

ENERGY REGULATORS REGIONAL ASSOCIATION

INTRODUCTION TO ELECTRICITY MARKETS

*Textbook developed for ERRA Training Course
by the Regional Centre for Energy Policy Research*

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TEXTBOOK EXTRACT

INTRODUCTORY TRAINING COURSE ON ELECTRICITY MARKETS EXTRACT

*Second draft, January 11th 2008**

Objective of the textbook

The purpose of this textbook is to introduce students to the design and operation of electricity markets, both in theory and in practice. The text consists of the following modules.

- Module 1 provides an elementary, non-technical introduction into the **methods** and tools of **economic analysis**, the role of incentives in influencing the behavior of economic actors, and the theory of efficiently working competitive markets.
- Module 2 describes the two main forces of a market for electricity: **supply and demand**. Technical and economic features of power generation are discussed both from a short and a long term perspective. We also study the characteristics of electricity demand with special emphasis on its price responsiveness.
- Module 3 deals with the design and operation of **wholesale markets**. We introduce the main market models and discuss their strengths and weaknesses. The role of the system operator is explained in detail.
- Module 4 introduces the **network issues** arising from the nature of electricity transmission. We discuss technical features, governance models, third-party access and methods of congestion management and capacity allocation.
- Module 5 provides an introduction to the consequences and detection of **market power** abuse in electricity markets.

Introduction

The liberalization of the electricity sector has been a very important development worldwide in the past two decades, and is still an ongoing process in most countries, especially those under transition from a socialist regime. This textbook aims to provide a clear explanation of the benefits of introducing competition into appropriate segments of the electricity industry

* The draft has been prepared by the Regional Centre for Energy Policy Research (REKK). Its main purpose is to define in detail the scope of the textbook accompanying the onsite and e-learning courses on the Technical and Economic Fundamentals to Understanding Electricity Markets organized by the Energy Regulators' Regional Association (ERRA). The material contained in the present draft is subject to more thorough exposition in later versions of the textbook.

TEXTBOOK EXTRACT

and guide the reader through the most important economic issues surrounding the creation and successful operation of electricity markets.

What do we mean by “appropriate segments” of the electricity industry? We have in mind the types of activities that do not exhibit serious returns to either scale or scope, in other words, those that are not natural monopolies. Natural monopolies, by definition, are those activities which can be done much more efficiently by a single company. Even if entry into these segments were left unregulated, one competitor would inevitably drive out the rest and become a monopolist simply by expanding output and producing (or providing service) at a lower cost than the others. Once he is left alone, he could exploit his grip on the market at will. For this reason, activities exhibiting natural monopolistic features are almost always (or should almost always be) performed by a single company under close regulation by the state.¹ In case of natural monopolies, we say that the *efficient scale* of production is large relative to the size of the market. However, this is not necessarily the case for all the activities carried out in the electricity industry. We will argue that technical progress in power generation and information technology has decreased the efficient scale of many activities in the sector to the point where different providers can actually compete with each other for customers without necessarily driving the rivals out of the market. We will see that the presence of competition is a strong force towards efficient operation and investment decisions, of which government regulation is only an imperfect substitute. For this reason, competition – wherever feasible – is mostly preferred to regulation.

Which segments of the electricity industry are the ones potentially suitable for competition, and which are the ones destined to be natural monopolies for the foreseeable future? Table 1 provides a general summary.

Natural monopolistic activity	Potentially competitive activity
System operation	Generation and ancillary services
Transmission	Wholesale trading
Distribution	Retail service provision

TABLE 1: Candidate activities for competition in the electricity sector

In this textbook, we will concentrate our attention to the potentially competitive activities and their organization into markets. It is, of course, neither possible, nor desirable to completely disregard monopolistic segments, because they have a strong influence on the design and operation of electricity markets themselves. Therefore, we will elaborate on both the very important role of the system operator and on the effects of different arrangements for the transmission of electricity.

Since this is only an introductory text with strong space limitations, our main focus will be on the wholesale level and we will almost completely omit discussion on retail competition. This

¹ Objectives, methods and principles of regulating natural monopolies have been described in detail in the textbook of a previous course by ERRA: Price Regulation and Tariffs.

TEXTBOOK EXTRACT

decision stems from the generally accepted notion that most of the gains of liberalization are to be had from the more efficient operation of the wholesale market.

MODULE 1

ECONOMICS OF COMPETITIVE MARKETS

In this module, we will discuss the main economic characteristics of competitive markets in general, without any reference to the nature of the product at all. It is our belief that a high level of generality helps the reader grasp the main conceptual points without needlessly getting bogged down in detail at an early stage.

Markets and market participants

All markets consist of a *supply* and a *demand* side. On the supply side, we find economic actors (people or companies) who are willing to provide some amount of a product or a service in exchange for money. The demand side consists of consumers (again, people or companies), who are willing to buy some amount of the product or service for money. Whenever the suppliers are ready to sell for a lower (or equal) price than what the consumers are prepared to pay, a mutually beneficial *opportunity for trade* presents itself, which the parties can take advantage of.

