Chapter 4
Economic theory of market functioning

The different market designs for electricity markets were analyzed in the previous chapter. The focus of this chapter is economic theory models of market functioning and their application to electricity markets. An overview of the alternative market models in economic theory is given. Reference models of perfect competition and monopoly are briefly discussed, then oligopoly models are examined. We then define the fundamentals of electricity markets, i.e. supply and demand, followed by a discussion of how the models can be applied to electricity markets. Finally the strengths and weaknesses of using economic models to analyze electricity power exchanges are discussed. The objective of this chapter is to describe background theories, how they have been applied to electricity markets and their strengths and limitation when used as a basis for analyzing power exchanges.

4-1 References models: perfect competition/monopoly

4-1-1 Introduction

The perfect competition and monopoly models are presented in this section. The objective is to describe briefly the concepts of these two polar extreme models between which all other market models are ranged. Only the main hypothesis and results are given for each model and the simplest version of the model is used, for instance, marginal costs are assumed constant. For detailed descriptions and criticism of these models see Katz and Rozen (1998), and Begg *et al* (2000).

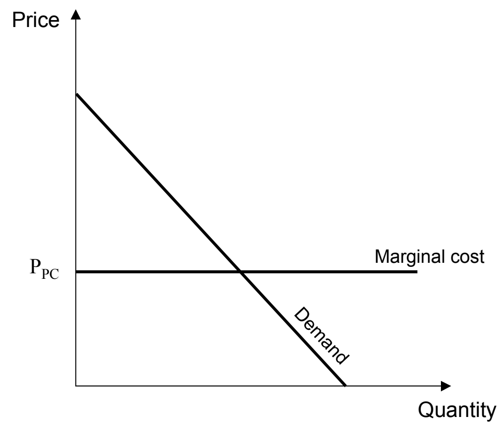
4-1-2 Perfect competition

According to the theory of perfect competition, and assuming a market for a homogeneous product with many buyers and sellers, the most efficient outcome is achieved if firms price at marginal cost. The model of perfect competition is based on four central assumptions.

1. Atomicity: there are so many buyer and sellers that no single buyer and no single seller can affect the price.
2. Product homogeneity: the product provided by the different competitors is exactly the same.
3. Free entry/exit: any firm can enter or exit the market freely.
4. Perfect information: all the players know the prices set by all the firms.

Each firm sets its price at the level of its marginal costs to maximize its profits. Hence, if a firm sets a price above the price of other firms it sells nothing. If a firm sets a price below the other firms', it will have to supply all of the market demand for the product. If a firm charges less than marginal costs, it will fail to break even for that unit of output. Results: in the perfect competition model marginal revenue equals price and each firm is price taker.

Figure 4-1: Perfect competition equilibrium



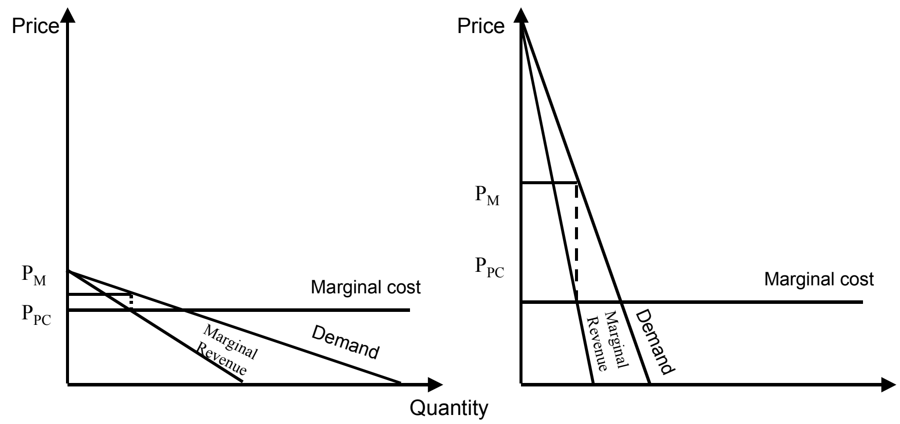
There are generally two types of equilibrium in perfect competition: short run and long run equilibrium. In the short run there is too little time for new firms to enter the industry while in the long run new firms can enter.

4-1-3 Monopoly

The monopoly model assumes that there is one single firm, which supplies a well-defined market and that entry in the industry is blocked. The firm, called the monopolist, sets price *p* or a quantity q at a value that maximizes its profit. Since price and quantity are related to demand D(*p*) it is does not matter if the monopolist chooses the optimal price or the optimal quantity. The level of supra profit depends on the elasticity of demand. The monopolist is therefore price maker, figure 4-2 shows that the difference between the monopoly equilibrium price and the perfect competition price depends on the elasticity of demand, represented by the slope of the demand curve[1]. When demand is inelastic the marginal revenue of selling an extra unit is low because a small increase in the quantity leads to a large drop in price.

[1] On the left the elasticity of demand is high, on the right the elasticity of demand is low.

Figure 4-2: Monopoly equilibrium



A monopolist can increase the price of a good by restricting its level of output. As shown in figure 4-2 the ability to increase prices is limited by the elasticity of demand.

4-2 Oligopoly competition

4-2-1 Introduction

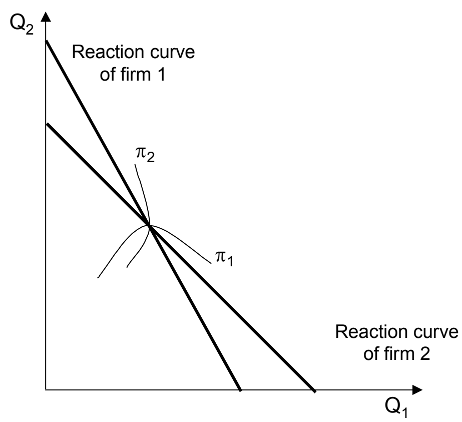
Since both perfect competition and pure monopoly are extreme cases that are rarely seen in practice, to analyze real markets, economists have developed alternatives models. The objective of these models is to cover the broad range of oligopolic competition between perfect competition and monopoly.

