

Congestion and Peak load pricing: a comparison in electricity and transportation¹

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Abstract: Prices signal the scarcity of resources on the market and produce their efficient allocation. Given the level of high fixed costs characterising most public utilities (electricity and transport are no exemption to this) there is a strong case for a discriminating use of prices. The demand for public utility service varies periodically and its management constitute the core of the peak load pricing problem. A fundamental aspect of peak load theory is the specific object of pricing. We assume that peak load implies pricing for the use of scarce resource capacity in production, whereas peak load for the use of a network, that is congestion charging, is aimed at the internalisation of external costs. In the case of transport we might adopt, for example, peak load pricing for the management of excessive bus demand and use congestion charging to internalise the external costs imposed by private transportation. In the electricity sector peak load pricing might be used to manage the excessive power demand while congestion pricing is just a part of the transmission pricing mechanism that has to be complemented by electricity losses charging. In the case of transport the two problems overlap since production and transmission coincide.

¹ Even if the paper presented is the result of a common effort, E. Marcucci has written paragraphs: 2.1, 3.1, and 4.1 whereas P. Polidori paragraphs: 2.2, 3.2 and 4.2

1 Introduction

Prices signal the scarcity of resources on the market and produce their efficient allocation. However, in many cases, especially for public utilities, market fails. In fact some of the fundamental hypothesis that should be satisfied are not as it is for the natural monopoly characteristics of some networks (i.e. rail for transportation and grid for electricity). Furthermore, the pricing mechanism will not work properly as a supply and demand co-ordinating instrument if those who do not pay for consumption are not excluded. In these cases prices may assume the characteristics of a tariff assuming the need for public intervention.

Given the level of high fixed costs characterising most public utilities (electricity and transport are no exemption to this) there is a strong case for a discriminating use of prices. However, since most public utilities are called upon to provide a universal service for the community, charging one single price for the same good (even though produced in different cost conditions) will imply a decision between the allocation of capacity costs and price discrimination. One way to tackle the problem

is to charge the extra costs imposed for the production to those who are directly responsible for it.

The demand for public utility service varies periodically and its management, given an optimally sized plant capacity and the corresponding investments and costs, constitute the core of the peak load pricing problem.

A fundamental aspect of peak load theory for this paper is the specific object of pricing. We assume that peak load pricing means pricing for the use of scarce resource capacity in production, whereas peak load pricing for the use of a network, that is congestion charging, is aimed at the internalisation of external costs. In the case of transport we might adopt, for

example, peak load pricing for the management of excessive bus demand and use congestion charging to internalise the external costs imposed by private transportation.

In the electricity sector peak load pricing might be used to manage the excessive power demand while congestion pricing is just a part of the transmission pricing mechanism that has to be complemented by electricity losses charging.

The definitions proposed have more a theoretical than a practical value since, in both cases the two phenomena subjected to the pricing mechanisms interact. In fact, one might consider the congestion problem as deriving from an excessive demand for network capacity.

Therefore, peak load pricing and congestion charging would be treated in the same way, that is with the aim of defining a system of prices in order to optimise the overall use of a given system capacity.

In the electricity sector in Italy, as it has been for many other countries (Percebois, 1997), production has been characterised by the presence of only one producer and by government imposed tariffs that have been, recently, slightly

differentiated according to time periods. The production sector is likely to open up to competition and, probably, a market based price system with the implementation of an energy spot market will substitute the present tariff system. The transmission network will remain under public regulation. Therefore, especially for this last aspect one has to expect the implementation and evolution of a peak load pricing mechanism. Whereas the production aspect in the electricity sector is governed by laws influenced by the different efficiency of production plants, the transmission aspect, on the other hand, is much more directly correlated to the problem of traffic congestion similarly to what happens in the

transportation sector. For this reason, an in depth analysis of peak load pricing models will be conducted with particular reference to congestion charging in transportation and electricity. In practice, the comparison between the two sectors will be made through the analysis of the respective network characteristics and on what happens when the demand saturates capacity.

As it is for transportation, we will primarily focus our analysis on the private mode of transportation in the urban context essentially because this restriction will give us the opportunity of concentrating our attention on a specific mode that, due to his peculiar characteristics, resembles more closely the functioning of electricity transmission. We will only marginally tackle the problem of pricing co-ordination among modes that would automatically have to be taken into account when considering a multi mode environment.