However, finding these mutually beneficial trading opportunities usually requires some exploration – after all, the parties must learn about and find each other, then work out the details of the trade (a *contract*) so that no one gets cheated, and must also be able to enforce the agreement afterwards. Thus the transaction itself is costly. Organized markets are created to make sure that transactions go as smoothly as possible and the costs associated with making trades are minimized.

Supply

Providing a product or service is costly. By and large, total production costs consist of a fixed and a variable part. Fixed costs must be incurred regardless of the level of production (think of the heating bill for the factory floor), whereas variable costs add up as producing more and more units entails additional expenses (*incremental* or *marginal costs*; such as the cost of raw materials in a car).

The per unit cost (*average cost*) of production comes together from two elements: the marginal costs of producing each unit, and the fixed costs distributed onto each unit of production. Average costs are usually decreasing with the level of production at first, as the fixed costs get distributed to more and more units. After a while, however, the decrease in *average fixed costs* becomes insignificant. At the same time, the marginal costs will usually start to increase at some point (perhaps because an additional – more expensive – night shift is

TEXTBOOK EXTRACT

needed, or production capacities must be expanded to enable higher production levels). The overall effect is that average costs decrease for a while as the company expands its production, but will hit a minimum level and then start increasing afterwards. The production level at which the company can supply the market at the lowest per unit cost is called the *efficient scale of production*.²

Now let us look at the optimal production decision of a competitive supplier. By competitive, we mean that the company believes that it cannot act in a strategic way regarding the market price (the main condition behind the textbook case of perfect competition). In other words, the firm takes the market price that it can get for the product as given, and does not believe that its own production decisions influence this price at all. This is the so-called *price taking assumption*, which we will also employ to describe the demand side of the market as well.

Optimal production level of a company

If a company sells one more unit of a product in the market, its total revenue increases by the market price, whereas its total cost increases by the marginal cost of producing the additional unit. Since the profit is the difference of total revenues and total costs, the firm's profit will increase with the market price minus the marginal cost of production. If this amount is positive, the company gains profit by increasing its output. Conversely, if it is negative (marginal cost is larger than the market price), the company gains profit by *reducing* its output.

As a consequence, *the optimal profit maximizing production level of a price taking company must be such that marginal costs at that production level are exactly equal to the market price*.

How does this behavior play out at the aggregate (industry) level? Here, we have to make a difference between the short and the long run consequences. By short run, we mean the time horizon within which no firm can enter or exit the market. Depending on the nature of the industry, this can be a few weeks, months, or even years. The long run, on the other hand, is characterized by free entry and/or exit of companies.

Let us look at the short run first. The number of companies is fixed. Moreover, the production decision of each company is given by its marginal cost curve, which describes the relationship between the level of production and the marginal cost of producing the next unit of output at that level. The reasoning is the following. Market price determines marginal cost (firms make sure that the latter equals the former), and marginal cost determines the production level (through the marginal cost curve).³ Therefore, the (increasing segment of) the marginal cost curve is really a relationship between the market price and optimal company production, which merits the name *individual, or firm-level, supply curve*.

² A natural monopoly situation arises when the decreasing element in the average cost is always the dominant one, that is, the efficient scale of production is as large as (or larger than) total demand. This can occur when fixed costs are sizeable and marginal costs are relatively negligible and non-increasing.

³ Strictly speaking, this is only true on the increasing segment of the marginal cost curve. But since firms will never find it optimal to produce on the decreasing segment, we may as well disregard that part altogether.

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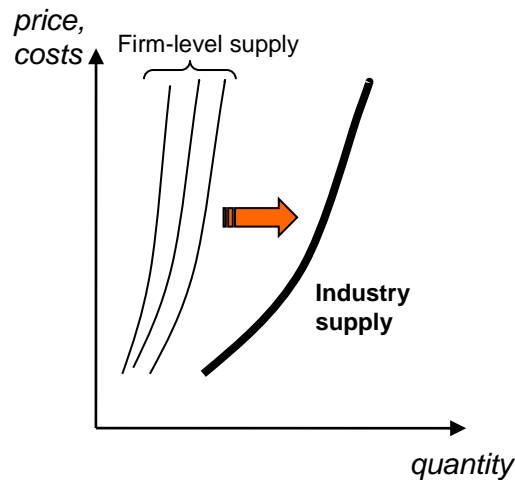


FIGURE 1: Short-run industry supply in competitive markets

How do we get from firm-level supply to market supply? Simply by adding up the individual supply curves of all the companies that are currently in operation in the industry. Since firm-level supply curves are upward-sloping, the industry supply curve will be upward-sloping as well, as Figure 1 shows. When market prices rise, the industry is willing to supply more of the product.

But how does the market price come about in the short run? To answer the question, we must first turn to the demand side of the market.