Oligopoly competition refers to a market structure where a few players coexist. One of the key ideas of such competition is that each firm believes its profits are affected by the actions of others firms, and that these actions also influence the profits of other firms. Taking perfect competition and monopoly models as the end points, there is an infinite number of theoretical possibilities for oligopoly models, all of which differ mainly in the assumptions used to characterize market structure and firm interdependencies (Bresnahan, 1981). First we present some models which assumed that the players are essentially equal, then some models in which one player is assumed to be dominant, finally we describe some approaches that do not fall into the two other categories.

4-2-2 The Cournot Model

Cournot developed the first model of oligopoly competition in 1838 (Cournot, 1838), this model takes into account the interdependencies between firms. Cournot's assumption of is that each firm will choose a level of output with respect to the rival's production decisions. Thus, in such a model players compete on quantity. The basic model is a duopoly model (n=2) where each firm has identical constant marginal production costs and faces linear demand[2].

Figure 4-3: Cournot equilibrium



The equilibrium formation of Cournot's model is shown in figure 4-3. The two axes define the output of the firms, so that any point represents their respective production volumes. In this model the reaction curve represents how much each firm would produce given an output decision from the other firm. The intersection of the two curves defines the equilibrium where each firm has maximized profit, given the output of the other. This equilibrium is a Nash equilibrium[3] since each

[2] Entry is not considered and the product is homogeneous in this model.
[3] A Nash equilibrium is a situation where each player's predicted strategy must be that player's best response to the predicted strategies of the others players.

firm is following its best course of action, given its expectations about its rival's actions and that the expectation are fulfilled.

Box 4-1: Cournot Equilibrium

Under the Cournot model the price depends of the level of output:

$$P(Q)=a - bQ \qquad (1)$$

Where P is the market price and Q the total volume of output.
The total level of output is the sum of the production of each firm:

$$Q= \Sigma q_n = q_{1+} q_2 \qquad (2)$$

Where q_1 is the volume produced by firm 1 and q_2 the volume produced by firm 2
The profit of each firm n is defined by the difference between its revenues and total cost:

$$\pi_n= P(Q)\, q_n - cq_n \qquad (3)$$

$$\pi_n = (a – bQ)\, q_n- cq_n \qquad (3.1)$$

$$\pi_n = (a – bQ-c)\, q_n \qquad (3.2)$$

Where c is the unit cost. In the Cournot model each firm assumes that the other will keep its level of production. Hence, firm n maximizes its profit by differentiating π_n with respect to q_n. The maximum level of output is found by calculating the first order conditions:

$$d\pi_1/dq_1 =0 \qquad (4)$$

For firm 1 the maximum level output is then defined by:

$$d\pi_1/dq_1 = P(Q)+(dP/dQ)\, q_1 - c = 0 \qquad (5)$$
$$d\pi_1/dq_1 = a-2bq_1 – bq_2 –c \qquad (5.1)$$

Hence, the level of production of firm 1 can be express using the level of production of firm 2:

$$q_1 = (a-c)/2b – 0.5\, q_2 \qquad (6)$$

This equation defines the reaction function of firm 1 to the level of output of firm 2. Similarly the reaction function of firm 2 is:

$$q_2 = (a-c)/2b – 0.5\, q_1 \qquad (7)$$

The equilibrium solution is defined by the intersection of the two curves

$$q_1 = (a-c)/2b – 0.5[(a-c)/2b – 0.5\, q_1]$$
$$q_1 = (a-c)/3b \qquad (8)$$

4-2-3 The Bertrand Model

Bertrand (1883) extended Cournot's model of by changing the rivalry notions using prices rather than quantity. In the simplest version of the model, two firms set their prices simultaneously. Since the two products are perfect substitutes the firm which sets the lower price will attract all the demand for the product in question. Again, we can use a reaction curve, only this time for prices rather than quantities. It is critical for the model that each firm has identical cost curves, otherwise the one which has lower marginal costs will always supply the entire demand. The Bertrand equilibrium is achieved when each firm's expectations about the price behavior of its rival are realized. The fundamental result of the Bertand's model is that industry has price and output level similar as under perfect competition. The reasoning is the following: when firm 1 has selected its price to maximize its profit, the best strategy for firm 2 is to undercut firm 1 by a small margin and take all the market. Hence, the best response of firm 1 is to undercut firm 2. This process ends when neither of the two firms can go any lower, i.e. when price equals marginal costs. For any price of a rival, a firm will opt for a price that is just lower. Equilibrium is obtained when price equals marginal costs.

4-2-4 Others theoretical approach

The *Stackelberg leader-follower* model (1934), built on the Cournot model, assumes that instead of the firms making simultaneous output choices, a dominant firm announce its output first (Stackelberg, 1952). The difference is that firm 2 maximizes its profit assuming that the output of firm 1 is fixed and that firm 1 will take this follower behavior into account. Hence, firm 1 incorporates the reaction of firm 2 into its profit-maximization problem.

The *Edgeworth's* model (1925) is a variant of the Bertand's model. Like Bertrand he assumes that firms compete in price, but unlike Bertrand, Edgeworth assumes that both firms have limit capacity which mean that neither can supply the all market. The great advantage of this assumption is that it improves the realism of the model. However such model does not allow for the definition of an equilibrium solution since prices oscillate between a monopoly price and lower prices.

