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EVOLUTION OF PRODUCTIVITY EFFICIENCY OF POWER GENERATION IN HUNGARY IN THE PERIOD OF 1990 - 2002[*]

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DRAFT

Abstract

This paper examines the restructuring of the Hungarian power industry between 1990 and 2002, and focuses on the effects of regulatory reforms regarding the base load fossil fuel power generation plants. According to regulatory policies we would expect an improvement of productivity efficiency of the plants especially that of the newly established gas turbines in the second half of the 90s. Applying a non-parametric mathematic programming of *Data Envelopment Analysis* (DEA) in GAMS for the determination of Malmquist productivity indexes and using distribution free statistical methods for verifying the significance of changes, it seems that there is no clear evidence of productivity efficiency improvements as a result of restructuring and regulatory changes. This result could be explained by the following circumstances: firstly, the existence of *Power Purchase Agreements* (PPA), which refer to around 80% of national production in 2001, (it means a serious constraint for establishing the merit order of plants); and secondly, the existence of overcapacity of the system and the slow withdrawal of plants that are at the end of their economic life. Regarding future developments, the opening of the electricity market in Hungary in 2003 and the fact that the share of PPAs is expected to fall in the coming few years might have a positive impact on productivity efficiency of the base load fossil fuel plants.

Keywords: power generation, restructuring, incentive based regulation, Hungary, Malmquist productivity efficiency index.

I. INTRODUCTION

In the last two decades restructuring of power industry was an important feature in economic policy in the majority of European countries. Given scale and scope economies of the power sector, traditionally it was considered as a typical natural monopoly where the different activities (generation, transmission and distribution) were vertically and horizontally integrated in a public company or in a few cases in regulated private companies. Liberalisation and restructuring began with the premise that the electricity sector as a whole was not considered as a natural monopoly anymore. On one hand, due to technological advances (especially the reduction of efficient scale size of plants) generation and supply

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[*] The ideas expressed in this paper are those of the author and do not necessarily represent views of the European Commission.

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became to be considered as potentially competitive activities, while on the other hand, transmission and distribution networks were maintained as regulated natural monopolies. Through unbundling the monopoly structure was either followed by a single buyer model (also called purchasing agency model) that gave way for a posterior wholesale and retail competition, or succeeded directly by a wholesale market model.

The structure of the industry in Hungary was similar to the practices in other EU countries given that the sector operated as an integrated monopoly run by the publicly owned incumbent company, MVM. From a regulatory point of view there was a cost of service regulation established and did not exist economic risks for the incumbent company since the state had a tight control over all decisions in the sector including long run investments and tarification. However, one of the major problems in the Hungarian power system was the lack of transparency regarding inter-sector and end-user prices. This meant that prices were set rather on social and not necessarily economic considerations. Moreover, prices did not reflect inflationary tendencies that at the end of the 80s stated to reach historically high levels (CPI greater than 30%). In these circumstances the electricity sector was protected from the overall economic climate that also affected decisions on investments as a result of the failure of correct economic signals.

Another important difference of the Hungarian power sector with respect to the Western European practise was its extremely high dependence on imports from the former Soviet Union (Ukraine) that reached the unusual level of 40% of net national production by the end of the 80s. This considerable import together with the existing overcapacity of the system protected the electricity industry from the effects of the sudden reduction of national demand (1990-94: net national consumption reduced by 17%) originated by the collapse of the command economy at the beginning of the 90s.

Restructuring of the sector started at the beginning of the 90s and led to the privatisation of generation plants and the regional distribution companies. The principal objective of reform policies was to achieve improvements of technical, dynamic and choice efficiency on the long run that would lead to the introduction of wholesale and retail markets. The cost of service regulatory framework dominant during the monopoly structure gave place to incentive based regulatory tools that combined rate of return regulatory elements and price caps. It is important to notice that the long run power purchase agreements (PPAs) between MVM and new investors signed during the privatisation process were an important obstacle for the efficient operation of the system that acted in the opposite direction of the introduced incentive mechanisms by minimising risks of generation companies.

The objective of this paper is to characterise the Hungarian power sector, especially the generation phase and study the effects of reform policies and quantify in no-monetary terms the improvement of productivity efficiency of the base load fossil fuel generation plants in the period of

1990-2002. For this reason we apply the Malmquist productivity index introduced by Ray and Desli (1997).

The structure of this paper is as follows. In chapter 2 we highlight the most important characteristics of restructuring and the privatisation process. In chapter 3 the incentives and obstacles of the regulatory framework are analysed in the overall power industry that is followed by the description of the main technical and economic situation of generation in chapter 4. Chapter 5 is dedicated to the presentation of theory on measuring productivity efficiency with a non-parametric frontier approach and the introduction of the Malmquist productivity index. Chapter 6 reveals the findings of the empirical analysis and finally, in chapter 7 we conclude.

II. RESTRUCTURING AND PRIVATISATION

In Hungary, as in the majority of the European countries, the power system was considered a strategic industry after the 2nd World War and operated as an integrated monopoly managed by the public company called MVM Trust. Restructuring started at the beginning of the 90s by a partial vertical unbundling of the power sector and MVM Trust was converted into a two-tier company. The first tier was a central organisation responsible for the technical (system operation and transmission) and economic management and overall coordination of the sector. The second tier included the generation units and the six regional distribution divisions that became joint stock companies still belonging to MVM Trust. According to the Electricity Act[1] approved in 1994 the horizontal unbundling had to be managed to give way to the privatisation process in 1995 with the principal objective of attracting foreign capital to the sector for its modernization.

All generation plants except for the nuclear power station, Paks, which remained property of MVM, participated in the privatisation process, although several coal plants remained in public ownership (MVM) especially those that got integrated with coal mines in 1993-94. At the same time gas turbines and mixed plants (those that use both gas and fuel oil) were sold basically to foreign investors. (See table 3 in chapter VI.1. that present the base load fossil fuel plants, the year of their privatisation and their owners) According to the Herfindahl-Hirschman index (HHI) the concentration in generation remained relatively high as it reached the value of 3.683. This result can be explained by the still high participation of MVM in power generation where the nuclear power station had around 22% of installed capacity of the system and produced around 40% of national production at the end of the 90s. Furthermore, the nuclear power station and the second largest company, Dunamenti (owned by

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[1] Act XLVIII of 6 of April 1994 on the Generation, Transmission and Supply of Electricity.