Demand

Consumer demand is the relationship between the price of a given product and the quantity that consumers would like to purchase of it at those prices. Graphically, it is usually represented by a downward-sloping curve, where price is on the vertical and quantity is on the horizontal axis (see Figure 2). Each point on the curve shows the maximum quantity demanded for the given price and at the same time it also shows the maximum price that consumers are willing to pay for the given quantity (reservation price). The negative slope indicates that people would like to buy less of the product when its price is higher, as we would naturally expect.

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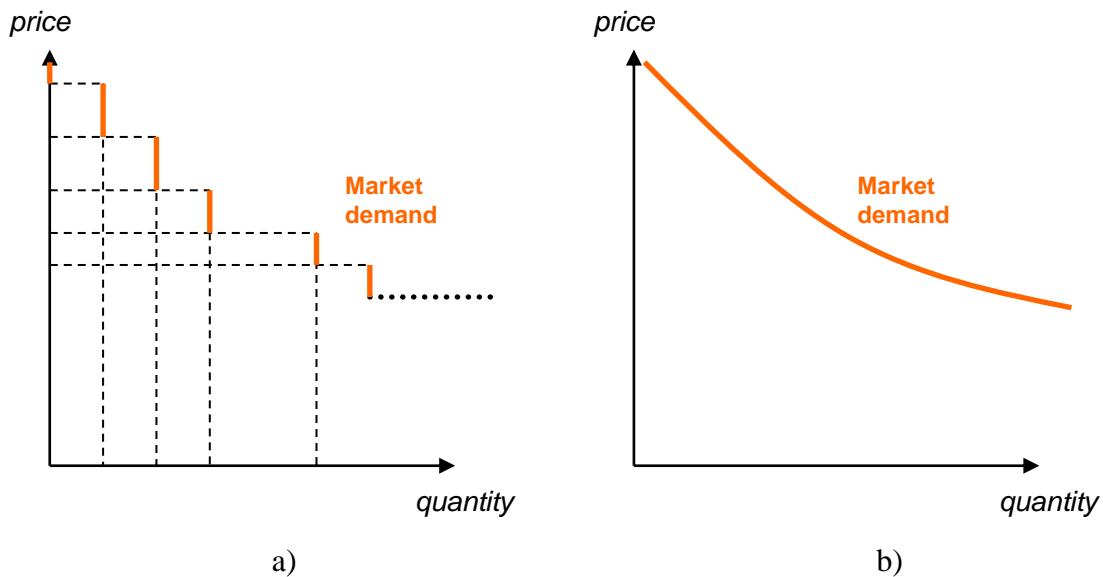


FIGURE 2: Consumer demand representations with small (a) and large (b) quantities

Another useful concept is the *(price) elasticity of demand*. This measure shows the percentage change in the quantity demanded that occurs in response to a 1 percent rise in the price. For example, if the elasticity of demand is -0.8 , then when the price of a product increases by one percent the demanded amount of it *decreases* by 0.8 percent. The demand is called elastic when the elasticity's absolute value is more than 1, otherwise it is inelastic. It is also usual to make the distinction between *more* and *less* elastic demand, the former denoting a point on the demand function where the absolute value of demand elasticity is larger.

Now we are ready to answer the question regarding the short-run determination of market prices. Obviously, the price must be such that the quantity supplied by the companies and the quantity demanded by the consumers exactly equal each other (the market *clears*). This point is shown by the intersection of the market-level supply and demand curves in Figure 3.

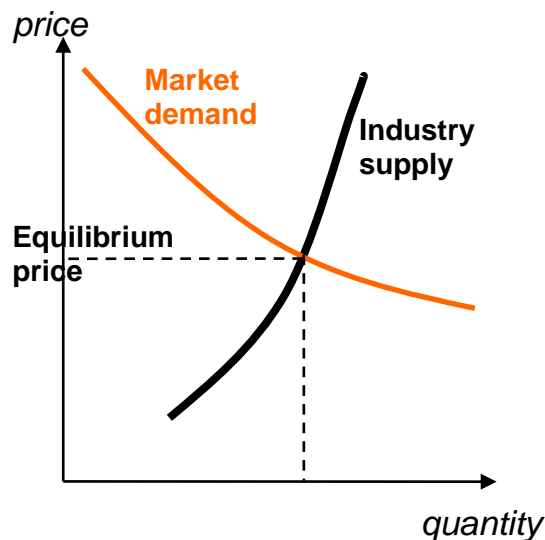


FIGURE 3: Short-run market equilibrium in competitive markets

TEXTBOOK EXTRACT

How is the long run different from the short run? It is still the case that the optimal production decision of any company is defined by the “price equals marginal cost” condition. But now we have an additional force to reckon with, and that is free entry (and exit).

If market prices happen to be above the average cost of production in the short run (which can easily be the case), then companies are making positive economic profits (in other words, they have above-market rates of return on invested capital). This will attract more capital to the industry, new firms will enter, and the industry supply curve will become flatter, bringing down the equilibrium market price and overall profits.