The most simple formulation of the peak load problem is presented in the Boiteux (1956) public pricing model which classifies the demand in different periods as the demand for different goods so to be able to treat it independently of time. The peak load problem becomes a special case of joint production and the optimal input choice allows us to find a price that optimises the operating and capacity cost mix. However, as it has been recalled, reality is much more complicated and more realistic assumptions are needed to model the peak load pricing problem. Some, among the most relevant adjustments, are the following: time dependent demand functions, profit and capacity constraints, form of the cost functions (fixed variable technology proportions), etc.

Significant research in this sector (Crew-Kleindorfer, 1979; Mitchell-Manning-Acton, 1977; Turvey-Anderson, 1977) has demonstrated the need for more realistic hypothesis calling for the development of a "special theory" of peak load pricing. Bös (1994) refers to the peak load trilemma that consists in answering the following issues: 1. The proliferation of different prices for the goods/services produced implies an increase of information and administrative costs for the government and greater uncertainty for consumers; 2. Distributional aspects foster the adoption of relatively low peak prices; 3. Government wants to meet all the demand due to the reliability characteristics of the public goods/services supplied.

In Italy different network charging schemes have been proposed and discussed both for the transportation and electricity sectors, however very little has been done on the practical level. What has been implemented is mostly ascribable to the external constraint imposed by the European directives concerning liberalisation of and competition in network systems. Under this respect one can notice that the difficulties evidenced in the trilemma posed by Bös are at the base of the limited development of pricing schemes. Only through institutional *stimuli* it will be possible to fasten the network systems management and proprietary reform process. From this point of view one witnesses, in Italy, a substantial delay in the transportation sector with respect to electricity which is mainly explicable by two partially interrelated factors: 1. Different

market structure that has favoured, in the case of electricity, the ongoing process of reform; 2. Presence of a regulatory Authority that has allowed a more centralised management of the tariff structure updating process.

In the next paragraph the main characteristics of the two networks will be described to pass on, in paragraph 3, to the analysis of the most relevant aspects of the peak load pricing problem in the two sectors. Paragraph 4 presents the main charging models usable to manage demand peaking in presence of network capacity constraints. Conclusive reflections are proposed in paragraph 5.

2 Network characteristics

2.1 Transport

Focusing on a unimodal system will implicitly exclude all the issues pertaining to tariff co-ordination and harmonisation among modes. One has also to make clear which is (are) the mode(s) considered since railway transportation, for instance, gives rise to problems that are completely different from those pertaining to other modes of transport especially if recognising that network functioning and organisation has a lot to do with the prevailing market structure involved. For example, while railway transportation is intrinsically linked to the problems originated by natural monopoly, bus transportation is connected to the oligopolistic or imperfect market competition, while private car transportation can be assimilated to atomistic and decentralised competition.

In the short run, an equilibrium model for urban transport networks with elastic demand may be subject to two forms of constraints: physical and/or environmental. Whereas the second is dictated by the environmental local sensitivity the first one is set by the maximum traffic volume that can be efficiently accommodated by the given structures. The capacity values are determined by the greatest flows that might ensure a good behaviour of the transport network. Traffic network as well as environmental and risk characteristics have strong repercussions on the conditions that allow for the existence of a network equilibrium to develop while avoiding the transpassing of maximum capacity values.

When the analysis focuses on the long run, the considerations concerning the potential repercussions of a network enlargement on the congestion costs arising from the manoeuvre become of critical importance. In fact, while without congestion travelling cost does not vary with the level of traffic flow, as long as road users tend to choose the cheapest route (in terms both out of pocket costs and direct and indirect - time input- costs), the construction of a new uncongested road should not increase the overall total travel cost. Braess has shown that this is not automatically true in the presence of congestion. He also showed that a new route may, indeed, be socially undesirable since it provides an increase in the travel cost for all users. Braess' paradox arises when users, subject to the average cost price mechanism adopted, chose according to their personal cost functions socially undesirable routes. The paradox vanishes if the pricing mechanism used

implies a payment according to the social marginal cost of travel. It has been showed that "... Braess' paradox is nothing but a special case of a general class of situations classified in the economic literature as external economies and diseconomies which are known to lead to market failure .." (Alperovich, 1997)