Electrabel) had more than the 50% of installed capacity of the system and around the 60% of national production by 2000.

Table 1. Herfindahl-Hirschman index (HHI) for generation and distribution

Generation		Transmission		Distribution	
1990	**2000**	**1990**	**2000**	**1990**	**2000**
10.000	3.683	activity in monopoly		10.000	2.351

Sources: Proper calculation based on HEO 2001, Varró (2001), data HEA (2002)
Notes: The HHI for generation is calculated on base load generation that covers the 98% of total net national production.

Transmission remained as a monopoly activity according to economies of scale and scope. However, during the period that embraces this study it was MVM the responsible not only for the transmission activities but also for system operation, dispatching, and auxiliary services. This structure gave the opportunity for discriminatory behaviour in favour of generation plants still owned by MVM and could be detrimental to other companies. Although this situation was remedied in 2002 by creating MAVIR Rt. as system operator under direct control of the Ministry of Economic Affairs, from the point of view of competition it would have been more straightforward to create an independent system operator (ISO). Another activity related to the wholesale activity of MVM was its monopoly power over foreign trade. Consequently, both the lack of an ISO and the maintenance of foreign trade as a monopolistic activity might lead to negative effects on productivity efficiency of generation.

The six regional distribution companies were privatised basically to three foreign investors: RWE, E.On and EdF (around 13% of the capital value of distribution companies remained in Hungarian ownership). This fact explains the relatively high HHI value for distribution. It should be noted here that the distribution companies have increasing interests[2] in generation, especially in new CCGT installation that might have negative effects in competition in the future electricity market.

The privatisation was accomplished practically by 1997 but the expected investments and modernisation of the acquired plants have arrived slowly at the end of the 90s. However, the main arrangement of privatisation was that the integrated monopoly structure was replaced by an oligopoly in generation, monopoly in transmission and regional monopolies in distribution.

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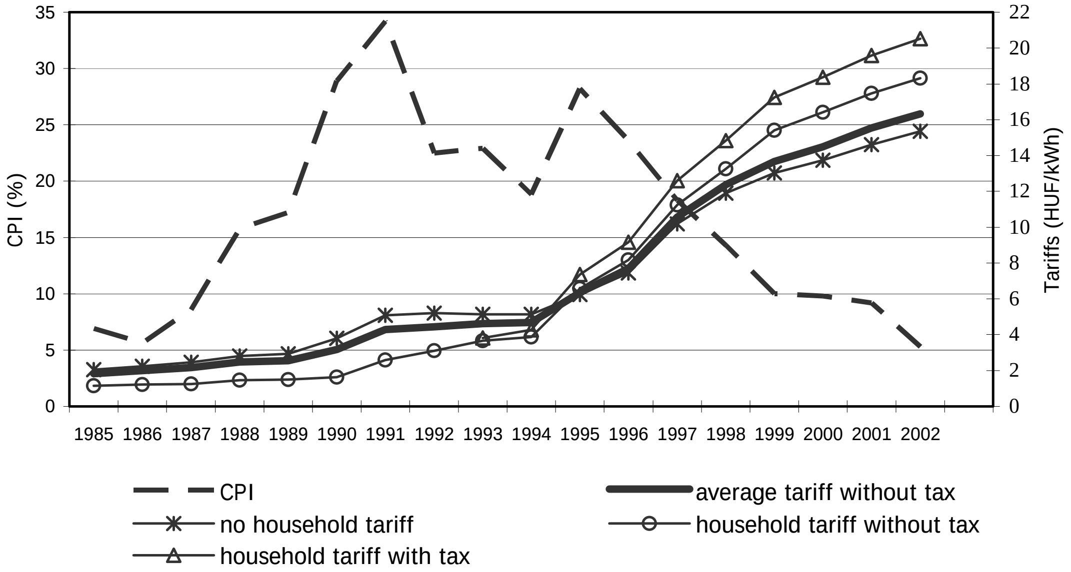
[2] RWE is the principal owner of the Mátra coal plant lately renovated with retrofit, E.On constructed new CCGTs in Debrecen and Nyíregyháza, and EdF became the principal owner of Budapesti Power Company in 2001.

III. INCENTIVES AND OBSTACLES IN THE REGULATORY FRAMEWORK

During the monopoly structure the state had a tight control over all activities of the sector where investments were supported by state budget and prices did not reflect incurred costs of the sector but were established rather by social, political and certain industrial development considerations than by economic foundations. There existed a certain kind of cost of service regulation where the public incumbent company had no risks in its operations, there were no incentives to put downward pressure on costs and optimise long run investments. In this structure three main consequences should be emphasized. Firstly, prices did not reflect neither real costs, nor inflationary tendencies of the overall economy, which from the second half of the 80s started to grow significantly and increased disequilibrium between incurred costs and prices. In these circumstances the power sector was protected by the state from the overall economic climate, which in reality meant the postponement of radical reforms. Secondly, according to the consideration of power supply as “social service” industrial customers (that by that time were mainly public) were sustaining and subsidising household consumption reflecting the practise of considerable cross subsidies. And finally, for absence of correct economic signals investments were mainly realised in generation to the detriment of the distribution network. This might explain the large quantities of losses in the distribution network that reached the unacceptable high level of 10-13% of national production even at the end of the 90s.

Figure 1. End-user tariffs and the CPI, 1985-2002



Source: Proper elaboration from data of HEA

Replacing the monopoly structure by a single buyer model implied the change of the regulatory framework. An incentive based regulation was applied where the maximum average cost pricing with multiparty tariff mechanism set up a system of reference prices for the overall sector. By employing this new pricing system the objective of regulator was adjusting prices to inflationary tendencies and to real costs, correcting cross subsidy practises, sending correct economic signals for investment, improving efficiency of the exploitation of the system by putting incentives to cost reduction and setting the bases for the introduction of future competition.

The establishment of a single buyer model, which represents a transitional arrangement before the conditions for a competitive wholesale and retail market are satisfied, has the possibility to introduce competition at the level of generation companies. In an ideal case it means that generators compete against each other in order to sell electricity to the purchasing agency, and the system introduces competition for the construction of new plants and for contracts to supply the purchasing agency. This way, market forces put incentives for an efficient exploitation of the system and assure the control of costs in generation. Taking into account that generation represents around two thirds of total costs of the power sector, the incentives obtained in the classical single buyer model give the possibility to improve considerably the efficiency of exploitation.

