the regulator. In some cases the deregulation process has been temporarily halted, e.g., in California after the 2001 crisis and more recently in 2013 in Arizona (O'Donnell, 2013), and an increasing number of jurisdictions are repealing certain aspects of deregulation. But the main driving force behind this recent trend of reregulation is the pressure to achieve environmental commitments at the national, regional and/or planetary level. Examples of such commitments include the European Union's "20-20-20″ climate and energy targets, reducing greenhouse gas emissions by 20% compared to 1990 levels by 2020 (Commission of the European Communities, 2008) or UN agreements like the COP 21 Paris Agreement (United Nations, 2016).

One of the external factors that have been forcing the hand of regulators and policymakers is technological development. The implementation of deregulation was facilitated to some degree by the arrival of a disruptive technology, CCGT, in the eighties. The possibility of building comparatively small generation units reduced the required investment to enter the market, thereby removing one of the major entry-barriers (Olaya et al., 2016). But the rising share of renewables has created new challenges for regulation. The wide-spread incentives to invest in renewable technologies, such as wind and PV, and their fast technological development have resulted in a previously unseen growth rate. In some countries, e.g., Germany, wind and solar energy at certain times account for over half of the total generation (Hanley, 2017). This forces a rethinking of the concept of capacity adequacy.

Renewable technologies are disruptive due to their intermittent nature and close to zero marginal costs, which create financial pressure for the existing generators. The impact of renewables far exceeds that of the introduction of CCGT, whose generation characteristics were similar to those of existing plants (fossil-fuel based variable costs, non-intermittent). When photovoltaic (PV) and wind generation peak, they displace peak-units, in particular thermal and hydro plants, and prices drop significantly (Traber and Kemfert, 2011). This leads to lower revenues and possibly losses for other generating technologies. To insure sufficient generating capacity when renewables are not available (e.g., cold winter evenings), regulators are forced to introduce incentives for thermal capacity, known as capacity payments.

The policy of green energy is thus gradually transforming what was originally intended to be a free market, into a highly regulated and subsidised market. Technological innovations can change the evolution of a market and set the regulatory system under pressure in ways which could not be anticipated when the regulation was initially designed. This highlights the fact that regulatory regimes designed for a specific context are likely to fail when this context changes; for instance, a regulatory design developed for a generation mix consisting mainly of thermal and nuclear plants is unlikely to perform well when renewables represent a significant share of the installed capacity.

The rush towards renewables has been driven by increasing environmental concerns. Coal plants in particular are being heavily criticised (Nace, 2011). Certain developing countries, for which coal has long been one of the main sources of fuel (e.g., China), face unsustainable levels of air pollution in their major cities (Huang et al., 2014). This has forced the regulator to step in to limit or stop the construction of coal-fired plants, despite these being the most attractive from an economic point of view. The problem is not limited to developing countries: coal-fired plants are a favourite target of activists and regulators in many countries, including Germany (Teffer, 2016). Other countries, however, are still planning major investment in coal-fired generation, e.g., Malaysia (Power Engineering International, 2014).

Nuclear power-plants have long been a source of safety concerns, with opposition soaring after the Fukushima accident. This has led policymakers to decide on the closedown of nuclear power-plants in Germany (Steitz and Copley, 2015) and to a Swiss vote to gradually phase out nuclear plants while encouraging investment in renewables. This illustrates another of the dimensions discussed in the previous section: public opinion, in this case environmental and safety concerns of the general public can influence regulatory and policy choices, outweighing economic interests.

Our focus on examples of regulatory failure might lead to the incorrect impression that deregulation is bound to fail. This is not the case. Deregulation of electricity markets has worked well for several countries. The Nordic electricity market (Nordpool), which is an integrated market of Denmark, Finland, Norway and Sweden, is an example of a successfully deregulated electricity market (Amundsen and Bergman, 2006). Another example is Texas, whose electricity market is referred to as a "robust competitive market" [Glachant et al., 2008, p.383].