The existence of such a paradox in practice might undermine all the effects that we can reasonably expect from a marginal cost pricing scheme. If we accept the idea that when congestion sets in land ought to be considered a scarce resource that has to go to the highest bidder, then the quantity of land used for roads and the price charged for it should simply be determined by what people are prepared to pay for that use. In other words, the idea is that pricing for scarce resources (streets) should be at the base of demand rationing thus allowing an increase of the speed achievable on the network. Those that are priced off the road have to face a trade off between accepting to move with an inferior quality mode (public transportation), change destination or else renounce to move altogether. The relevant aspect in the resource allocation process is the excessive use of the resource giving rise to congestion. This leads to slower speed than it would be possible if an optimal road price were charged. It might appear to be economically convenient to increase investments in road capacity improvements more than it would be the case (Friedlaender, 1981). A question posed by Mogridge revolves around the process of causality in decision making. He asks a question concerning the reasons that might justify a certain speed of a given congested road system. Whereas the common answer to this question had so far been that the equilibrium is determined by the meeting of the supply curve, average private cost, and the demand curve, Mogridge affirms that "... the speed at which one will find the traffic operating is set by a simple equilibrium mechanisms between car-journey speeds and the speeds achieved on the mass transit network.." (Mogridge, 1986). This position is backed up by practical considerations concerning the effective functioning of a road network and contrasting it with the hypothesis adopted in simulating network functioning. Mogridge bases his analysis on the classical "Wardrop's principle" that "... the journey times on all the routes actually used are equal, and less than those which would be experienced by a single vehicle on any unused route or ... the average journey times is a minimum" (Wardrop, 1952). Using shortest-path algorithms will then determine the optimal routes in the network while, through the assignment process one can determine the O-D flows and the link flows. Further refinements have demonstrated the necessity of additional hypothesis to determine a convergent and unique equilibrium point (Evans, 1976). Travel demand should fall with increasing costs of travel and travel cost should rise at an increasing rate with increasing flows on links. The increasing of travel cost at an increasing rate with increasing flow on links that might, ultimately, lead to infinity, while speed approaches zero at a finite capacity of a link represents a standard hypothesis. Nevertheless, this is not realistic in a congested urban environment since car-following

theory referring to driver's behaviour demonstrates that the maximum flow takes place at half the free-flow speed without drivers interaction. Further traffic concentration, up to a bumper to bumper situation, provoke further speed reduction until both speed and flow fall back to zero. (Ashton, 1966,). Since "... The calculation of an equilibrium assignment in congested urban conditions is thus based on an unsound hypothetical base ..." (Mogridge, 1986) the traffic analyst, before considering the total jamming of traffic flows, has to consider the alternatives available to travellers in congested situations. More specifically, one has to consider the change in modal split, the change in destination, distribution or change in trip generation so to maintain the model within the range of validity of the hypothesis. The perspective change suggested by Mogridge lead us to reinterpret the pricing approach attributing to it not only the rationing function (excess demand) but the redistribution function among modes. Therefore, one should explicitly consider the influence road user charging will have both on private as well as public transportation.

2.2 Electricity

In the case of electricity, the system is in equilibrium only if, at any one time, total electricity injection and collection flows are in balance and the energy transmitted on each line is smaller, or at least equal, to its maximum capacity. The equilibrium in an electric grid implies that the whole system has to be dynamically in equilibrium and it is rare to observe exchanges between producers and consumers where energy paths follow financial contracts or bilateral agreements. In case of imbalance serious and dangerous blackouts might occur.

A power grid can be imagined as a system where generators and consumers inject and collect energy but its physical path is different at any one time with the variation of supply and demand. A further complication is due to the capacity constraints of some lines. The use of more efficient plants could be limited simply by the physical characteristics of the grid and, even more important, these constraints change dynamically with variations in supply and demand. Such a system could be managed with difficulty but the development of powerful information technologies has increased the spectrum of electricity grid management and control possibilities providing an opportunity of competition in generation.

The problem is not only technical but also economic especially considering the evolution towards competition common to many national electricity sectors (Zaccour, 1998). In fact, in a vertically integrated monopolistic industry under public ownership the problem of having more efficient plants used first to supply energy is less stringent than in a sector under competition. In the former situation, all the decisions concerning investments in new plants are taken by the monopolist hopefully with the idea of adding capacity to minimise the total production cost. In a liberalised sector, system externalities could no longer be controlled and the strategic decisions of producers and consumers, even though efficient on a personal level, might no longer be so for the system as a whole².