Klemperer and Meyer (1989) developed a model where a firm facing uncertain demand, rather than competing only on price or quantity will define a supply function (price and quantity). The idea is that when firms have to decide of their strategy, before knowing what the demand will be, they will define an entire supply curve with different prices for different quantities. This hypothesis makes such approach more realistic than traditional “one-variable” approaches. According to this model, in the absence of uncertainty, any price exceeding marginal cost along the demand curve can be a supply function equilibrium. In general all supply curve equilibria are bounded by the Cournot and Bertrand equilibria. When demand is uncertain, the set of possible equilibrium is reduced.

Box 4-2: The contribution of game theory

The foundations of game theory were laid in 1944 by Von Neumann and Morgenstern. While all oligopolistic models recognize the importance of interdependence between firms, game theory focus on the study of interactive decision making and because of this game theory can be seen as a direct development of classical oligopolistic competition models. Game theory has been applied in many fields of economic analysis and its application to the electricity industry is just one of its many applications. Game theory is especially relevant for the analysis of competitive bidding, collective bargaining, auctions, and cooperative and non-cooperative strategies.

Game theory models (or games) are traditionally divided into two categories: static and dynamic models. In static models firms do not know the strategy of the other and cannot change their strategies in response to others' strategy. Moreover the game is played only once and the firm is not interested in futures interactions. In dynamic games, a firm can observe the decisions of competitors and can react to these decisions in following games. Cournot and Bertrand models can be considered as static games since in these models no firm will change its strategies given the strategies of the others because there is no possibility to improve one's profit.

One of the most promising applications of game theory for electricity markets relates to auctions. Since most organized markets use auctions to determine prices and auctions are repeated games, game theory represents an interesting approach to analyzing the behaviors of market participants. However, Game theory is difficult to use for analyzing actual competition because it is almost impossible to isolate the behavior of a firm in reaction to a rival's behavior. For this reason game theory is use mainly as an analytical tool, to help analyst to understand possible behaviors. However, valid results that can be used by competition authorities and others, are unlikely to emerge, because reality is almost always too complex to be modeled in a game. Thus game theory is use mainly for theoretical experiments rather than for real case studies.

4-3 Characteristics of electricity markets

4-3-1 Introduction

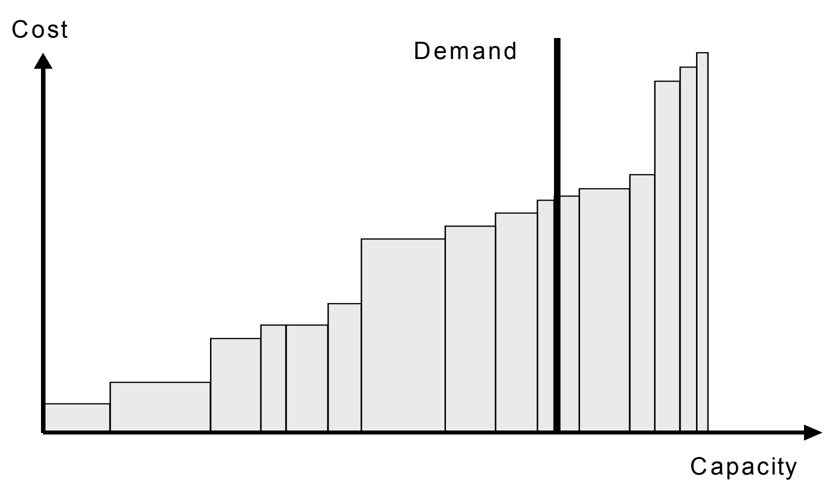
When applying economic theory to electricity markets one is confronted to two major difficulties concerning the nature of demand and supply. One, elasticity of demand is very low if not zero. Two, the characteristics of supply costs in electricity markets are not compatible with the assumptions made in competitive economics. We will now describe how supply and demand are usually presented in electricity markets and their main characteristics.

4-3-2 Supply

Supply in electricity markets is the combined output of all generators used to satisfy the consumer's demand for electricity. As in any market, the supply curve shows the total amount offered for sale at any given price for any given period. In the short term electricity supply is considered to be fixed while in the long term the production capacity may be altered. Three main aspects of electricity supply must be considered: the different cost levels, the nonconvexity of generator costs and the concentrated structure of the market.

When an electricity market is defined, the total electricity supply is usually represented by a merit order curve. Such curves range from the least expensive to the most expensive units, figure 4-4 is a representation of a supply curve in which each unit is shown as a step. The merit order curve presents the costs and capacities of all generators. The differences between costs are mainly due to the technology used and its related fuel. For instance hydropower and nuclear power plants have usually low marginal costs compared to gas powered plants.

Figure 4-4: Merit order curve



Taking a single power plant, the characteristics of supply are not compatible with assumptions of competitive economics because production costs are not convex. Convex costs have the property that twice as much output always costs at least twice as much to produce (Stoft, 2002). Electricity production costs are not convex due mainly to the existence of startup costs and no-load-costs. For instance if the startup cost of a plant is 20 Euro/MWh and if its marginal cost is 25, producing one MWh over two hours would cost 70 Euro/MWh[4] while producing two MWh in the same period would only cost 120 Euro/MWh[5]. Hence, producing twice as much is cheaper per unit. This characteristic is important when estimating the real cost of production in a competitive environment.

Finally, since the electricity industry in the past was organized as a monopoly, most power plants today are owned by a small number of companies. Given this history the number of sellers tends to be low and this is a major problem when attempting to establish competitive markets. At present, in half of the major European electricity markets, one player owns more than 50% of generation capacity[6]. Such a market structure represents the most important barrier for competition and a serious concern in term of market power.