Entry will occur up to the point where rates of return become normal again, yielding zero economic profit. At this point, average costs will be minimal and will equal the long-run market price. Companies will produce at the efficient scale (with the lowest per unit costs possible). The long-run equilibrium number of companies will be determined by how many firms it takes to satisfy demand at the long-run market price, given that each firm produces at its own efficient scale of production.

Competition and welfare

Why do we think that free market competition is generally a good way of organizing the provision of most products and services that people in a society would like to consume? In order to answer this question, we first have to define how we understand “good” and “bad” from an economic point of view.

The definition of welfare

We use the idea of *social welfare* to describe the aggregate well-being of consumers and producers in a given market. What is welfare composed of? The two main ingredients are *consumer surplus* and *producer profits*.

Company profits are easy to understand: we deduct total costs from total revenues. This is the amount that shareholders of the company earn as capital income. The higher the profit, the higher the income of the shareholders.

Consumer surplus, on the other hand, is somewhat more difficult to grasp. We try to measure it by the difference between what consumers are willing to pay for a product and what they actually have to pay for it. Willingness is measured by the demand curve, as we have discussed before. What people have to pay is, of course, the market price. Therefore, consumer surplus is nothing but the aggregated difference between the reservation prices of different people who buy the product or service and the market price they pay for it. This is depicted by the shaded areas in Figure 4 for the two separate demand functions in Figure 2.

TEXTBOOK EXTRACT

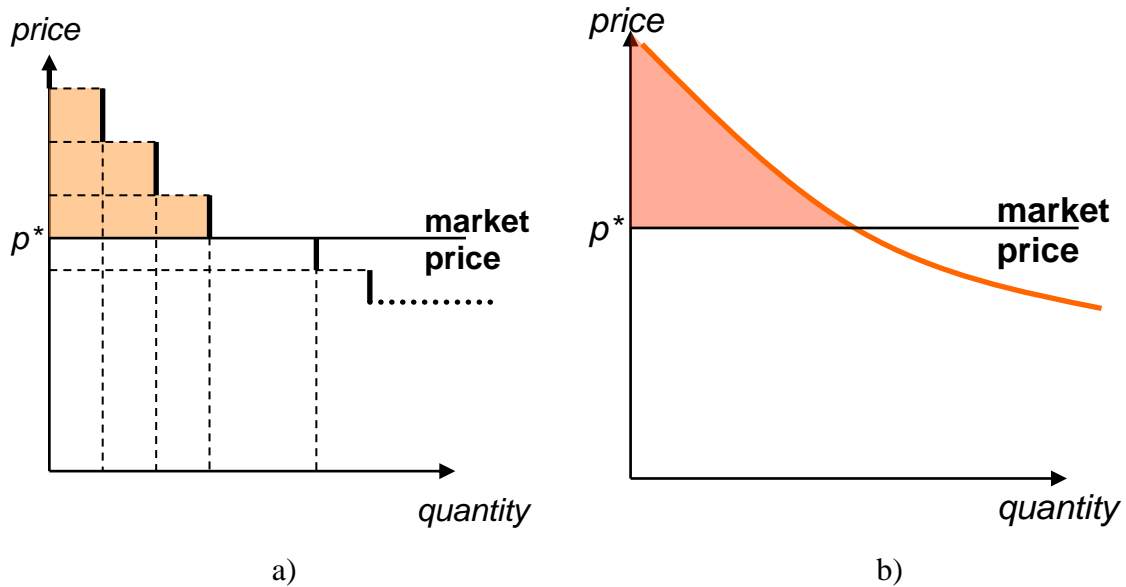


FIGURE 4: Consumer surplus with small (a) and large (b) quantities

Now we can put together the consumer surplus and producer profits to calculate total welfare in the market. We see immediately that the market price of the product does not factor in directly. When calculating the consumer surplus, we take account of the market price by subtracting it from reservation prices. From another point of view, we aggregate the reservation prices of people (the whole area underneath the demand function) and subtract the total expenditures of people (market price times the quantity consumed).

However, total expenditures of consumers (counted as a minus in consumer surplus) equal total revenues of the companies (counted as a plus in producer profits). When we add up the two, expenditures (i.e. revenues) cancel out.

Therefore, total welfare in a market is nothing but the aggregated reservation prices (willingness to pay) of consumers minus the total cost of producers.

Welfare and efficiency

Social welfare, by our economic definition, encapsulates the benefits of a market to the society. It is reasonable to increase this benefit as much as possible.

Let us suppose that we are in a situation when there is some consumer who would be willing to pay more for another unit of the product than what it costs to the firm to produce that unit. What happens if the firm produces that unit and sells it to the consumer for some price between the consumer's willingness to pay and the extra production cost? Both the consumer and the firm would definitely benefit from such a transaction, and social welfare would increase.