In this context, transmission and dispatching management as well as transmission price fixing become important.

Transmission and dispatching are two different phases of a joint process which might or might not be integrated. Dispatching is the allocation of energy flows on a grid selecting the available plants according to energy demand. With demand fluctuations the technical problem becomes that of dynamic optimisation for the joint use of plants and system. This is true because demand varies with time and the electricity supply may also change because of plant and line malfunctioning. These technical problems arise owing to the physical laws that govern the processes of energy transmission. Electricity moves on the grid following Kirchoff's laws, according to which energy is distributed along the electric lines presenting the least resistance (depending on the distance among different nodes and on the physical characteristics of the system). As shown in fig.1, in a simplified network (with only three lines and similar technical features all over the system), energy flowing depends on line length and resistance. For example, in a system without electricity transmission losses, to transmit 900 Mega Watt (MW) of power from node 1 (nodes 1 and 2 are producers) to node 3 (consumers) a transfer of 600 MW will take place along line 1-3 and 300 MW along lines 1-2 and 2-3, under the hypothesis that all the lines in question are equal in length.

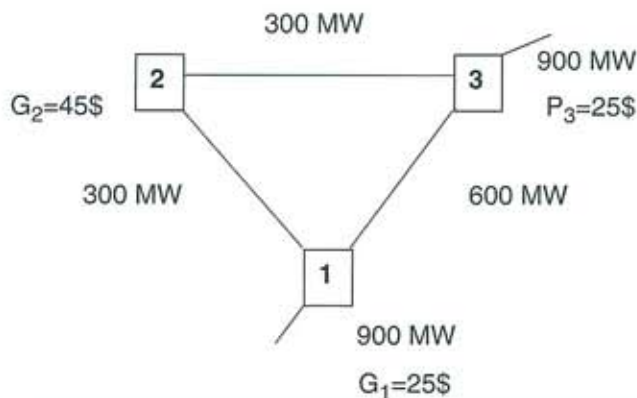


Figure 1: simplified energy network

Therefore, in an electric network, free from lines capacity constraints, energy flows depend on lines resistance that it is not necessarily correlated to its ownership or to the characteristics of the supplying contracts. The difference between the free flow path and the contract one is called the "loop flow" which is characterised by the circulation of power creating inefficient utilisation of the available capacity. Usually a loop flow involves two or more utilities (or districts). Each is supplying its own loads from its own sources, but the actual flow on the system from the combined operations results in the use of transmission in other systems in such a way that there is an apparent circulating power flow around a closed loop (Hingorami, 1996, Casazza, 1996). Loop flows are often jointly determined by limit capacity constraints and Kirchoff's laws.

As an example of what the effect of this joint action could be suppose that in fig.1 line 1-3 has a maximum capacity of 600 MW. With a demand at node 3 equal to 900 MW (as in the example) it is possible to satisfy the request with all the power produced by generator 1, the most efficient given that its generation price is equal to $G_1=25\$$. If demand rises at 1800 MW Kirchoff's laws and the capacity limit on line 1-3 allows only to supply the energy requested if all the power is now generated at node 2 with energy flows equal to 1200 MW along line 2-3 and 600 MW on lines 2-1 and 1-3. However, plant 2 is less efficient than plant 1 ($G_2=45\$$) and this inefficiency is simply due to technical limits (congestion) of the system and not to managerial or economic malfunctioning. The situation is complicated if transmission losses are considered. In fact in order to adequately price transmission it is necessary to assign losses to the subject which generates them. And because losses depend on the path electricity follows it is necessary, to reach efficiency, identifying dynamic models of pricing that incorporate the dispatching procedure.

3 Peak Load pricing in Electricity and Transport

3.1 Transport

Following the approach outlined by Glaister (Glaister, 1974) we will concentrate on the peak load problem generated in the provision of public bus transportation services even if the work of Keeler and Small (Keeler & Small, 1977) testifies that the peak load problem is also deeply rooted in the debate concerning pricing and investment policies for the provision and use of urban roads. Glaister, by widening the pricing perspective so to include public transport as well, allow us to clarify the distinction that can be made between the peak load pricing and congestion pricing approaches in transport.