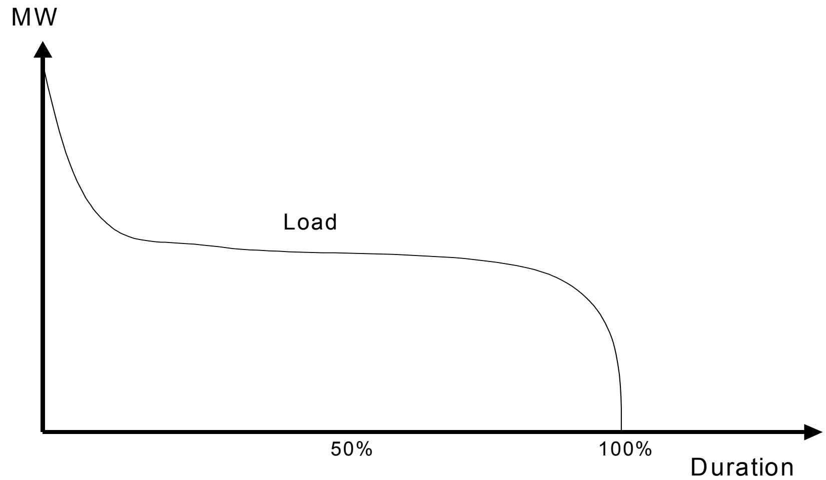
4-3-3 Demand

Market demand is generally defined as the quantity of electricity that end-users are willing to consume at any given price. Electricity demand has three important features: seasonal variations, segmentation of consumers and low elasticity.

The seasonal variations of demand presented in figure 1-2 of chapter 1 are usually summarized in a load duration curve. This curve plots demand against duration. Such a curve can be constructed for different time scales and areas.

[4] 20+25+25
[5] 20+50+50
[6] See chapter 7

Figure 4-5: Load duration curve



The demand of electricity varies widely between peak time (day) and off peak time (night) and seasons (winter/summer). This variation is simply due to the fact that most companies and households do not consume electricity during the night. Very high peaks of demand occur during very hot or very cold weekdays when everyone is using air conditioning or electric heating. The lowest levels of demand for electricity occur in the middle of the night.

Demand can be divided into several segments according to the level of need and sensitivity to price change of its buyers. Different categories have been defined in Europe, as a result of the adoption of Directive 96/92EC, and in accordance with the requirements of Directive 90/377/EC, to improve the transparency of electricity prices charged to industrial end-users and domestic consumers. Domestic consumers and industrial consumers are broken down into three categories according to their level of electricity consumption: small, medium and large consumers. An overview is given in box 4-3.

Box 4-3: An example of segmentation of demand

Domestic consumers
Small: Annual consumption of 600 kWh; subscribed demand: 3 kW; standard dwelling: 50m2
Medium: Annual consumption of 3.500 kWh; subscribed demand: 4-9 kW; standard dwelling: 70m2
Large: Annual consumption of 7.500 kWh; subscribed demand: 6-9 kW; standard dwelling: 90m2

Industrial consumers
Small: Annual consumption of 50 MWh; maximum demand: 50 kW; annual utilization: 1000 hours
Medium: Annual consumption of 2.000 MWh; maximum demand: 500 kW; annual utilization: 4000 hours
Large: Annual consumption of 50.000 MWh; maximum demand: 10 000 kW; annual utilization: 5000 hours

Source: Eurostat, http://europa.eu.int/comm/eurostat/

The elasticity of demand is a sensitive issue in electricity markets. As in any market, the elasticity of demand represents the responsiveness of consumers to a change in price, in this case electricity prices. In electricity markets elasticity of demand is very low for most consumers due to the lack of substitutes and the high importance given to the product by consumers. Large consumers directly connected to the high tension grid and acting at the wholesale level can react to some extent to electricity prices. Households and small and medium industry are almost unresponsive to price fluctuations because wholesale volatility is not passed on to retail consumers, or at least not in real time. These small consumers, which do not act directly on the wholesale market do not have the incentive to respond to price volatility because they pay a retail price that is averaged over time.

Table 4-1: Price elasticities of demand for UK industries

Type of firm	Maximum	Average
Water supply firms	-0,860	-0,400
Copper/brass manufacturing firms	-0,300	-0,060
Hand tools/finished metal goods manufacturers	-0,062	-0,002
Steel tubes manufacturing firms	-0,014	-0,004
Timber and wooden furniture manufacturing firms	-0,036	-0,004
Food, drink and tobacco manufacturing firms	-0,00035	-0,00001

Source: Patrick, Robert H., and Frank A.Wolak (1999)

In most markets, consumers choose whether to consume or not depending on the market price. In electricity markets, consumers do not reduce their consumption when supply becomes tight simply because they do not see a price difference in the short term; even large consumers have low demand elasticity. Patrick *et al* (1999) have estimated price elasticities for large and medium size consumers purchasing electricity on the wholesale spot market in England and Wales for different time periods (table 4-1). Their study shows that, with the exception of water supply firms that have the ability to shift the pumping of water to different periods at very short notice, all the types of firms studied had a price elasticity inferior to 0.06 on average. This means that a one percent increase in price during a pricing period may lead to at the most a 0.06 percent decrease in electricity consumption in that period. Moreover this value is even lower than 0.01 for four of the six categories of consumers studied. This lack of demand response hampers load reduction in response to price increases. Combined with a concentrated market structure this lack of responsiveness of demand represents a major concern, that requires specific attention with respect to market power and market modeling.

4-4 Economic theory applied to wholesale electricity: recent developments

4-4-1 Introduction

Technical models have been developed and used for many years by integrated utility and system operator to ensure the smooth operation of electricity systems. Technical models are used to simulate least-cost production solutions for a given level of demand and available generation resources (Miller and Malinkowsky, 1970). The characteristics captured by these models are: heat rate, capacity level, minimum up/down times, outages rates, fuel costs, maintenance costs etc. These models provide solutions for a utility to use a specific power plant. Dealing with electricity flows, transport constraints and unit commitments, these models are also used by system operator to ensure operation of the grid (Grainger and Stevenson, 1994). For instance the "Norwegian power pool model"[7] focuses on flow into reservoirs and weekly production in a hydro-based system.