Fig. 1 provide an overview of the process in five countries mentioned in the preceding discussion: England & Wales, Germany, Belgium, Denmark and Switzerland. The figure illustrates the evolution of these countries' markets over time, showing in particular that they follow the steps laid out in our proposed model, but are currently at different stages.

England and Wales is an example of a jurisdiction which reached the last stage of the model. The price setting mechanism of the market was modified in 1999, but the retail market was maintained. However, in 2013 capacity mechanisms had to be introduced to ensure capacity adequacy (Baker, 2018). Germany simultaneously introduced wholesale and retail competition in 1998 (Glachant et al., 2008), while Belgium only opened its wholesale markets in the late 1990s (Al-Sunaidy and Green, 2006) and its retail market in 2007 (Küpper et al., 2009). France (not shown in figure) followed a similar pattern. These three countries reached the reregulation stage in 2019, when the EU allowed the introduction of capacity mechanisms to ensure capacity adequacy and security of supply (European Commission, 2018).

The fourth example is Denmark, which introduced wholesale competition in 1999, and retail competition in 2003 (Rüdiger, 2007). This country differs from the previous examples as it aims to keep an energy only market for the time being, i.e., there are no plans to increase the influence of the regulator on capacity decisions. Switzerland lags behind the other European countries: wholesale competition was only introduced in 2009 (Swiss Federal Office of Energy, 2007). While the discussion about the introduction of retail competition has been ongoing for several years, its implementation has been postponed repeatedly; it is currently not clear when this step will be taken, but it could happen fairly soon as the government will submit a proposal to parliament during the first quarter of 2020 (Government sticks to plan, 2019).

6. Discussion

In this section we discuss how the different behavioural factors we identified influence the evolution across the different stages, leading to uncertainty for market participants and an ever-increasing need for regulatory intervention.

Table 3 summarizes a selection of issues observed in the different phases, from monopoly to deregulation and reregulation. Its aim is to illustrate how the behavioural elements we identified contribute to these issues, without claiming to be exhaustive. The selected examples, discussed in more detail below, do illustrate how a static, purely economic approach to regulation, without behavioural aspects, fails to capture important elements necessary to understand the functioning and the

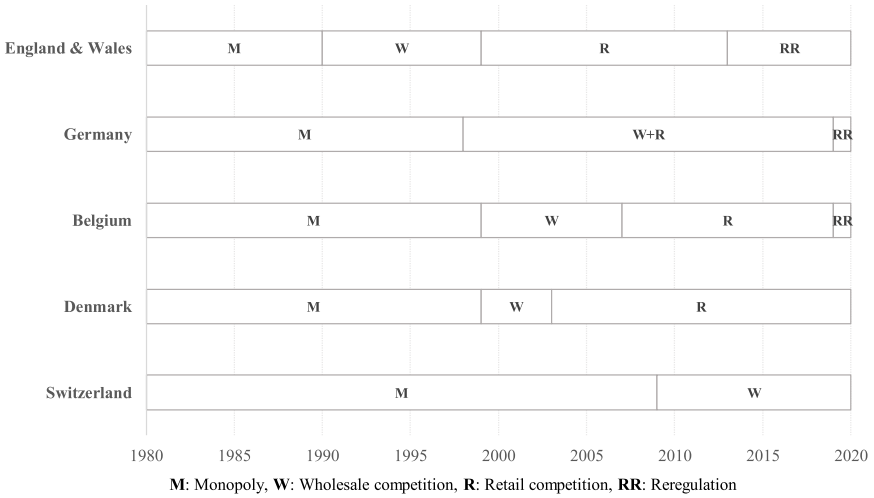

Fig. 1. Overview of the evolution of the markets.

Table 3
Overview of the examples and the role of behavioural elements.