Therefore, the situation we started with could not have been efficient, since we could make both parties better off by increasing production and harmed no one. We can also make the reverse argument, that a situation in which producing the last unit was more costly than the

TEXTBOOK EXTRACT

willingness of consumers to pay for that unit is not efficient and not welfare maximizing either (society would be better off by decreasing production).

As a result, we see that *efficiency and welfare maximization in a market require the lowest willingness to pay for a product (among those who purchase) to equal the (marginal) cost of producing another unit of the product in the industry.*

Efficiency of the competitive market equilibrium

In a competitive market, where both buyers and sellers are price takers, the market equilibrium implies the following two relationships.

- The market price is equal to the marginal cost of producing the next unit of output (as a result of producer optimization).
- The market price is equal to the lowest willingness to pay for the product among those people, who purchase (as a result of consumer optimization).

These two conditions taken together imply that the competitive market equilibrium situation is both efficient and welfare maximizing. We simply cannot do any better from a social welfare point of view than letting the market work unhindered.

Investment incentives

We have seen how market prices coordinate consumption and production activity in such a way that an efficient and welfare maximizing outcome is reached in the short run. In this section, we will also show another role for market prices: that of investment signals.

The basic idea is a very short one to state. When prices go up (as a result of an increase in demand, for example), companies earn more revenue and therefore more profit as well. Higher profits mean higher returns to invested capital, which the capital markets will notice.

As a result, more capital will enter the sector in the form of new investment and new firms. The increase in demand will be followed by an increase in supply, bringing down prices once again to the level that provides a normal return on investment.

TEXTBOOK EXTRACT

MODULE 2

SUPPLY AND DEMAND CHARACTERISTICS OF ELECTRICITY

Module 2 describes the two main forces of a market for electricity: supply and demand. We will discuss technical and economic features of power generation both from a short and a long term perspective. We will study the characteristics of electricity demand with special emphasis on its price responsiveness.

Basic features of electricity supply

Electricity is mostly used as an intermediate product that helps to produce final consumption goods (cars, computers) and to create useful services for people (heating, lighting, driving the electric engine of the washing machine). Because electricity provides useful services for them, people are willing to pay for getting it – or in economic terminology we can say that there exists a *demand* for electricity. The major features of electricity demand will be discussed in the next section.

However, in order to meet the demand for electricity, someone has to put substantial resources (money, machines, working time, etc) into *producing*, or as we will call it, *supplying* this particular product.⁴ These resources can not anymore used for other purposes at the same time, that is, all other alternative uses of these particular resources are given up in order to produce electricity. This is a case when we say it is *costly* to produce electricity.

Also, a significant *investment* is needed to put a specific physical infrastructure, the electricity transmission and distribution network into place to transport electricity from the place of production (generation) to the specific places where it is consumed (load). Network related issues will be dealt with in a subsequent section.

In this section we will concentrate on understanding the supply characteristics of electricity generation. Since the demand for electricity varies in space, time and quality, supply has to be able to meet these variations in need. The producer should be *willing* and *able* to produce so that it meets demand. We will assume that the supplier is willing to produce only if it is paying off to do so (that is, generation does not produce permanent losses).⁵ While the producer might be willing to supply, his/her ability might still be limited by technical constraints (lack of fuel, capability of a generator to accelerate within a given time range), so it is important also to understand the basic technical characteristics of electricity generation.

⁴ While the meaning of the term *production* is almost identical to that of *supply* here, we generally refer to the former when describing the physical process of producing an economic good, while supply refers to the economic conditions of meeting demand.

⁵ More precisely we assume that producers are motivated to maximize their profits.

TEXTBOOK EXTRACT

In our analyses we distinguish between *short term* and *long term* electricity supply. In the short term case we assume that a given generation capacity is already in place and it can not be modified within the scope of our analysis, e.g. through investments. The producer can only decide whether it operates or not, or to what extent it uses the given capacity. In the short run the capacity is fixed and it has a binding capacity constraint. This is the typical situation for intra-day or intra-week operations of an electricity system.

In the long term analysis we allow for investments to take place so that generation capacity becomes variable. In the long run suppliers do not only optimize the use of an already existing generation capacity but rather decide on the optimal level and composition of generation capacity and its operation.

Electricity as a product

Producing electricity is essentially converting some primary energy source into electric energy with a given rate of efficiency (heat rate). The primary energy source can be fossil (e.g. coal, oil, gas) or nuclear fuel or renewables (e.g. wind, solar, hydro, geothermal). Besides its fuel base, the most important characteristic of electricity generation is the efficiency by which the original heat content of the fuel is transformed into electric energy.

The conversion is made by the use of some equipment that we call generating capacity. The unit of this capacity is measured in megawatts (MW). One MW of capacity has the option to produce 8760 MWh of electricity a year, thus capacity can be transformed into a flow variable. This will be important when we try to measure the costs of generation. Generating capacity is created by investment.