While the genuine purpose of these models in the past was cost minimization for regulated utilities, such models are still useful nowadays but are utilized from a profit maximization perspective (Davidson *et al*, 2002). The output of these models provides a relevant benchmark for analyzing the level of competition. However there are some limits. For instance, some assets may be used in totally different ways before and after liberalization. Secondly, these models were mainly developed for well-defined isolated areas, today, cross-border trading plays an important role in the price determination process. Finally the most important weakness of technical models is that they totally overlook economic interactions between competitors. Hence, these traditional technical models have little relevance when analyzing liberalized markets consisting of a number of competitors.

[7] See www.risoe.dk for more information

Similarly, theoretical economic models, such as perfect competition and monopoly models, are too generals to be applied directly to the electricity industry since they do not take into account many fundamental aspects of actual electricity markets. Given the above, the liberalization process of the electricity industry worldwide has led to important efforts in the research community to develop models that reflect the new market context. Using existing tools taken from the two approaches, i.e. technical operation and economic theory, an important set of economic literature in which new models, adapted to take into account the features of new competitive wholesale markets, has been developed.

Recently developed models combine the technical characteristics of electricity based on operational models and the modeling of firms behaviors based on oligopoly competition theory. The models differ mainly in the set of assumptions and of variables they deal with. We present a survey of the most relevant models in this section focusing on the technical characteristics they take into account, the economic model they use and the purpose they serve. The relevance, advantages and disadvantages of these models are presented and analyzed with regard to using them for the study of power exchanges.

4-4-2 Recent developments

It is well recognized that, given the concentrated nature of the market structures, oligopoly competition models are the most suitable models for analyzing electricity markets. The choice between Bertrand and Cournot competition represents the two major alternatives (Hobbs *et al*, 1999). Depending on the purpose of the model and the type of market, one approach might be more relevant than another. In general, and especially in period of high demand, it appears that the Cournot paradigm corresponds more closely to electricity markets (Borenstein and Bushnell, 1999). The use of Cournot Competition is supported by the fact that electricity suppliers have limited capacity. In the Bertrand approach, any firm can capture the entire market by pricing below other competitors but, since electricity producers have increasing marginal costs and limited installed capacity, Bertrand's assumptions regarding behaviors appear less realistic (Hobbs, 1986). However, in some circumstances, e.g. periods of low demand, it has been argued that Bertrand models might be a relevant approach (Green and Newbery, 1992; Wolfram, 1998). Hence, the level of demand and the level of capacity constraints are fundamental variables that need to be taken into account to choose between Cournot and Bertrand competition.

Kahn (1998), Hobbs (2000) and Ventosa *et al* (2002) have examined the characteristics of the different economical models applied to the electricity industry. These models can be classified using different criteria. For instance, models can be classified by the degree of competition they assume, i.e. perfect competition, Cournot, Bertrand, supply function; the intended market, e.g. California, United Kingdom, Spain; time scope, e.g. short-term, long-term; the intended user, e.g. system operator, competition authority, generator; and so on. One classical approach consists of identifying the purpose the model serves. Since giving insight into a problem is the reason why models are developed (Sterman, 1991) this criteria is especially relevant. The purpose of the models are multiple, e.g. risk management (box 4-4), strategic bidding, economic planning, congestion management etc. For instance, Ventosa *et al* (2002) define two categories of models: equilibrium models and optimization models. In equilibrium models, the behavior of each participant is modeled taking into account competition among all participants while the behavior of only one firm is considered in optimization models. Optimization models are formulated as a single optimization program in which a firm maximizes its profit. Equilibrium models take into account the profit maximization of each firm simultaneously. Drawing up a full list of existing models applied to electricity markets with all their characteristics is beyond the scope of this work. Below, we focus on recent developments.

Kahn (1998) focuses on models, which analyzes market power. Kahn's models assume profit maximization of market participants under oligopolistic competition. Two categories of oligopolistic competition are modeled. The first one is Cournot competition (quantity) while the second model uses the supply function approach (price-quantity). Kahn's main conclusion is that the Cournot approach is more flexible and tractable and that is why it is more commonly used. However he argues that the supply function equilibrium approach is conceptually superior to the Cournot competition.

Box 4-4: Model and risk management

In a competitive environment characterized by uncertainty and price volatility, models are used for risk management. Risk management models are mainly derived from financial models. For instance, they use specific tools such as Black-Scholes analysis or Monte Carlo simulations. These models rely mainly on historical data to estimate volatility. For this reason such models can only be applied in mature markets where price data are available and the level of liquidity is sufficient (Fleten *et al,* 1997). In Europe, only Nord pool fulfills these criteria.

Monte Carlo simulations have been recently used for electricity markets. The Monte Carlo method is used to calculate the variation in prices using a sample of randomly generated price scenarios that are assumed to be equally probable. Such an approach requires making assumptions concerning market structure, about the stochastic processes that the prices follow and about the correlation between risk factors and the volatility of these factors. Monte Carlo simulations can combine historical information with market expectations. For instance, Monte Carlo simulation can be use to model forced outages (Borenstein *et al*, 2000). The first criticism of this method is that it is computationally demanding. Moreover, the mathematics underlying the calculations are complex which makes the outcome very sensitive to assumptions. Another criticism is that it requires subjective input in the choice of simulation model structure. In general the fact that a Monte Carlo simulation use a random process represent an important limit in operational circumstances.