Examples	Behavioural elements	
Monopoly		
Overcapacity in Europe	Feedback	- *Guaranteed cost recovery*
	Attitudinal factors	- *Avoiding blackouts is the top priority, leading to overinvestment*
Capacity shortage in developing countries	Feedback	- *High non-technical losses* - *Loss of revenue and uncertainty about return on investments*
	Long-term	- *Lack of resources to invest*
Wholesale Competition		
(Illegal) collusion	Attitudinal factors	- *Testing the limits of the regulatory framework to enhance profitability* - *Believe regulator will not discover collusive behaviour*
Overcharging captive customers	Feedback	- *Competition drives down wholesale prices*
	Stakeholders	- *Powerless captive customers vs large consumers*
Retail Competition		
Capacity shortage in Europe	Long-term	- *It took over a decade to realize that the market designs might not deliver enough capacity*
Market power	Feedback	- *Price increases, conviction of invulnerability*
	Long-term	- *Long delays in adapting the regulation*
Re-regulation		
Technological innovation	Long-term	- *The regulatory framework did not evolve fast enough to accommodate the technological changes*
	Feedback	- *Endangering the economic viability of traditional generating sources (e.g., thermal) through subsidies for renewable sources (e.g., PV)*
Public opinion	Attitudinal factors	- *e.g. the attitude towards nuclear power, in particular after a major incident*

evolution of deregulated markets. This list of issues should not be interpreted as a negative view on deregulation and reregulation; rather, we argue that when regulatory frameworks are designed and implemented, special attention must be paid to behavioural aspects in order to avoid these undesirable events. Note that in this table we have chosen to explicitly distinguish between feedback related issues and long-term commitment aspects, despite these being closely related and discussed together in section 4.

We provide a general discussion of the evolution through the different stages, before discussing the examples of Table 3 in more detail. An important factor characterizing the industry is the number of stakeholders, which increases across the different stages as more and more actors can directly participate in the market. While in a monopoly there are relatively few direct participants, this changes with the introduction of wholesale competition: more generators and distributors are involved, as well as the larger customers. The number of participants explodes when retail competition is introduced, with small consumers entering the market, although few of these participate proactively. As the market matures, and the reregulation stage is reached, a new category of actors enters the market due to technological improvements inside and outside the industry. Examples include firms managing smart grids or installations to reload electric cars.

A second factor, feedback, interacts with the number of interdependent decisions companies need to make (i.e., the commercial complexity of the operations of the company) and how these decisions affect the other market participants and their actions. Such decisions include capacity investments, bidding, contract negotiation, etc. As the market moves through the different stages, the number of decisions to be

made increases. The entry of new agents, such as electricity brokers, increases the available contracting strategies, and moving to retail competition requires developing a communication strategy aimed at small customers. As each action may cause a reaction of other stakeholders, feedback is omnipresent. When reaching the reregulation stage, certain tasks are taken over by the regulator, leading to a reduction in feedback and complexity. One example is investment planning through various capacity mechanisms.

To summarise, as the industry moves away from a monopoly situation, the number of stakeholders increases, it becomes more difficult for them to have a global view of what is going on in the industry, and they are required to take a larger number of more complex, interrelated decisions. Consequently, the uncertainty in the industry as a whole increases significantly, affecting all stakeholders.

This increased uncertainty makes investment decisions particularly challenging for generators: competition renders their demand less predictable, subsidies for certain technologies affect prices and supply, and regulatory changes become increasingly difficult to predict. This uncertainty also affects the regulator, who is forced to take decisions under increasingly incomplete information. This raises the probability that specific measures do not achieve their intended objective, compelling the regulator to intervene more frequently, thereby fuelling a spiral of uncertainty for all actors. The increased level of regulatory intervention moves the market towards the reregulation stage.

6.1. Monopoly

As can be seen from the overview in Table 3, behavioural elements help explain difficulties arising in the different phases: they already played a role before deregulation, explaining some of the problems that contributed to the decision to deregulate the electricity sector. On the one hand, the issue of overcapacity in developed countries, where companies were allowed (if not encouraged) to invest in excess capacity led to unnecessarily high electricity prices, a cost not directly "visible" to most consumers. While there are different ways of characterizing excess capacity, we focus on the concept of capacity margin, i.e., a comparison between available generating capacity and peak demand. In France, the desire for energy autonomy after the oil-crisis of the seventies started a process of electrifying the society. This process was enabled by an aggressive nuclear research and construction programme, supported by the government (Hadjilambrinos, 2000), which led to significant overcapacity in the eighties (Léautier and Crampes, 2017).