In the Hungarian electricity system the single buyer model was adopted in 1995 but it operated without exploiting the possibility of competition between generators. Mainly it was a consequence of the power purchase agreements (PPAs) signed during the privatisation process between MVM and the generation companies.

PPAs are usual practises in all types of power sector structures in interest of an integrated and efficient operation of power system and for cost and risk reduction motives (Hunt and Shuttleworth, 1996). There are two basic requirements for an efficient system operation with PPAs. Firstly, the establishment of energy and capacity fees must correctly reflect incurred cost of generators where the marginal cost of dispatching equals the marginal cost of running the plant. In this scheme the contract is based on economic terms and the minimisation of operational costs is accomplished. Secondly, PPAs should not refer to excessive amount of capacity and production in the overall power sector and neither should they extend to a long time horizon in order to permit flexible adaptation of the system to demand requirements.

In Hungary neither of these basic requirements were fulfilled. According to Horváth (2004) PPAs affected around the 80% of national power production at the end of the 90s that meant a very important constraint for the system by implying to take over generation not necessarily according to efficiency criteria and the incremental cost principal. Moreover, the time horizon of PPAs is extremely long, 50% of production should be dispatched considering the PPAs until 2012. This long time span and the quantity of contracted generation and capacity mean that the system has elevated stranded costs, which at the same time makes the system very rigid and inflexible for future changes. Furthermore, PPAs meant bilateral contracts between the purchasing agency and the generator that implied an individualised regulatory system and eliminated operational risks and might have narrowed the effects of potential regulatory incentives for generators.

In these circumstances the stipulation of justified costs became the core issue of incentive based regulation that started in 1997 and established four year long regulatory periods (1997-2000 and 2001-2004). According to economic theory, prices should be put as close as possible to marginal costs at all levels of the industry (generation price, wholesale price and end-user tariffs) in a way that by escalating prices the end end-user tariffs should cover all the costs and benefits of the different activities. In this sense, justified costs were stipulated at the beginning of each period covering both fixed and variable costs of all activities. Prices of different phases were linked by indexed maximum average prices that also included an efficiency factor (X) establishing a CPI-X regulation. This regulatory framework was complemented by a rate of return regulatory tool (guaranteed benefit in all phases) putting incentives for investment.

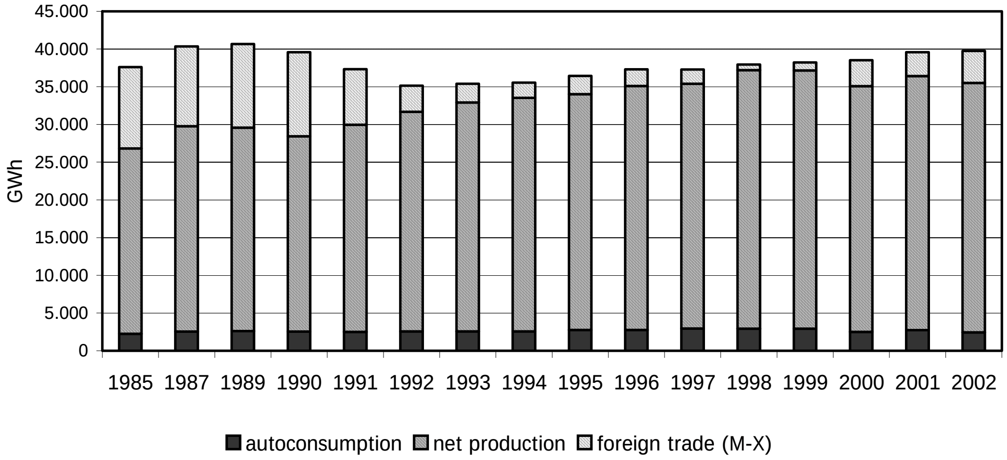
Although these regulatory elements improved asignative efficiency by determining prices on a justified cost base, enhanced productivity efficiency by putting incentives for cost reduction and encouraged investment, there were two major deficiencies of the regulatory framework. One was the mentioned PPAs that might have reduced the effects of the incentives, and the other was the stipulation of remuneration of transmission services. During the single buyer model this activity received important direct subsidies from state budget in order to cover its deficit. This meant that justified costs were not equal to incurred costs of transmission and permitted that regulator used transmission price as a ’buffer’ in order not to pass generation price increases directly to end-users. According to Bálint (2003), after repeated increases of end-user prices and elimination of cross subsidies, incurred costs were covered by 2003.

In the following chapters we centre our attention to the characteristics of the generation phase.

IV. KEY TECHNICAL AND ECONOMIC CHARACTERISTICS OF GENERATION PHASE

The structure of the Hungarian power generating system has undergone significant changes in the 90’s due to restructuring, privatisation and the new regulatory framework. It is important to highlight that besides these reforms the collapse of the command economy at the beginning of the 90s also affected power generation according to the drastic reduction of electricity consumption due to general crises and restructuring of the industry, especially that of the heavy industry. In a period of four years power demand was reduced by 16% reaching its bottom value in 1993 at a net consumption level of 28 TWh. The increasing tendency in net electricity consumption from 1994 was due to the increase of household consumption and to a smaller extent to the relatively rapid recuperation of the industry not as intensive in electricity as before. It is to notice that net consumption in 2002 did still not reach that of 1989.

Figure 2. Gross consumption of electricity in Hungary, 1985-2002



Although there was a strong reduction of demand, electricity production was increasing along the whole period except for 2000 and 2002. This situation was due to the fact that during the monopoly model the Hungarian electricity system was strongly depending on imports, mainly form the Soviet Union (Ukraine), reaching internationally unusual high levels of around 40% of net national production. Importations form Ukraine practically stopped by 1994 for lack of reliability of supply. This way reduction of imports and the existing reserves in the system could palliate the possible negative effects of the sudden reduction of demand and permit increase of generation. Taking into account that in the middle of the 90s there were practically no investments in installed capacity of the system (see table 2.), the increasing production with practically constant capacity suggests that there must have been augmenting of productivity efficiency due to the intensification of input use. At the end of the period foreign trade balance increased repeatedly, but this time the major partners were Slovakia and Austria.