Peak load pricing is mainly adopted to deal with shortages of capacity (bus capacity in our case), whereas congestion pricing is more directly related to the social problem of congestion (external cost)³. Congestion problem is aggravated by the peaking of demand for public transport, unless public transport services are completely produced within reserved lanes that are subtracted from private transportation use. In this case the two aspects could be considered completely separate since there would be no interaction between the two modes. However, even though there is a generalised tendency to operate public transportation within dedicated lanes in order to improve its speed, reliability and quality, it still seems unrealistic to assume zero interactions between the two modes.

The justification for limited bus capacity might be explained either by the limited capability of directly borrowing the funds needed to finance the operations. This might be so if, due to large operating deficits, the public decision makers opt for under investment or else because the various institutional, contractual or governmental problems might prevent the acquisition of the necessary labour inputs needed to operate the system at its best.

A more general approach compared to that proposed by Williamson (Williamson, 1966) has to deal with the demand interdependency through time as well as with the fact that the achievable output is also linked to the level of congestion. The number of peak bus journeys supplied cannot exceed the available road capacity which, in turn, depends also on private peak traffic, while there is no such a capacity constraint in the off-peak periods. The off-peak price will generally be set lower than the marginal cost in order to move some public and private peak demand towards the off peak public mode. The desired effect is a reduction of congestion so to free capacity. In the case of interdependent peak load problem the usual conclusion, relating to the off peak prices set equal to marginal operating costs while fixing peak prices at the level assuring an equilibrium between demand and available supply, do not necessarily hold. In fact, when private congestion interacts with public peak load production of bus services, it might become convenient to attract not only public but also private peak travellers in the less congested modes and times that is in the peak and off-peak busses. This might be achieved by an appropriate fare policy that could imply lowering the off-peak fare further and to lower the peak one as well in order to induce peak car users to take the bus. However, given the knowledge of the price and cost elasticities of demand there is no *ex ante* justification for the common policy recommendations suggesting to impose high prices in peak and marginal cost pricing in off peak.

3.2 Electricity

The main experiences of electricity peak load pricing are in the field of generation while the use of dynamic transmission pricing systems is less developed. Differences between transport and electricity sector are less evident in the transmission context.

When analysing generation peak load pricing it is useful to review three models of pricing: real time pricing and reliability pricing, and a third model of demand side management (DSM)(Pineau, 1998).

Under real time pricing customers pay the exact price of their consumption and energy is allocated according to willingness to pay. The use of these models involves several problems: high performance and high cost information systems are needed to provide a dynamic (real time) customer satisfactory service; customers need to monitor prices and adjust their consumption at any time; new metering technologies have to be installed; capacity shortages might occur if customers do not respond to price signals; load management is not instantaneous since it depends on customers reaction to prices.

Reliability pricing have significant advantages over real time pricing. The main advantages are: real time load management (as opposed to the other system which has only a delayed effect) and the possibility of different reliability levels for different proportions of customer supply. The price customers pay is based on the reliability level they choose. Energy is allocated according willingness to pay. Energy rationing is provided for every kind of shortage. Some of the problems

that might arise with this form of pricing mechanisms are: only a limited part of demand may be subject to interruption; customers lose control over some of their consumption and a cultural change is needed to accept that electricity consumption is no longer perfectly reliable.

With DSM systems the utility implements some efficiency education programs aiming for demand reduction by promoting the efficient use of energy equipment. These programs have an impact on the overall demand and not only on the peak alone. The main problems are: risk of decreasing sales during off peak periods if the DSM program is too effective; high investment costs; results are not directly visible and delayed.

Peak load pricing may also be applied to electricity transmission (what has been called dynamic transmission pricing) and, in the general debate, many contribution have dealt with the technical and economic centrality of the transmission and dispatching sectors (Percebois, 1997; Joskow, 1997; Joskow and Schmalensee, 1983).

Dispatching is the only sector which, due to its natural monopoly characteristics, should remain under public ownership, or, alternatively, should be subjected to a thorough regulation. Controlling energy transmission and dispatching implies influencing the electricity market strategically in such a way so to exploit the technical and physical properties of electric systems thus either favouring or penalising the construction of a competitive market in the generation sector (Joskow, 1997; Einhorn and Siddiqi, 1996).