Green and Newbery (1992) and Bolle (1992) were the first to employ the supply function equilibrium approach in electricity markets. Their objective was to estimate the level of competition in the British electricity spot market. Bolle used this method to estimate the risk of tacit collusion in a concentrated market. Rudkevich *et al* (1998) have also used the supply function approach to analyze strategic bidding and to attempt to predict joint behavior of market participants. Falk (1998) criticize their model showing that the number of simplifications led to astounding conclusions. Day *et al* (2002) have extended the supply function approach by introducing the anticipation of firms concerning the output of rivals (Conjectured Supply Function). Hobbs *et al* (2002) have applied this model to the Benelux, French and German markets in order to analysis the inefficiency of transmission pricing in Europe[8].

The most recent developments in market modeling in the literature are related to the Californian crisis. Borenstein and Bushnell (1999) used historical cost data to simulate the California electricity market assuming static Cournot competition. They argue that such approach is superior to classical Hirschman-Herfindahl Index (HHI) which appears to be unsatisfactory for electricity markets[9]. Joskow and Kahn (2001a) used a very sophisticated model to analyze pricing behavior in California during the crisis in the summer 2000. The objective of their analysis was to build a competitive wholesale benchmark and to compare it to the prices that were actually observed: the difference between the two values represents an estimate of the level of market power. In their model they take into account several factors such as hydro output, imports, natural gas costs, air emission regulation (nitrogen oxide, NOx), heat rates, forced outages rates etc. This model has been extensively criticized by Harvey and Hogan (2001) who argue that market power might be one of the reasons for the very high prices but that other factors should not be forgotten. In response Joskow and Kahn (2001b)

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[8] See chapter 9

[9] See chapter 10

replied somewhat sharply[10] to Harvey and Hogan criticism and made some improvements to their first model.

In conclusion, research into modeling electricity markets is continuing and is the subject of many debates. All types of competition (Cournot, Bertrand, supply function…) are utilized and have their advantages and disadvantages for electricity markets. It is well recognized that models cannot address all questions of interest, however they appear to be a powerful tool for understanding whether electricity markets are delivering the expected benefits of liberalization.

4-4-3 Relevance of models: the inevitability of using models

Models have been used widely in economic analysis for decades from worldwide macroeconomics to local microeconomics studies. Such models have become an important tool for analyzing and forecasting, in public institution and private companies. Models are useful because they can be used to compute and interrelate many factors simultaneously; this allows us to simplify reality and helps us to better understand a complex situation.

Electricity markets have specific features which make modeling a very interesting approach to use in this field. First, the nature of the product is very easy to identify. All electrons are comparable in contrasts to foods or cars. Second, estimations of production costs are relatively easy to do compared to others products. The production process is well defined and the cost of 1 MWh for a specific power plant, or type of plant, is quite simple to estimate based on the technical characteristics of the power plant and the cost of fuels used in the plant. Finally existing technical models containing historical data and well-defined parameters, can be used to facilitate the development of economic models.

[10] *"[…] we find that their arguments as a whole are unpersuasive, that they are applied inconsistently […]"; "Harvey and Hogan present a litany of largely unsupported arguments that ignore what economic theory and common sense suggest about behavioral incentives"*

In practice, models that have been developed for electricity markets have three main uses. One, they are indispensable for gaining insight into the modes of behavior of the market participants (Hobbs, 2000). Such models can be used to model the different possible behavior of market participants to allow comparison between participants behavior and the impact of this on competition. For instance, simulating market prices in a defined market and changing the market structure in terms of ownership of the power plants provides insights into the role of market concentration on competition. Two, they can be used for forecasting. Based on historical data, models can be used to provide forecasts of market outcome to help decision-makers. Three, models are useful for ex-post analysis. Models can be used to provide a benchmark to understand what happened in a market. The analysis then consists of explaining the difference between the model output and the actual output. This last type of analysis is especially useful for the analysis of market power (Borenstein *et al*, 1997, Joskow and Kahn, 2000)

4-4-4 The disadvantages of models

Models in general have a variety of limitations and problems, which are not specific to electricity models. Assuming that data are available and reliable, the main limits of models concerns how realistic are the assumptions made in the model. Making assumptions is the first step when building models and this represents the true weak point of a model. Assumptions are made during the description of the system to be modeled and of the relationships between variables. For instance, in electricity models it is assumed in a majority of models that players compete on quantity (Cournot) rather than on price (Bertrand), while in practice the two parameters are important. Secondly, in order to permit calculation, model builders have to define a value for price elasticity. This parameter is exogenous and the value chosen crucially influences the outcome of any simulation. Indeed, a price elasticity of zero, which appears to be the most realistic in the short-term, leads to infinite price under Cournot competition. Moreover, under Cournot competition, rivals do not change production if the price changes. This assumption is very restrictive. Moreover, the definition of the objective function, the problem of linearity, the lack of dynamic, the choice between endogenous and exogenous variables, the quantification of soft variables and the choice of model boundaries (Sterman, 1991) represent critical assumptions which widely impact the outcomes of models.

The objective function of market players in economic theory is usually profit maximization, because of this most models assume that players will take decisions that allow them to maximize their profit. Though this hypothesis is widely accepted by economic theory, in reality, companies can have different objectives. For instance a company may try to maximize its market share, which involves a different strategy. A company may also make investments, which reduce its short-term profit but will increase its long-term profits. Hence, behaviors that diverge from profit maximization are ignored while they can be perfectly rationale. Moreover, many economic models assume perfect information, which implies that players can perfectly anticipate the consequences of their actions and those of their competitors. Such assumption makes little sense in reality. In the real world the level of information is always incomplete leading to biased decisions.