Table 2. Installed capacity and reserves in Hungary, 1980, 1990-2002

	1980	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
(1) Installed capacity (MW)	5.735	7.184	7.193	7.278	7.259	7.317	7.307	7.536	7.534	7.847	7.842	8.282	8.392	8.311
(2) Available installed capacity (MW)	5.144	7.071	6.987	6.942	6.854	6.979	6.993	7.380	7.276	7.668	7.648	7.993	8.082	8.184
(3) Real available capacity (MW)*	4.467	6.071	6.086	6.249	6.165	6.074	6.215	6.673	6.666	7.180	7.031	7.435	7.147	7.268
(4) Peak load. (MW)	5.107	6.534	6.252	5.641	5.612	5.550	5.731	5.794	5.731	5.817	5.801	5.742	5.965	-
(5) Reserves [((2)-(4))/(1)] (%)	**1%**	**7%**	**10%**	**18%**	**17%**	**20%**	**17%**	**21%**	**21%**	**24%**	**24%**	**27%**	**25%**	**-**

Source: HEA and Annual Statistics (2002), p.64.
Notes: * ´Real available capacity´ is calculated by resting from the available installed capacity the capacity affected by not expected breakdown.

In the last years of the monopoly structure two gas turbines Dunamenti GT1 and Dunamenti GT2 started to operate. After the privatisation process was concluded investment did not reach the expected levels, they were basically covering the amortisation of the plants. After 1998 installed capacity increased due to the retrofit renovation of Mátra coal plant and the inauguration of two gas turbines Csepel and Debrecen. There were also three quick start reserve CCGTs inaugurated in order to accomplish the obligations for being an UCTE (*Union for the Cooperation of Transmission of Electricity*) member[3].

The diversification of fuel use comprises basically four types of combustible: nuclear material, coal, gas and fuel oil. The geographical characteristics of the country are not favourable for hydraulic generation that along the period of 1990-2002 did not reach 1% of gross national generation. At the beginning of the 90s almost half of the generation was based on nuclear resources, while 30% originated from coal combustion and hydrocarbon resources played a role up to 20% in total power generation. As it can be seen in the figure under, in absolute terms the nuclear plant has maintained its production and both coal and hydrocarbon resources have augmented it. However, in relative terms it is only the gas and oil plants that increased their share in the total of generation.

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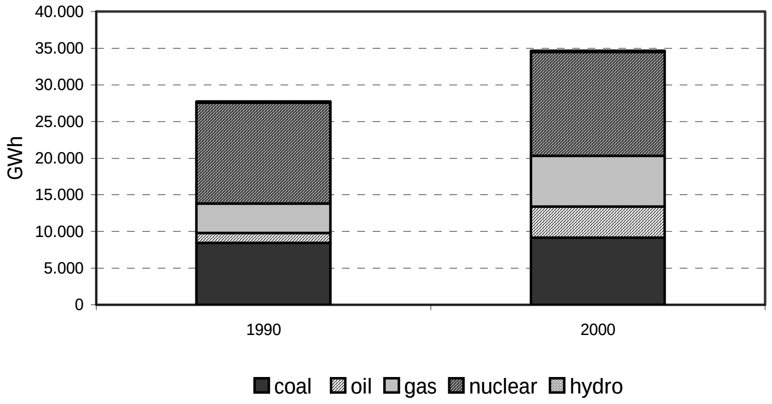
[3] Until 1992 the Hungarian power system belonged to UPS (United Power System) gathering the countries of the communist block. The principal aim of this system was the transportation of large amount of power to long distances. For this reason there existed a network of 750kV, unusual in Western Europe that permitted to transport electricity in the Soviet nuclear power stations. Hungary became member of UCTE in 2001 after fulfilling the requirements of this organisation for cooperation that obligates member states to dispose of quick start plants. In Hungary it meant inaugurating at least 460MW installed capacity as quick reserve which is the installed capacity of a block in the nuclear power station.

Figure 3. Electricity fuel mix, 1990 and 2000



There is clear evidence that the system is increasingly depending on the utilisation of gas. Taking into account that the majority of coal plants are getting to the end of their economic life and they will be closed in the coming few years, the system will mainly rely on nuclear generation and gas turbines in the near future.

V. MEASURING PRODUCTIVITY EFFICIENCY WITH A MALMQUIST PRODUCTIVITY INDEX

In economic parlance the concept of economic performance rests on productivity or on the change of productivity from one period to the next. In these terms, productivity is a key concept in production theory that seeks the answer for the question of how inputs are transformed into outputs along a production process. In this paper we apply for total factor productivity (TFP) measures where outputs and inputs are simultaneously considered and aggregated terms are not employed.

The literature on productivity performance provides an ample set of methods for the determination of TFP growth both for micro- and macroeconomic units. Traditional approaches as the growth accounting models, the Solow residual or the index number approaches (e.g. Fisher or Törnquist) assume that all firms or individuals are efficient and they associate productivity change with technological change (shift of the production function). If inefficient operation is contemplated in the analysis, changes in productivity are no longer associated only with a shift of a production function, but also with other factors such as technical efficiency change or scale efficiency change. The identification of components in the context of productivity change are possible by employing Malmquist-type productivity indexes, which allow drawing conclusions on the underlying economic decisions and activities made by individual units or the effects of regulatory policy. For example a slowdown in productivity due to lack of technical change should imply different policy measures than a slowdown that originates from increasing inefficiency of production. It implies that different treatment should be applied when innovation falls short in an industry or when institutional barriers restrain improvement of production. According to this argument important advantages of the Malmquist-type indexes over other total factor productivity measures are the simultaneous consideration of both efficient and inefficient units and its capacity of decomposition.

The authors Caves, Christiensen and Diewert (1982) introduced the Malmquist-type productivity indexes[4] that use distance functions (in mathematics also called gauge functions) for the representation of production. The original objective of Caves et. al. was to provide a productivity index applicable for all kinds of production structures that at the same time does not require a continuous representation, but a discrete one. They employed an input and an output vector and compared this production structure with a reference technology by radial input and output distances, which means using distance functions.