The efficiency of fuel conversion will largely depend on the type, age and operation mode of a generation technology (think of your car compared to others'). Low efficiency means that a large proportion of primary fuel is wasted during the conversion process, so it is apparent that efficiency has a major impact on the economics of electricity production. Table 2 provides estimates of average efficiency of electricity generation by type of fuel/technology.

Year of build	Gas- or oil-fired thermal unit	Coal-fired thermal unit	Gas- or oil-fired gas turbine (SCGT)	Combined cycle gas turbine (CCGT)
1960	32%	30%		
1970	34%	32%		
1980	36%	34%	25%	
1990	38%	36%	29%	45%
2000	40%	38%	31%	50%

TABLE 2: Net thermal efficiency parameters for power plants built in different years
Source: KEMA Consulting (2005)

The costs of electricity production and the short run supply curve

The resources needed and thus the costs involved for supplying electricity falls into two broad categories. The first is connected to the investment activity to create the generating capacity. Here the capital that is most needed to purchase land, equipment and workforce to put the unit

TEXTBOOK EXTRACT

into place. Once the investment is made, the capital is to be paid back with a sufficient return on it. The second category of resources are needed for the operation of the generation unit.

Let us start with assuming that we already have our generation capacity in place. It is useful to divide the *total cost (TC)* of generating with this capacity into *fixed costs (FC)* and *variable costs (VC)*. Fixed costs are those that do not change in the short run and do not depend on the level of production. For example, capital and interest payments to the lending bank is a typical fixed cost. But in the short run, operating and maintenance, wages and even social payments might have a fixed cost characteristics. We call variable costs those cost elements that depend on the level of production. For electricity production the most important variable cost is the cost of fuel (except for renewable generators).

Since a producer does not have any control over fixed costs in the short run (they are to be paid anyway), these costs will not influence his short run production decision. The producer's question to be answered is whether the additional revenue from producing one more kWh (marginal revenue) will exceed the additional cost of producing the additional kWh (marginal cost). If the answer is yes, the producer will be willing to produce.

In most cases, the marginal revenue for the producer equals to the regulated or market price of electricity and it is relatively easy to get this information. But as we have seen before, the other crucial variable on which the production decision depends is the marginal cost of generation. Let us now have a closer look at how to derive this information.

We assume that the only relevant variable cost is fuel cost and we also know that electricity production is nothing but fuel conversion with a given rate of efficiency. Thus what we do is costing fuel conversion into a short run marginal cost of generation. For example in the case of gas based generation, we take first the unit cost (in \$/m³) and the heat content (in GJ/m³) of gas. We can estimate the amount of kWh that corresponds to a 100% efficient conversion of the heat content and can adjust with the estimated efficiency to arrive at a marginal cost estimate. Assuming, for example, a 234 \$/1000m³ gas price, a 31.736 MJ heat content for a cubic meter of gas⁶ and a 50% efficiency rate for a relatively modern CCGT plant, we arrive at a 53 \$/MWh marginal cost for generation.⁷ Now, if the producer can get \$53 or more when selling this unit, he might be willing to produce it.

If we put generation units into an increasing order by their marginal production cost, we arrive at a stepwise electricity *supply curve* (often also called the *merit order curve*) for the given generation park, as in Figure 5.

⁶ Under these conditions 1 m³ of natural gas contains 8.816 kWh of energy.

⁷ The marginal cost estimate arises from the following equation: $MC = 0.234 \text{ [$/m}^3\text{]} / 31.736 \text{ [MJ/m}^3\text{]} \times 3600 \text{ [MJ/MWh]} / 0.5 = 53.09 \text{ [$/MWh]}$

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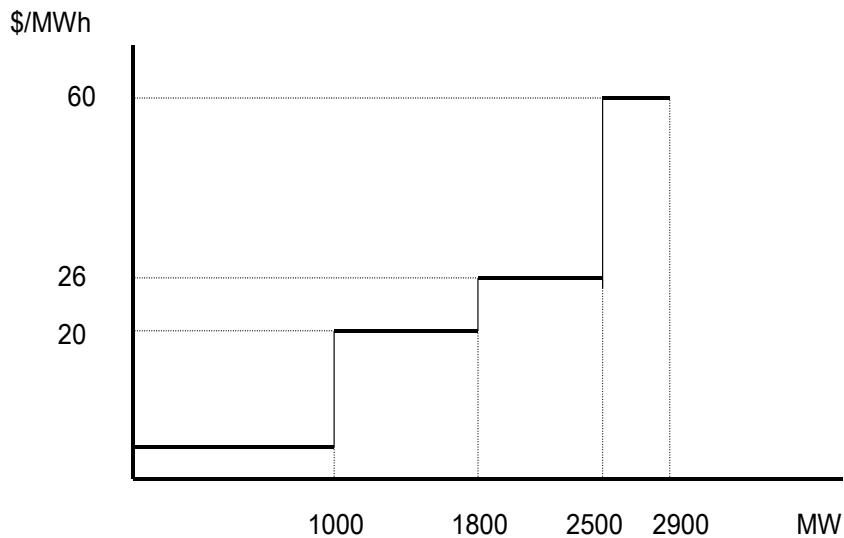


FIGURE 5: Example for a merit order curve of a generator park

The curve illustrates that at a price lower than 4 \$/MWh there will be no producer on the market. Also note that even at an infinite price, this park can not generate more than 2900 MW: this is a binding capacity constraint in the short run.