On the other hand, developing countries suffered from capacity shortages, as the problem of consumers not paying for their electricity limited investments. For instance, Colombia (Larsen et al., 2004) experienced two major blackout periods between 1983 and 1993. The country decided to deregulate the electricity sector to remove the financial burden from the government budget and to attract foreign investments. It was expected that the private sector would be better able to cover the problem of technical losses.

In both developed and developing countries, economic growth was negatively affected, respectively by the high cost or the insufficient availability of electricity, leading to the logical conclusion that the system needed to change. However, the option selected by policymakers, to deregulate the industry and to create competition, was one of the most drastic changes observed in any industry in over fifty years (Dyner and Larsen, 2001); not surprisingly it resulted in a whole new set of problems.

6.2. Wholesale competition

The process of deregulation and the creation of wholesale competition were initially subject to a high degree of inertia: companies behaved as if they were still monopolies, adapting slowly to the new environment. This is not a surprise; from an organizational perspective this is the stage of exploitation (March 1991), i.e., relying on what one already knows. However, companies gradually switched to an exploration mode, taking advantage of the newly granted freedom and discovering the opportunities created by deregulation. In this stage, companies pushed the limits of the regulatory framework to enhance their profitability. For instance, in England and Wales firms used signalling to coordinate their strategies, thereby creating implicit collusion (Sweeting, 2007). In the 1990s, while fuel prices (the main component of a generator's marginal cost) decreased significantly, the average electricity prices did not follow the same trend (Sweeting, 2007).

When liberalization is limited to wholesale competition, small customers are captive: they cannot switch providers. This is the case in Switzerland, where the wholesale market is deregulated since 2009, while full liberalization keeps being postponed (Government sticks to plan, 2019). On the one hand, captive customers are being overcharged by local distributors who benefit from a monopoly position (Besson and Lambiel, 2017). On the other hand, the producers who do not have access to these captive customers compete in a deregulated wholesale market, where competition drives down the wholesale prices (Besson and Lambiel, 2017). This creates a situation of unfair competition.

6.3. Retail competition

When, at the next stage, retail competition is introduced, one would expect electricity markets to function like any other market. With sufficient competitors, market prices should provide adequate investment signals. In particular, when capacity is tight, prices should enable the recovery of both variable costs and CapEx. However, there are few, if any, examples where this has indeed been the case. The level of uncertainty in the market made the major players reluctant to commit to new capacity. This happened at a time when companies were reaching the end of the rationalisation process launched during the initial stage of deregulation, creating major problems in many developed countries. Europe in particular moved within a decade from a situation of excess capacity to one with concerns about capacity adequacy. Countries such as Spain and Finland, among others, had to introduce several regulatory mechanisms to ensure generation adequacy (Vazquez et al., 2002).

With retail competition, the limited previous experience and the absence of regulatory foresight rendered the markets vulnerable to the exploitation of market power by the larger players. This was the case for instance in England and Wales (Salies and Waddams Price, 2004): a significant amount of time elapsed between the moment the regulator, realising the need to intervene, started the discussion process, and the actual implementation of the changes (Grubb and Newbery, 2018).

6.4. Reregulation

The introduction of retail competition has coincided with a period of significant technological change. Due to environmental concerns and technological improvements, different incentive schemes for renewable energy (primarily wind and PV) were introduced. While a reasonable response, this created major problems in many developed countries, as the regulatory framework failed to keep up with the speed of the technological changes. The surge in renewables rendered thermal generation unprofitable: investment plans were cancelled and existing plants mothballed.