The distance function approach provides a formal functional representation of a multiple output and input technology and gives the same information about technology as the production function. It has the very useful property that its construction does not require an *a priori* specification of the behavioural objective of the decision making unit such as cost minimisation or profit maximisation. The technology is deduced through information on data of the observed inputs, outputs and prices (using information on prices is optional). Since distance functions permit the admission of multiple inputs and outputs, they are well suited to characterise all kinds of technologies without having to make aggregation of inputs and outputs that most of the time are problematic and probably unwarranted. Unequivocally this is an important improvement in the treatment of data in productivity analysis that leads further away from the Solow residual or index number approaches.

Caves et.al. introduced two versions of the Malmquist productivity indexes: one approach is output oriented where the objective is to maximise production with a given level of input, and the other is input oriented by minimising resource utilisation to achieve a given level of output. Taking into account that the output oriented approach fits better to the empirical study of power generation; in the followings we reproduce only this version according to the formalisation of Färe and Primont (1995).

The output distance function can be defined in the output or input set where output quantities belong to an M-dimensional vector with non-negative values, that is $y \in R_+^M$, and input quantities are represented by an N-dimensional vector with non-negative values, that is $x \in R_+^N$. The production set $S^t \subset R_+^N \cdot R_+^M$ or $S^t = \{(y^t, x^t): x^t\, produce\;\, y^t\}$ represents all possible input-output combinations in period t. The production set contains both the input and output sets where the Färe and Primont (1995)

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[4] Malmquist (1953) created a quantity index by measuring the radial distance of two output vectors from an indifference curve. This idea was elaborated in a parallel way by Shephard (1953). In reality it was Shephard who defined and formalised this approach in the framework of distance functions. It would have been more appropriate to call the Malmquist productivity index as a Shephard productivity index.

axioms hold. The most important assumptions of these axioms are that the sets are closed, convex and satisfy strong disposability of inputs and outputs.

The output set is defined as $P^t(x) = \{y^t | (y^t, x^t) \in S^t\}$ which for every $x \in R_+^n$ has an output isoquant where only the efficient firms are on the output isoquant.

(1) $$IsoqP^t(x^t) = \{y^t : y^t \in P^t(x^t)\}, t = 1,..,T.$$

The production technology can be represented by the output distance function which is defined for any pair of vectors of inputs and outputs (x,y) in time t as:

(2) $$D_o^t(x^t, y^t) = \min\left\{\theta : \left(\frac{y^t}{\theta}\right) \in P^t(x^t)\right\} ,$$

where 'o' refers to the output distance function y 'θ' is the efficiency coefficient of each productive unit. This optimisation problem can be resolved in the framework of mathematic programming using its dual and applying the adequate restrictions in the following way:

(3) $$\left[D_o^t(x^t, y^t)\right]^{-1} = \max_{\phi, \lambda_j^t \geq 0} \phi \qquad \text{where } \phi = \frac{1}{\theta}, \text{ and}$$

$$\text{s.t.} \quad \begin{aligned} &\phi \cdot y_{m,j}^t \leq \sum_{j=1}^{J} y_{m,j}^t \cdot \lambda_j^t \\ &\sum_{j=1}^{J} x_{n,j}^t \cdot \lambda_j^t \leq x_{n,j}^t \\ &\sum_{j=1}^{J} \lambda_j^t = 1 \\ &\lambda_j^t \geq 0 \end{aligned}$$

The above expression serves for the calculation of the efficiency coefficient supposing variable returns to scale. For the simulation of constant returns to scale the $\sum_{j=1}^{J} \lambda_j^t = 1$ restriction should be omitted[5]. The value of the distance functions with output orientation can be less or equal to 1, $D_o^t(x^t, y^t) \leq 1$. When a production unit in a period t is on the isoquant, then this unit is efficient and $D_o^t(x^t, y^t) = 1$. In the case when the unit is not efficient, the output vectors are not elements of the isoquant and $D_o^t(x^t, y^t) < 1$.

The output distance function measures the maximal possible proportional expansion of all outputs given the input vector. Having the axioms on technology sets in mind, the following properties of

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[5] For a discussion on return to scale considerations and theoretic background in non-parametric analysis see Caves et.al. (1982), Banker et.al. (1984) and Cooper et.al. (2000).

distance functions should be stressed out: firstly, monotonocity that is $D_o^t(x^t, y^t)$ is non-decreasing in y and increasing in x and secondly, homogeneity that is $D_o^t(x^t, y^t)$ is homogeneous of degree (–1) in outputs.

Caves et al. suggested defining the Malmquist productivity index as a ratio of two distance functions or as the geometric mean of the two Malmquist indexes. In more recent literature the equation (6) is used most of the time. The output oriented Malmquist productivity index is shown for period t and t+1.

$$MPI_O^t(y^{t+1}, x^{t+1}, y^t, x^t) = \frac{D_O^t\left(y^{t+1}, x^{t+1}\right)}{D_O^t\left(y^t, x^t\right)} = D_O^t\left(y^{t+1}, x^{t+1}\right) \tag{4}$$

$$MPI_O^{t+1}(y^{t+1}, x^{t+1}, y^t, x^t) = \frac{D_O^{t+1}\left(y^{t+1}, x^{t+1}\right)}{D_O^{t+1}\left(y^t, x^t\right)} = \frac{1}{D_O^{t+1}\left(y^t, x^t\right)} \tag{5}$$

$$MPI_O(y^{t+1}, x^{t+1}, y^t, x^t) = \left[M_O^t(y^{t+1}, x^{t+1}, y^t, x^t) \cdot M_O^{t+1}(y^{t+1}, x^{t+1}, y^t, x^t)\right]^{\frac{1}{2}} \tag{6}$$

Caves et.al. made the supposition that all firms were efficient and that a constant returns to scale assumption prevailed. In these circumstances the proposed Malmquist productivity index in equation (6) measures the distance between the frontiers of period *t* and period *t+1* and shows progress, stagnation or regression of productivity if the index is larger, equal or less than unity, respectively. The adjacent distance functions, $D_O^t(y^{t+1}, x^{t+1})$ and $D_O^{t+1}(y^t, x^t)$ refer to the distance between the observation of production combination in period *t+1* and technology in period *t*, and to a combination of production factors in period *t* and technology in *t+1*, respectively.[6]