Two main aspects of electricity delivering have to do with the transmission peak load pricing problem. These are the existence of congestion costs and energy transmission losses. In order to develop a mechanism so to foster an efficient use of the grid we need to develop dynamic pricing schemes, addressing all the dispatching issues, so that each user will be charged for the use of the network comprehensive not only of the congestion generated but also of the relative power losses. This last kind of pricing scheme will be considered in the following paragraphs and will be presented as the peak load pricing possibility that has more similarities with dynamic pricing in the urban private transport sector. In this respect it will be possible to verify that many implementation difficulties typical of transportation apply to electricity as well.

4 Which sort of pricing for what kind of congestion?

4.1 Transport

Professor Vickrey (Vickrey, 1963) recalls that "... in no other major area are pricing practices so irrational, so out of date, and so conducive to waste as in urban transportation". We will elaborate on this statement by arguing the need of changing the use of road infrastructure at the margin rather than on average. The analysis of a pricing mechanism will be focused on its influence on the internalisation of congestion which is just one of the various externalities imposed by motorists. As it was recalled before when examining the Braess paradox, just increasing capacity is no solution to the excess demand for roads (Downs, 1962, 1992).

In the short-run, given that the number of trips taking place in a competitive market situation would generate congestion due to excessive demand, the quasi-rent generated by a road would be lost due to competition for public goods. To recover the quasi-rent of the public good the government has to behave as the profit maximising firm would in the case of private goods: it has to discriminate. One should divide all the fixed costs and allocate them according to use in the provision of transportation services. In the short run the efficient equilibrium is given by the point where the demand curve meets the short run marginal cost (inclusive of operating cost and variable road maintenance cost). In the long run a planning authority will evaluate network expansion (overlooking the sunk costs) just confronting the additional benefits and costs deriving from road building. Therefore community's benefits will be maximised by expanding the network up to the point where additional benefits just equal additional costs. In other words, road expansion might be convenient when the quasi-rent of the existing capital stock is greater than the normal market return on the costs of replicating the invested capital plus the maintenance and depreciation costs. In the case of roads, the variable component is given by time and operating costs and is self financed, whereas the non-use-related part has to be financed on a separate basis through toll congestion revenues.

Mohring (Mohring, 1965, 1970) showed that not only would marginal cost pricing optimise the short run network operation but also that the toll revenues generated would be just sufficient to cover the amortized costs of construction, maintenance and depreciation of roads under constant returns to scale in road construction, maintenance and use conditions. Short-run marginal cost pricing would therefore both guarantee long-run cost coverage as well as an optimised instrument for dealing with cyclical demand variations.

4.2 Electricity

From an economic point of view, the physical characteristics of electric networks are relevant since they affect price determination. Moving from a monopolistic and vertically integrated structure to a liberalised system is necessary to define a dispatching program that assigns flows on the network and determines transmission prices without distortions. Transmission prices should be comprehensive of transmission losses and congestion costs. Congestion costs are due to the use of less efficient plants because of capacity limits of some lines. These costs can be interpreted as opportunity costs due to system constraints. An efficient price system is needed to maximise social welfare and to supply an incentive system stimulating the efficient location of new generation plants and transmission lines.

Defining generation costs at node i as G_i , losses along line ij as L_{ij} and congestion costs on the same line ij as C_{ij} , the prices for energy consumption at node i and j will be:

$$P_j = G_i + L_{ij} + C_{ij}$$

and

$$P_i = G_i$$

The transmission price along line ij will be $L_{ij} + C_{ij}$ plus a certain amount for the system capacity premium⁴.

In the traditional vertically integrated networks the most commonly used transmission pricing system is the *postage stamp rate*. This is based on embedded costs of transmission service. The rate is equal to the utility's total book cost of transmission divided by the utility's peak load. This total cost is comprehensive of depreciation, return on capital and other capital-related costs plus operating and maintenance expenses. Postage stamp rates are a flat amount per KW and distance does not affect the price, nor do other location-related factors such as congestion costs in some lines of the network. Prices determined in this way have a poor incentive effect on the use of resources and on the location of new plants. Furthermore, as long as a single transmission price is offered for a wide range of market conditions at different times of the day, week and year, the price cannot be very sensitive and therefore is not suitable for an electric sector open to competition.

There are also some modified versions of postage stamp rates with changes introduced in order to differentiate the rate within the traditional embedded-cost approach thus trying to incorporate dynamic factors such as location, seasonal rate differentials and transmission services unbundling (Hughes and Felak, 1996). In any case these are only approximations of the real cost, insufficient in the search for efficiency in competitive contexts.