Linearity is a common feature of large models, because large models involve hundreds or thousands of variables and constraints, the problem of finding a solution is extremely difficult. For this reason, the relationships between variables are often modeled as linear. The cost of a power plant is most of the time explained by a linear relationship with the cost of fuel used, e.g. 2 units of fuel are necessary for the production of 1MWh. Albeit such estimates can be made, but overlook the differences in efficiency of a power plant with respect to levels of use (Stoft, 2002), i.e. when a plant is used at 20% of its maximum capacity its efficiency may be lower than when it is used at 80% capacity. Concerning elasticity of demand, consumers may not react to a price change until a 20% price increase, but they will start to consider decreasing their consumption, they will actually start to decrease their consumption when prices increase by 30%. Hence if linearity is mathematically convenient, in reality it is often invalid and its use can strongly biase results.

Most models do not incorporate dynamic aspects of competition. They define an equilibrium situation for a particular moment in time regardless of any possible changes with time or “learning process” on behalf of participants. For example, take the problem of modeling and accounting for the impact of entry with regard to new generating units or the construction of new transmission capacity. Another example is the fact that in a market with repeated interactions, firms will learn how their competitors behave and will adapt their strategies. Static models do not capture such aspects. Dynamic models, however complex, this complexity often causes the results of the model to be unrealistic or indeterminate (multiple equilibrium). Furthermore, dynamic models do give a clear guide to the net effect that dynamic factors have on prices.

When all relevant parameters and variables have been identified, choices have to be made as to whether they are endogenous or exogenous. Exogenous variables are not calculated using the model. These parameters usually include: elasticity of demand, number of player, capacity of lines, production costs, production efficiency, level of demand, prices of fuel etc. Endogenous variables are mainly prices or costs. Defining exogenous variables simplifies calculation while integrating of all variables as endogenous will result in additional complexity, which can make the model insoluble. The existence of these two categories of variables makes impossible to take into account the feedback between the types of variables (exogenous and endogenous). For instance if the level of prices simulated by the model are very high, new players may enter the market which in turn will influence the market structure.

Models are powerful tools for analyzing a large amount of numerical data, however they are limited when it comes to dealing with soft variables. Soft variables are qualitative data that are difficult to quantify. They represent descriptive information, which may be crucial for the functioning of a market. For instance, political environment, organizational realities, non-economic motives, regulatory framework, market design, reputation of players, business practices etc all have an important role in the functioning of a market and yet it is difficult to handled these variables in models. For instance, in an oligopolistic market structure, actual prices can be lower than prices simulated by a model because firms fear regulatory intervention. Psychological aspects are also soft variables. One important weakness of models is their inability to take into account such aspects. Yet these qualitative data are especially important in decision making since decisions made by a company are made by people not machines. Decision-makers will have different perceptions and interpretations of market situations, and these differences are difficult to include in a model.

Defining the boundaries of a model is an important issue for modeling. The classic boundaries of electricity models are time horizons and geographical area. Electricity prices vary hour by hour, even by minute in some markets, in response to constant changes in supply and demand, which in turn are influenced by several parameters, e.g. weather, time of the day, outages, maintenance, transmission constraints etc. Hence even if some parameters can easily be identified as more relevant than others, neglecting some implies assuming zero impact and this is probably the only value known to be wrong (Forrester, 1980). Moreover, electricity market models are very often related to a geographical area, and hence, exclude other geographical areas. Excluding other areas for a country like New Zealand has no consequences since it is an island that is unconnected to others areas. However, such approach is more arguable for interconnected countries. Thus, modeling the German or the Californian market, make little sense because import and export of electricity may have a large influence on the market. A common way to deal with this is to assume that import and export are constant or that exports are only a part of demand while imports are only an “extra” generator. In a competitive international environment, however, the price of two or more areas will be interdependent and changes in one market can explain changes within another.

In conclusion, models are an inescapable analysis tool. However, their use should be restricted to a specific purpose. A single model cannot address all issues. How even sophisticated they might be, models are only simplifications of reality, and they rely strongly on assumptions. This is best illustrated by the fact that two models developed by equivalent, top-level economists can produce radically different results due to minor, and reasonable, differences in the assumptions made when beginning to model. Moreover, a fundamental problem in modeling is that, due to the central role of assumptions, the margin of error may well be larger than the magnitude of the effect that one is attempting to measure (Hogan, 2001). For these reasons models should be seen as a complementary tool for analysis that help the analyst to improve their judgement and intuition, and should not be seen as substitutes for critical analysis on behalf of the analyst (Sterman, 1991).

4-4-5 The advantage of using modelling for the analysis of power exchange

Modeling of spot markets for electricity has been widely done for power pools. These models have been developed mainly for the United Kingdom, and California (Wolfram, 1999; Green and Newbery, 1992; Borenstein and Bushnell, 1999; Wolak and Patrick, 1998;). However, with the exception of Nord pool (Hjalmarsson, 2000) there is no available model in the literature for power exchanges' day ahead spot market, hereafter power exchange. This is surprising because at a first glance building models for electricity power exchanges appears to be a promising approach.

The important feature of power exchange which favors modeling is the explicitness of the price determination process, i.e. the auction. Buyers and sellers submit bids, which are aggregated by the exchange. Hence, estimating the impact of any increases (or decreases) of supply or demand can be easily achieved since reproducing the algorithm used daily by the power exchange to determine the market-clearing price can easily be done. For instance, if one wants to know the impact might have been on prices for supplying one additional MWh, a simulation using all actual bids and a new bid with this extra quantity can easily be done.

A model can be useful for analyzing power exchange to estimate any change in the rule of functioning of the exchange. For instance, if an exchange wants to introduce pay-as-bid instead of marginal pricing[11], simulations can be realized to study the reaction of participants and the possible changes in market equilibrium. Hence, models can be used to test new auction system. Even if the model can not predict exactly what will be the new behaviors of participants, running simulations can quickly show the potential disadvantages of a new system. Though a model does little to prove that the new rules of the auction will work in practice, it can definitely eliminate wrong options.