Regulatory decisions are also influenced by public opinion. For instance, the changing attitude towards nuclear power causes premature shutdowns, which can challenge the security of supply. An example of this occurred in Australia: while in 2010 the population favoured nuclear power as a low carbon alternative to fight climate change, two years later the majority had turned against nuclear (Bird et al., 2014). This change in attitude was not based on any objective increase in the riskiness of nuclear plants. Rather, after Fukushima, the public started to perceive this technology as riskier.

These events took the evolution of the deregulated markets to a new stage where, to ensure sufficient capacity at times where renewables

cannot deliver enough electricity, the regulator had to step in and subsidise traditional generators. In other words, the sector is moving to a point where most generators are subsidised in one way or another – raising the question as to what actually happened to the market. With the introduction of capacity mechanisms, the regulator to a large extend took back control over investments in new generation capacity: a situation not unlike the one we started from – a monopoly – just significantly more complicated and less effective.

To summarise, we have outlined the role behavioural factors have played in the evolution of electricity markets throughout the different stages of deregulation, ending up in a stage exhibiting a surprising number of similarities with the situation the industry started from – a monopoly.

7. Conclusion and policy implications

When, from the late 1980s onwards, many electricity markets went through a liberalization process, the aims varied widely across countries, ranging from increasing efficiency and lowering prices through the creation of a free competitive market, to ensuring the necessary investment in generation (Sioshansi, 2006). However, as discussed in the previous section, the implementation process and the ensuing evolution were in many, if not most cases, far from smooth. Regulators and market participants alike realised that the markets neither performed nor behaved as predicted by theory. Regulatory adjustments, and even full overhauls, were implemented to correct emerging market imperfections or to drive the industry into a particular direction, e.g., increasing the share of renewables. However, unanticipated side-effects created new market imperfections, needing further corrections, resulting in a self-sustaining cycle of continuous regulatory change.

We can think of a successful regulatory process as one that manages to dampen this cycle, i.e., a negative feedback process that brings stability by creating over time a better fit between the market and its regulation. In other words, a successful regulator should learn faster than the market and be able to anticipate and mitigate future imperfections, thereby minimising unanticipated side-effects. On the opposite, an unsuccessful regulator's failure to manage this cycle could unleash an escalation of ever more frequent regulatory changes, leading to increasing levels of uncertainty in the market.

To successfully address the challenge of designing a deregulated market that will evolve towards and remain in equilibrium, it is necessary to understand the behavioural factors that affect the coevolution of markets and their regulation. Markets have often been designed based on relatively rational economic assumptions. But, as has been increasingly acknowledged over the last decades, among others in the literature on behavioural and experimental economics (e.g. (Parisi and Smith, 2005)), economic decisions are often irrational. We believe that to create a sound regulatory framework it is not only necessary to look at economics, but also at the more behavioural factors we discussed.

Today's regulatory systems generally have a relatively narrow focus; most of the effort is devoted to ensuring competition and capacity adequacy in the liberalised industry. After the initial design stage, regulators have tended to be reactive, while facing innovative and proactive market participants; this has resulted in many cases in a regulatory framework lagging behind the realities of the industry. Such a situation creates a need for further regulatory interventions, leading to increased uncertainty and market malfunctioning, requiring further interventions, a never ending story.

It is thus necessary to focus on what a forward-looking, adaptive, regulatory system would look like: only such a system has the potential to create increased competition among market participants, while achieving an acceptable level of stability. There is a need for a comprehensive framework for behavioural regulation in the electricity sector, but which respects the idiosyncrasies of the different countries.

This paper takes a first step in this direction, by identifying some of the aspects that must be considered in a behavioural regulatory framework: a long-term perspective giving attention to feedback, the increased number of stakeholders with their changing roles and attitudinal factors. We have illustrated how each of these behavioural factors has played a role, sometimes a major role, in the challenges encountered when deregulating the electricity sector. Taking these factors into account when designing regulatory frameworks will result in a more agile, forward looking regulation, requiring less frequent adaptations and overhauls. This will reduce uncertainty in the industry, resulting in more desirable outcomes for companies and consumers alike.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Busra Gencer: Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Visualization. **Erik Reimer Larsen:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Ann van Ackere:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition.

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