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[6] The calculation of the adjacent distance function are the following:

$$D_o^t\left(x^{t+1}, y^{t+1}\right) = \min\left\{\theta : \left(\frac{y_{m,j}^{t+1}}{\theta}\right) \in P^t\left(x^{t+1}\right)\right\} \tag{7}$$

$$\left[D_o^t(x^{t+1}, y^{t+1})\right]^{-1} = \max_{\phi, \lambda_j^t \geq 0} \phi, \quad \phi = \frac{1}{\theta}, \tag{8}$$

$$\begin{aligned} & \phi \cdot y_{m,j}^{t+1} \leq \sum_{j=1}^{J}\sum_{s=1}^{t} y_{m,j}^s \cdot \lambda_j^s \\ \text{s.t. } & \sum_{j=1}^{J}\sum_{s=1}^{t} x_{n,j}^s \cdot \lambda_j^s \leq x_{n,j}^{t+1} \\ & \sum_{j=1}^{J}\sum_{s=1}^{t} \lambda_j^s = 1 \\ & \lambda_j^s \geq 0 \end{aligned}$$

$$D_o^{t+1}\left(x^t, y^t\right) = \min\left\{\theta : \left(\frac{y_{m,j}^t}{\theta}\right) \in P^{t+1}\left(x^t\right)\right\} \tag{9}$$

$$\left[D_o^{t+1}(x^t, y^t)\right]^{-1} = \max_{\phi, \lambda_j^{t+1} \geq 0} \phi, \quad \phi = \frac{1}{\theta}, \tag{10}$$

$$\begin{aligned} & \phi \cdot y_{m,j}^t \leq \sum_{j=1}^{J} y_{m,j}^{t+1} \cdot \lambda_j^{t+1} \\ \text{s.t. } & \sum_{j=1}^{J} x_{n,j}^{t+1} \cdot \lambda_j^{t+1} \leq x_{n,j}^t \\ & \sum_{j=1}^{J} \lambda_j^{t+1} = 1 \\ & \lambda_j^{t+1} \geq 0 \end{aligned}$$

After the incorporation of the Malmquist-type indexes in productivity measurement realised by Caves et.al. (1982) there has been an extended literature[7] developed in this field. The authors exploited the possibility given by the characteristics and construction of the distance functions that permit, on one hand, the supposition of inefficient production and, on the other hand, the assumption of both variable and constant returns to scale. In the followings we represent the Malmquist index approach developed by Ray and Desli (1997) that offers a consistent decomposition[8] of the index into different factors in the following way:

$$MPI_o^{t,t+1}(y^{t+1},x^{t+1},y^t,x^t)=\left[\frac{D_O^t\left(x^t,y^t\right)}{D_O^{t+1}\left(x^t,y^t\right)}\cdot\frac{D_O^t\left(x^{t+1},y^{t+1}\right)}{D_O^{t+1}\left(x^{t+1},y^{t+1}\right)}\right]^{\frac{1}{2}}\cdot\frac{D_O^{t+1}\left(x^{t+1},y^{t+1}\right)}{D_O^t\left(x^t,y^t\right)}\cdot$$

$$(11)\qquad \cdot\left[\frac{\dfrac{D_{OC}^t\left(x^{t+1},y^{t+1}\right)}{D_O^t\left(x^{t+1},y^{t+1}\right)}}{\dfrac{D_{OC}^t\left(x^t,y^t\right)}{D_O^t\left(x^t,y^t\right)}}\;\frac{\dfrac{D_{OC}^{t+1}\left(x^{t+1},y^{t+1}\right)}{D_O^{t+1}\left(x^{t+1},y^{t+1}\right)}}{\dfrac{D_{OC}^{t+1}\left(x^t,y^t\right)}{D_O^{t+1}\left(x^t,y^t\right)}}\right]^{\frac{1}{2}}=\Delta T\cdot\Delta TE\cdot\Delta SE=MPI^{RD}\qquad ,$$

Here ‘c’ refers to constant returns to scale. This way Ray and Desli integrated technological efficiency change (ΔT), technical efficiency change (ΔTE) and scale efficiency change (ΔSE) in the Malmquist productivity index. Firstly, technological efficiency change quantifies the shift of the production frontier between two periods of time. Secondly, technical efficiency change, which is also called ‘catching-up’ effect, measures how far a production combination is from the production frontier of all firms and how it changes over time. Finally, in the case of scale efficiency change Ray and Desli (1997) use both the constant and variable returns to scale assumption to simulate how far a unit is from optimal scale.

In the following chapter, realising the empirical study on the Hungarian power industry, we will make use of the Malmquist productivity index introduced by Ray and Desli and adopt it to our dataset.

In the equations (8) and (10) the assumption on variable returns to scale is reflected, however the assumption on constant returns to scale can be arranged by omitting the restrictions $\sum_{j=1}^{J}\lambda_j^t=1$ and $\sum_{j=1}^{J}\lambda_j^{t+1}=1$. For further discussion on variable and constant returns to scale representation see the work of Banker et.al. (1984) and Cooper et.al. (2000).

[7] See the theoretical works of Färe et al. (1994), Ray and Desli (1997), Grifell-Lovell (1999) and Lovell (2001), Bjurek (1994 and 1996), Bjurek et al. (1998), Førsund (1997), Balk (2001) and the empirical applications by Arocena (1996), Färe, Grosskopf and Roos (1998), Grifell_Tatjé and Lovell (1999), Álvarez Pinilla (2001), Arocena y Waddams (2002), Shestalova (2002) and Sarkis and Talluri (2004).

[8] See the comparison of different decomposition techniques in the paper of Lovell (2001).