Finally, the reasoning use in models is interesting for an analysis of competition on power exchanges. Keeping in mind the different kind of interaction between players (Bertrand, Cournot, Supply function…) can be use to guide the analysis of actual data. If empirical observation shows that a player has decreased the level of its supply and that this has resulted in an increase in prices, market analysts will certainly opt for the use of a Cournot model. Similarly, if a player has decreased the price of its bids to maximize the volume of its sales, a Bertrand model might be more relevant.

4-4-6 The weaknesses of existing models for analyzing power exchanges

The first challenges for modeling power exchanges is the nature of the players. While in classical power pools, the sellers are generators and their characteristics are directly identifiable through their assets, in power exchanges every type of market participant can be a seller. In most existing models for the analysis of electricity markets, supply is estimated based on installed capacity and different characteristics of power plants. However, on a power exchange, any participant that has over-contracted on the bilateral market can be a seller on the power exchange's spot market. For instance a distribution company or a large consumer can sell electricity on the power exchange if they realize, one day before actual consumption, that they will actually consume less than what they had forecast weeks or months before when they signed physical bilateral contracts. Moreover, pure traders, without physical assets, can sell electricity on a power exchange, which can initially come from a bilateral contract or from arbitrage with another country. Finally producers of electricity have developed trading departments which also act as pure traders, i.e. make arbitrage between type of contract or between location. Hence, a producer which sells 10 MWh on the power exchange may have bought this amount of energy from a distribution company which in turn bought it from another producer. From a modeling point of view this separation between physical asset and sale on the power exchange make the identification of sellers characteristics difficult and represents a serious problem for the estimation of supply.

Defining the relevant approach to estimate the nature of competition on a power exchange is also a difficult task. As described above, most models of electricity markets assume Cournot competition. However, on a power exchange, players bid on price and quantity and manipulating prices can be done using price and/or quantity, e.g. not offering 1 MWh or offering it at 1 billion Euro can be considered as equivalent or at least as having an equivalent effect. For this reason the supply function approach developed by Klemperer and Meyer appears to be a more realistic approach. In practice, this is difficult because supply function models have a major drawback due to the multiplicity of solutions provided. These solutions range from perfect competition to Cournot equilibrium.

[11] See chapter 3

The possibility for pure traders, distribution companies and large consumers to act as sellers on the power exchange also represents a serious problem with respect to the use of oligopolistic models. Indeed, the number of participants in most existing power exchanges is over thirty[12] and assuming that at least half of them are active as sellers, it is questionable whether oligopoly competition is a sufficiently adapted framework.

The problem of identifying the relevant market players is also due to the fact that power exchanges are voluntary markets. In an extreme case a large generator may not participate in a power exchange. Furthermore, a large producer can find it more economic to buy electricity on the spot market rather than using its own units. Hence, a generator can buy on the power exchange to honor its bilateral contracts. A generator can even be a very large buyer if it faces an outage of one of its plant and buys electricity on the exchange that has come, for instance, from an over-contracted distribution company.

By definition a power exchange represents only part of the market and companies are likely to use power exchanges as part of their overall trading strategy. Since spot trading can also occur on a bilateral basis, depending on the trading practice some companies may favor the use of the bilateral market even for spot trading rather than the use of the exchange. This is true for both mandatory centralized markets (pool) and voluntary exchanges, because of the existence of bilateral contracts (financial or physical) that limits the relevance of the spot price. Hence, a model focusing only on trading on the power exchange will overlook all possible behaviors on the other markets and their interaction with the power exchange.

The dynamic aspects of competition are fundamental in a power exchanges' spot markets. Interactions between firms take place daily and repeatedly. Hence, the fact that firms will adapt, with time, their bidding behaviors is crucial. Moreover, in

[12] See chapter 7

a concentrated market structure with repeated interactions tacit collusion is likely to occur to decrease the level of competition. The importance of dynamics in power exchanges is therefore a serious limitation for the use of classical (static) models.

Finally spot trading is particularly sensitive to random external events. Amongst them, outages represent the most common reason of price spikes. When a generator loses one generation unit, in the short term buying electricity on the power exchange represents the best alternative before having to pay balancing charges. Unexpected hot or cold weather conditions also have a direct impact on spot prices. Similar to outages, an unexpected temporary reduction of interconnection capacity can dramatically influence price level on power exchanges. Other considerations like cooling water problems, a worker’s strike at a very large consumer or the end date of a specific bilateral contract are also reasons for the extra volatility of power exchanges. There is also the problem of the lack of historical data, and when it is available it may be invalid due to changing conditions on the market. This characteristic of power exchanges represents an important challenge for modeling because models are not well able to take into account a high level of volatility.

In conclusion, due to the nature of the power exchanges’ spot market which differs widely from power pools, existing models are unlikely to be able to handle all the factors which influence competition on power exchanges and their functioning in general. For this reason even very sophisticated models appear not to be capable of incorporating all factors which influence trading on these markets. However very simple models might be useful for testing very specific aspects of the power exchange and further research will certainly improve existing approaches.

4-5 Conclusion

This chapter consists of a review of different economic theory models of market functioning and their application to competition analysis in electricity markets. This contains descriptions of background theories, how they have been applied to electricity markets and their value and limits for the analysis of power exchanges. Reference theoretical models were briefly presented. Subsequently, we identified the major difficulties encountered when applying economic theory with respect to the nature of demand and supply in electricity markets. Different applications for models in electricity markets and recent work in the field were discussed. Finally the strengths and weaknesses of models for the analysis of power exchanges were analyzed. Based on this work, it appears that we need to understand the general functioning of power exchanges better before we can build relevant models.