Any system suitable to manage energy tariffs under competition should fulfil four requirements (Hogan, 1992): a) maintain the system in equilibrium; b) reckon and control energy flows even in a delimited area of the system; c) supply all the necessary information to the regulatory Authority in order to govern the monopolistic situation; e) generate a tariff system reflecting production costs as well as congestion and transmission losses along the lines. There are two main models satisfying these requirements that are currently being debated in the literature. The first is *nodal pricing* originally elaborated by Schweppe et al. (1988) and developed with the name of *contract network* by Hogan (1992). The second model is due to Chao and Peck (1996) and is based on the definition and exchange of transmission property rights⁵. The two models offer different but converging solutions to the problem of transmission price definition in a competitive environment. Hogan suggests a tariff definition based on a two-step procedure. In the first, energy prices, comprehensive of losses and congestion constraints, are calculated at each node of the system. In the second, transmission prices are defined as the difference between energy prices at each node. The concept of contract network provides a mechanism for allocating long-term transmission capacity rights subject to maintaining short-run price efficiency. The Chao-Peck property rights approach explicitly incorporates the network externality impacts into the competitive trading mechanism.

The main idea of the model proposed by Hogan is that of defining a system of rules that automatically identifies a network of contracts through which transmission costs may

be associated to any energy transaction. The price at any node is obtained by the sum of the generation cost (equal to the cost of generation alone, if a generation plant is located in the same node, or, alternatively, equal to the generation cost of the plant supplying energy in that node), plus losses and congestion costs that can be referred to that node. Therefore, given that:

$$P_i = G_i + L_i + C_i$$

the transmission price TP along line ij can be defined as the difference between spot prices calculated at each node:

$$TP_{ij} = P_j - P_i = (G_j - G_i) + (\tilde{L}_j - L_i) + (C_j - C_i)$$

Since we can define the losses due to transmission along line ij as:

$$TL_{ij} = (L_j - L_i)$$

and congestion costs as:

$$TC_{ij} = (C_j - C_i)$$

we can also express TP_{ij} as:

$$TP_{ij} = TL_{ij} + TC_{ij}$$

which is true when $G_i = G_j$, that is in all the situations where along a single line energy is produced in one of the two nodes and consumed in the other one.

Spot prices determined in this way vary as a function of market demand and supply conditions. In fact, energy demanded at one node of the system, together with physical network characteristics, determines, on the one hand, which plants will be called upon to generate energy and, on the other, the energy paths followed. A shift in energy demand influences generation costs as well as transmission losses associated with that particular transaction.

In a system under competition, spot prices could be calculated using a two-stage process. In the first stage (as in UK) producers participate to a series of repeated auctions, at different intervals t (for example $t = 30$ minutes), where they bid for the energy supply and its relative price. At each interval t a merit order with the most efficient plants will be identified. These plants should be called to produce but technical system constraints need to be verified. In the second stage, the system operator dispatches energy and an out-of-merit order will be identified. Therefore, *ex ante* prices will be determined by production costs (known by generators) and *ex post* transmission prices by dispatching operations. With postage stamp rate tariffs on the contrary only *ex ante* prices exist because there are no contingent valuations correlated to demand and supply fluctuations.

The efficiency of the model proposed by Hogan relies upon powerful information technology systems, needed to calculate at any interval t spot prices (and therefore transmission prices) based on demand and supply variations.

In the Chao-Peck model similar results are obtained even though through a different procedure. The model defines the price for the use of congested lines. The main idea is that of associating lines demand (supply) to any energy injection (collection). In other words property rights are associated to lines. Following the example of fig.1 the transmission of 1 MW from node 1 to node 3 implies the consumption of transmission property rights equal to: 2/3 MW of line 1-3 and 1/3 MW of lines 1-2 and 2-3⁶. In the same way the generation of 1 MW at node 1 will imply the production of transmission rights equal to: 2/3 MW on line 3-1 and 1/3 MW on lines 2-1 and 3-2⁷. Power flow models are used to determine the available transmission capacity (24 hours a day, 365 days a year) of a particular system characterised by given reliability conditions. The rights to use the available transmission capacity are then sold to generators, distributors or retailers. Such rights could be directly used or traded to third parties for use. Chao-Peck demonstrate that if it is possible to have an efficient market for such rights it is also possible to have an efficient energy dispatching on the system with a set of transmission prices equal to those defined in the Hogan model.