The next figure illustrates in a more general setting how the interplay of demand and supply sets the market price under competitive short run electricity market conditions. Note that under these conditions all generators are paid the market price that is set by the “marginal” generator. Note also that low marginal cost generators that are mostly characterized by larger fixed costs are allowed by the market mechanism to recover their fixed cost.

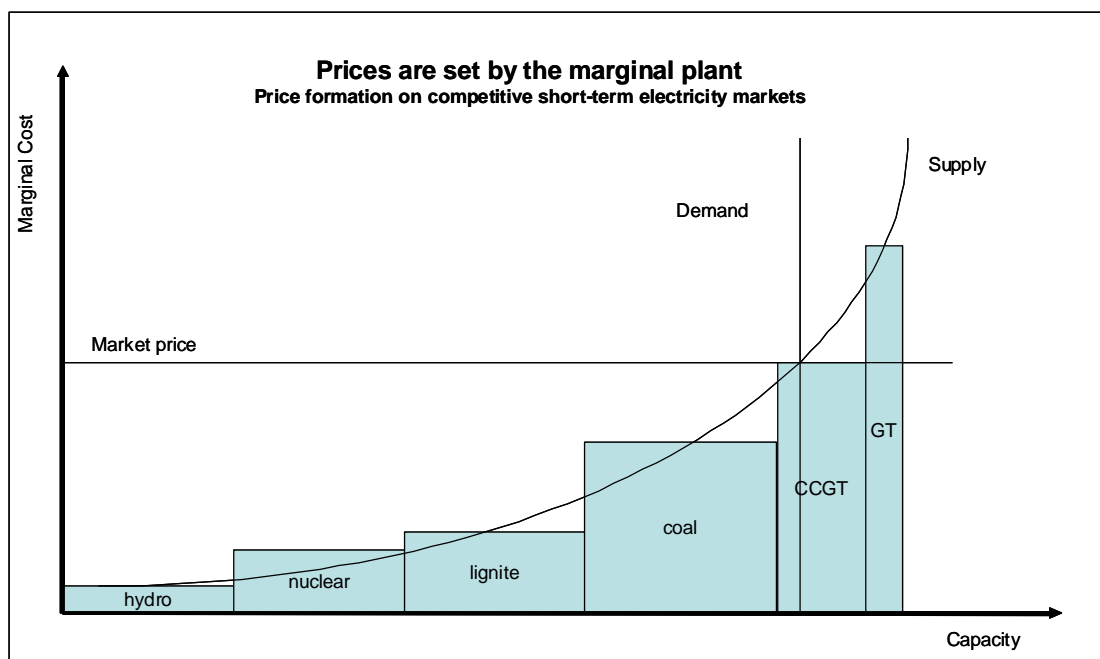


FIGURE 6: Determination of the market price

TEXTBOOK EXTRACT

Because of the fuel conversion nature of electricity production, it is also common to compare electricity market prices to fuel prices expressed in \$/kWh terms. The difference between the electricity market price and the \$/kWh gas price is called **spark spread**. The difference between the electricity market price and the \$/kWh coal price is called the **dark spread**.

Using the above concepts, it is possible – after detailed data collection – to construct estimated system marginal cost curves for existing electricity systems. Figure 7 illustrates the results of such an effort for selected Central and Eastern European countries.