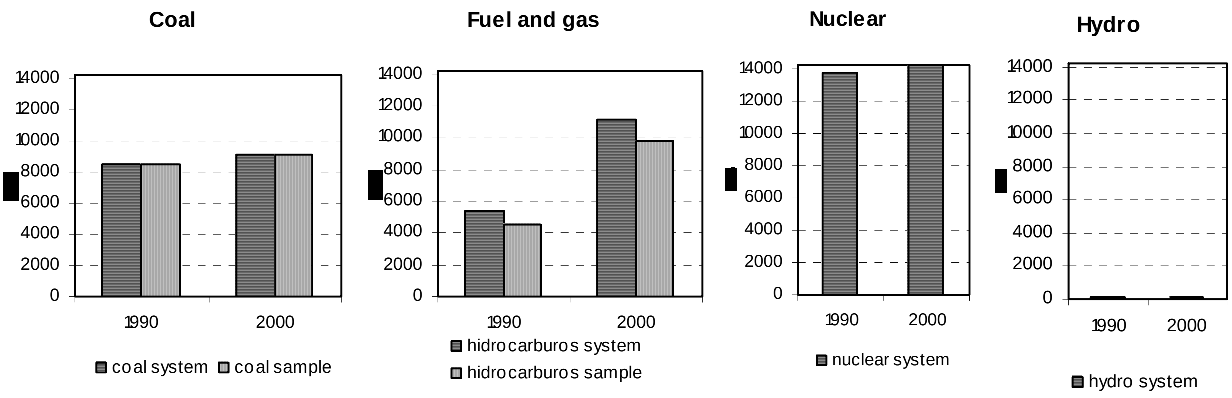
VI. EMPIRICAL ANALYSIS

VI.1. DATABASE

The database, provided by the Hungarian Energy Agency (HEA), is formed by the base load fossil fuel plants in Hungary in the period of 1990-2002. This means that the plants included in the sample have more than 50MW of installed capacity and its fuel use is coal, hydrocarbon (oil and gas). Although the nuclear power station produced between 40% and 50% of power in the country in the mentioned period and represented around 25% of total installed capacity, we have excluded it from the dataset due to its different cost structure with respect to fossil fuel plants (fixed costs are relatively higher and the variable costs are relatively lower compared to the fossil fuel plants). Hydro electric installations are not included due to the fact that they have less installed capacity than 50MW and their production does not reach considerable share in overall power generation.

The following figure shows the representation of the different types of power plants in the sample in 1990 and 2000. It should be highlighted that all coal generation plants are included in the analysis, while around 80% of production of oil and gas plants are represented in the sample. In this manner, not counting the nuclear power station our sample produces more than 95% of national production and represents between the 85-72% of installed capacity along the whole period.

Figure 4. Fuel mix in the system and in the sample



Source: HEA data

The next table reports a summary on some relevant characteristics of the 17 plants included in the sample. The number of years of operation is a key factor in the determination of the analysis and it should be noted that not all plants operate along the whole period. In the group of coal plants Inota was closed in 2001 by ending his economic life. In the group of mixed plants Dunamenti I. was also closed for similar reasons as Inota. In the group of gas turbines the majority of the plants got incorporated in the system in the second half of the period.

Table 3. Classification of plants according fuel use

	Plants	Principal owner in 2001	Operating years	Year of privatisation*
Coal	Ajka	MVM	1990-2002	Public
	Bánhida	MVM	1990-2002	Public
	Borsod	AES	1990-2002	1995
	Inota	MVM	1990-2001	Public
	Mátra	RWE	1990-2002	1997
	Oroszlány	MVM	1990-2002	Public
	Pécs	Mecsek	1990-2002	2000
	Tiszapalkonya	AES	1990-2002	1996
Mixed	Tisza II	AES	1990-2002	1996
	Dunamenti I	Electrabel	1990-2000	1997
	Dunamenti II	Electrabel	1990-2002	1997
Gas turbines	Dunamenti Gt1.	Electrabel	1994-2002	1997
	Dunamenti Gt2.	Electrabel	1996-2002	1997
	Kelenföld Gt	EdF	1990-2002	1997
	Kelenföldi Kombi	EdF	1996-2002	1997
	Debrecen Gt	E.On	2001-2002	2000**
	Csepel	NRG	2000-2002	1995***

Source: HEA data
Note: * The year of privatisation is considered to be the year when more than 50% of the property was owned by private companies. ** New establishment.
*** Not operating until 2000 due to overall reconstruction.

Although the sample comprehends the totally of base load fossil fuel plants (each might have different number of blocks) there is a relatively small number of observations per year. It would have been of great interest to realise the empirical analysis with data on blocks. However, in absence of available data on blocks in HEA, this was not possible. On one hand, the small number of observations limits the number of variables applicable in the analysis and on the other hand, this small number of observations per year requires an adjustment of the analytical framework of Malmquist productivity index by using a sequential method. In the following two subsections we define the variables employed and the sequential Malmquist productivity index applied.

VI.2. VARIABLES

The variables are employed in physical terms. Input variables are installed capacity (MW) of each plant and fuel utilization for power generation (GJ), this way fixed costs are represented by installed capacity and variable costs by fuel utilisation. The output variable is the net power production (kWh) of the plants that does not contain auto consumption.

The lack of homogeneous information on labour has impeded the incorporation of labour as input variable. The main problems concerning labour sources were two fold. Firstly, in the case of coal plants data on labour included the employees not only of the units but also of the corresponding coal mines. Secondly, in the majority of the cases labour data was only available on company and not on plant level. Nevertheless, in the following table the employee growth rates are represented at company level. The table highlights that besides the coal plants that got integrated coal mines in 1993-94, the hydrocarbon plants implemented considerable reduction in labour.

Table 4. Growth rate of employees in power companies from 1990 to 2001

Company (plants in the sample)	Growth rate (1 ≡ zero growth)
AES Tisza (Tisza II , Tiszapalkonya)	0,12
AES Borsodi (Borsodi)	1,48
Bakonyi (Ajka, Inota)	0,97
Budapesti (Kelenföldi Gt, Kelenföldi Kombi)	0,68
Dunamenti (DmI, DmII, DmGt1, DmGt2)	0,42
Mátra (Mátra)	1,66
Pannonpower (Pécs)	0,5
Vértes (Oroszlány, Bánhida)	2,79

Taking into account that power generation is highly intensive in capital, labour cost represents only a small part of total costs. In this sense we consider that leaving out the input variable labour of the analysis should not affect the outcome.

The incorporation of other variables regarding polluting gas emissions (nitrogen oxides, CO, CO_2, SO_2), which could have been interpreted as ‘bad’ outputs[9], was not convenient according to the small number of observations.