5 Conclusions

This paper has analysed both the status and perspectives of the adoption of efficient pricing mechanisms in electricity and transportation. The analysis, departing from the technical description of the characterising features of both networks has shed light on some of the aspects suggesting and justifying the adoption of peak load pricing.

For electricity there is a clearly defined general and internationally accepted tendency towards the full liberalisation of the generation sector. The problems arising from the implementation of peak load pricing will become less important since demand peaking will be dealt with by appropriately functioning markets. The same cannot be said for transportation.

Considering the application of peak load pricing in transmission the similarities between the two sectors might become more evident when considering the network constraints. In fact in both sectors the fundamental problem is finding a price capable of internalising the external costs provoked by excessive congestion. Theoretical models for individuating a pricing mechanism for network congestion management do exist even though suffering from some limitations when dealing with network investments.

The electricity market portions that will not probably be liberalised (transmission and dispatching) could be regulated via a peak load pricing mechanism as described in paragraph 4. If these models will also have to provide indications, concerning dynamic capacity control, they might encounter similar problems to those arising from the introduction of road pricing schemes at a local level.

The two traditional transmission pricing models presented for the electricity sector should only be considered a benchmark for the transmission pricing management possibilities. When dealing with transmission the property rights and contract

network models are efficient, given an already existing transmission network, but nothing, or almost nothing, can be said about the efficiency of transmission price incentives toward new investments in transmission infrastructures. Given the economies of scale and investment externalities of electricity sector it is most likely that, in the near future, the system operator, managing transmission and dispatching, will still have to co-ordinate grid investment decisions, as it is in monopolistic and nationalised market structures. This situation suggests that, in the case of electricity, the institutional economic context is doomed to be profoundly influenced by the technical characteristics of the transmission system.

As it is for transportation, the implementation of an efficient pricing mechanism has been widely explored in the literature concerning road pricing but its extension to other transportation modes can also be conceived. As it has been shown the difference between the peak load and congestion problem in this sector is more subtle than in electricity due to the specific characteristics of the production function. The people transported are producers and consumers at the same time. It is exactly demand peaking that provokes the upsurging of congestion. However, when considering a multimodal environment the two problems can be separated. In fact, public transportation demand peaking might prime peak load problems in the production of the service (busses). At the same time this might have repercussions in the more general urban transportation market characterised by congestion due to both public and private excess demand for transport infrastructures.

The differences that have been underlined between the two sectors are also at the base of the different institutional frameworks of reference. If in the case of electricity we have witnessed a rapid ripening of the consciousness concerning the liberalisation and regulation needs for the sector, with the consequent institution of an Authority, nothing comparable has happened in transportation. The various market forms characterising the different transportation modes, their strong interrelationships and the unclear definition of the institutional authority on the single modes have provoked a slow down in the liberalisation and regulation process.

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NOTES

¹ Even if the paper presented is the result of a common effort E. Marcucci has written paragraphs: 2.1, 3.1 and 4.1 whereas P. Polidori paragraphs: 2.2, 3.2 and 4.2.

² This idea recalls the concepts that are at the base of Wardrop's rules on equilibrium of systems applied to traffic assignment techniques. See Thomas, 1991.

³ One has to recall that even in the case of congestion we might interpret the problem as arising from road capacity scarcity thus paving the way to the reinterpretation of congestion pricing in the light of peak load pricing in terms of scarce road capacity. The distinction is still valid, in our opinion, to keep the private production aspect separate from the social problem arising from increasing production costs.

⁴ Energy lost in the transmission line is a second order relationship with respect to power flow, so marginal losses are linearly increasing with flow, therefore the total amount collected based on the marginal losses will be greater than the average losses of the network. This operating surplus is usually credited towards recouping the capital investments. See Hsu 1997 and for a different position Bassi et al. 1999.

⁵ A synthesis of Hogan and Chao-Peck models can be found in Hsu 1997.

⁶ Remember that given Kirchoff's laws energy distributes in function of power transmitted and lines length and in the example of fig. 1 all the lines have the same length.

⁷ This because it is possible to reduce a capacity constraint limit of a give line ij with an injection of energy with direction ji .