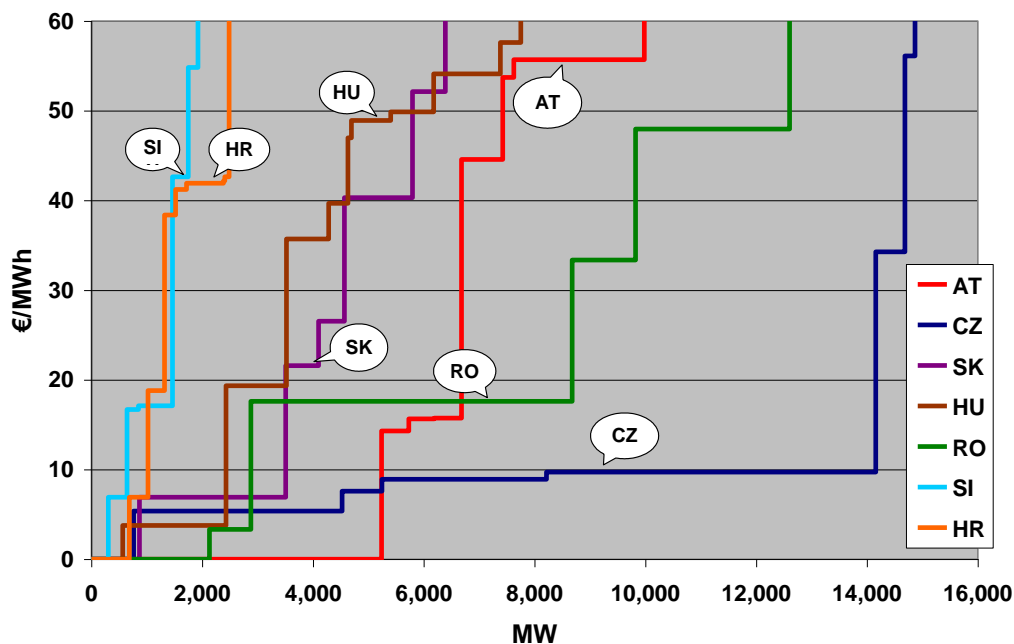


FIGURE 7: Regional merit order in Central and Eastern European countries
Source: REKK (2006)

The long term and the costs of investment

Certainly, capacity constraints are getting less binding as we extend the time frame for our analyses. Capacity can be expanded over time by investment. There is no even a thing like fixed cost in a long term analysis: all costs are becoming variable.

In the long term the question for the producer also changes. Beyond the short-run question of “producing or not producing”, a more strategic issue arises: should I expand my capacity? If yes, what size of generation asset should I build and on what fuel?

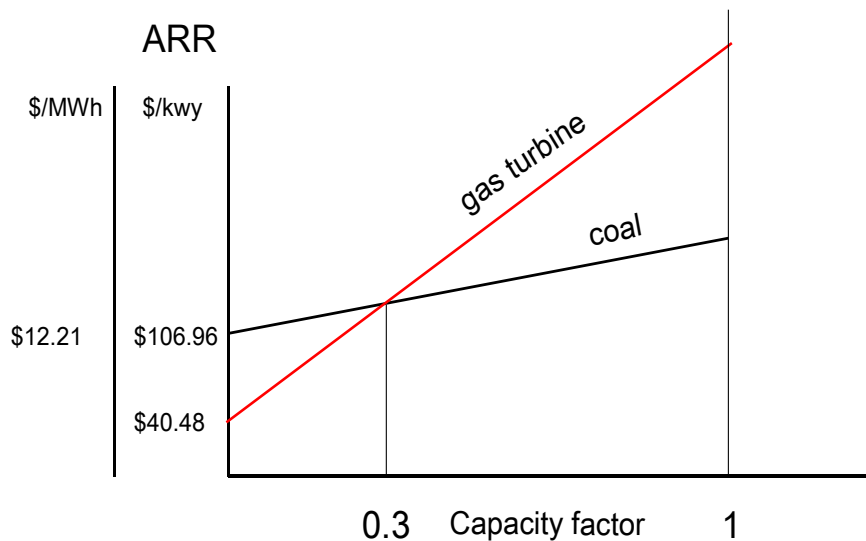
To answer such a question is a really complex task and a detailed discussion of the topic is far beyond the scope of this textbook. The investment decision will depend on several factors, including fuel costs and availability, site, market environment and regulatory stability and a hundred other things. What we discuss in the followings is a simple tool, called the *screening curve*, to compare investment alternatives that are different in their cost structure. We will illustrate its use for comparing a gas versus coal based investment option.

TEXTBOOK EXTRACT

In order to do that, we need some additional information to short run marginal cost. In particular, we need information on the cost of creating the capacity. We will call the lump sum upfront payment to construct the capacity as the *overnight cost of capacity* (as if it was built during a single night). We will also use the concept of *capacity factors*. It is the percentage of the 8760 hours of a year when the generation unit is used (or expected to be used, when we are planning an investment).

Let us now turn to the following example. Assume that the overnight cost of a kW of gas generation is \$350 as compared to \$1050 for a more capital intensive coal unit. However, while creating a coal-based unit is more expensive, operating it is cheaper than gas generation. In order to be able to compare the two alternatives, we first have to translate the overnight costs into annualized fixed costs. We do this by applying a discount rate and utilizing information about the expected life time of the compared units.

After translating the overnight cost into fixed cost, we draw the screening curve (or the total cost curve). It becomes apparent that it is worth to invest into coal as opposed to gas only if the expected capacity factor for the new unit will be at least 30%. If the expected capacity factor is below this value, it is more economic to invest into a gas based unit.⁸



$$\text{Annual Revenue Requirement: } ARR = FC + cf \times VC$$

FIGURE 8: Screening curves for a gas turbine and a coal-based unit

The use of the screening curve in the above example might give a hint on why coal plants are more frequently applied in base load mode while gas plants are used more often as peak generators.

⁸ Try to explain, why this is the case!