VI.3. APPLIED METHODOLOGY

The application of non-parametric methodology with distance functions is a formal representation of technology and as mentioned in the former chapter, it does not need the definition of a functional relationship between variables. However, it requires an ample set of data in order to determine the frontier of technology (reference technology). Knowing the limited dataset on the Hungarian generation plants and the relatively few observations per year, it is convenient to replace the reference technology, interpreted in chapter V. in a contemporaneous framework, by a sequential construction of frontiers.

The sequential methodology, as introduced by Tulkens and Vanden Eeckaut (1993), permits the construction of the frontier around a set of input and output vectors that are feasible up to the period *t*. Formally,

(12) $$H^t = \left\{ \left(x^s, y^s \right) : x^s \_produce\_ y^s \right\} \quad s = t, \quad t = 1,2,....T ,$$

meaning that observations in the past also form part of the reference technology where the output set is closed, limited, convex and determined as

(13) $$P^t(x^t) = \left\{ y^t : \left(y^t, x^t \right) \in H^t \right\}; \; t = 1,2,....T .$$

In this structure the incorporation of observations of the past implies the representation of knowledge accumulation by the units in time. At the same time it also improves the stability of the analysis in the case of a relatively small sample. In the sequential framework the distance function is defined as follows:

(14) $$D_o^s\left(x^t, y^t \right) = \min\left\{ \theta : \left(\frac{y_{m,j}^t}{\theta} \right) \in P^t\left(x^t \right) \right\}$$ and is calculated like

(15) $$\left[D_o^s\left(x^t, y^t \right) \right]^{-1} = \max_{\phi,\lambda \geq 0} \phi , \quad \text{where} \quad \phi = \frac{1}{\theta} , \text{ and}$$

s.t.
$$\begin{aligned}
&\phi \cdot y_{m,j}^t \leq \sum_{j=1}^{J} \sum_{s=1}^{t} y_{m,j}^s \cdot \lambda_j^s \\
&\sum_{j=1}^{J} \sum_{s=1}^{t} x_{n,j}^s \cdot \lambda_j^s \leq x_{n,j}^t \\
&\sum_{j=1}^{J} \sum_{s=1}^{t} \lambda_j^s = 1 \\
&\lambda_j^s \geq 0
\end{aligned}$$

Just like in the contemporaneous definition equation (15) refers to the assumption of variable returns to scale and by omitting the restriction $\sum_{j=1}^{J} \sum_{s=1}^{t} \lambda_j^s = 1$, the constant returns to scale assumption is represented. According to this modification the Malmquist productivity index changes and is written as:

$$MPI_o^s (y^{t+1}, x^{t+1}, y^t, x^t)^{RD} = \Delta T^S \cdot \Delta TE^S \cdot \Delta SE^S =$$

(16) $$= \left[\frac{D_o^s\left(x^t, y^t \right)}{D_o^{s+1}\left(x^t, y^t \right)} \cdot \frac{D_o^s\left(x^{t+1}, y^{t+1} \right)}{D_o^{s+1}\left(x^{t+1}, y^{t+1} \right)} \right]^{\frac{1}{2}} \cdot \frac{D_o^{s+1}\left(x^{t+1}, y^{t+1} \right)}{D_o^{s+1}\left(x^t, y^t \right)} \cdot \left[\frac{\dfrac{D_{oc}^s\left(x^{t+1}, y^{t+1} \right)}{D_o^s\left(x^{t+1}, y^{t+1} \right)}}{\dfrac{D_{oc}^s\left(x^t, y^t \right)}{D_o^s\left(x^t, y^t \right)}} \; \frac{\dfrac{D_{oc}^{s+1}\left(x^{t+1}, y^{t+1} \right)}{D_o^{s+1}\left(x^{t+1}, y^{t+1} \right)}}{\dfrac{D_{oc}^{s+1}\left(x^t, y^t \right)}{D_o^{s+1}\left(x^t, y^t \right)}} \right]^{\frac{1}{2}}$$

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[9] See the article of Arocena and Waddams (2002) incorporating bad outputs.

The adjacent distance functions are defined like:

(17) $$D_o^s\left(x^{t+1}, y^{t+1}\right) = \min\left\{\theta : \left(\frac{y^{t+1}_{m,j}}{\theta}\right) \in P^t\left(x^{t+1}\right)\right\}.$$

(18) $$\left[D_o^s\left(x^{t+1}, y^{t+1}\right)\right]^{-1} = \max_{\phi,\lambda\geq 0} \phi,\ \phi = \frac{1}{\theta},$$

$$\begin{aligned} & \phi \cdot y^{t+1}_{m,j} \leq \sum_{j=1}^{J}\sum_{s=1}^{t} y^s_{m,j} \cdot \lambda^s_j \\ \text{s.t. } & \sum_{j=1}^{J}\sum_{s=1}^{t} x^s_{n,j} \cdot \lambda^s_j \leq x^{t+1}_{n,j} \\ & \sum_{j=1}^{J}\sum_{s=1}^{t} \lambda^s_j = 1 \\ & \lambda^s_j \geq 0 \end{aligned}$$

(19) $$D_o^{s+1}\left(x^t, y^t\right) = \min\left\{\theta : \left(\frac{y^t_{m,j}}{\theta}\right) \in P^{t+1}\left(x^t\right)\right\}.$$

(20) $$\left[D_o^{s+1}\left(x^t, y^t\right)\right]^{-1} = \max_{\phi,\lambda\geq 0} \phi,\ \phi = \frac{1}{\theta},$$

$$\begin{aligned} & \phi \cdot y^t_{m,j} \leq \sum_{j=1}^{J}\sum_{s=1}^{t+1} y^s_{m,j} \cdot \lambda^s_j \\ \text{s.t. } & \sum_{j=1}^{J}\sum_{s=1}^{t+1} x^s_{n,j} \cdot \lambda^s_j \leq x^t_{n,j} \\ & \sum_{j=1}^{J}\sum_{s=1}^{t+1} \lambda^s_j = 1 \\ & \lambda^s_j \geq 0 \end{aligned}$$

Discomposing the sequential Malmquist productivity index modifies the interpretation of the technological change term (shift of the frontier). In this case given the incorporation of past observations in the determination of the frontier, the frontier can move only forwards but not backwards. This is a realistic supposition if we accept that plants accumulate knowledge and there is no “amnesia of technology”. In the rest of the decomposition factors there is no difference between the contemporaneous and sequential approaches.

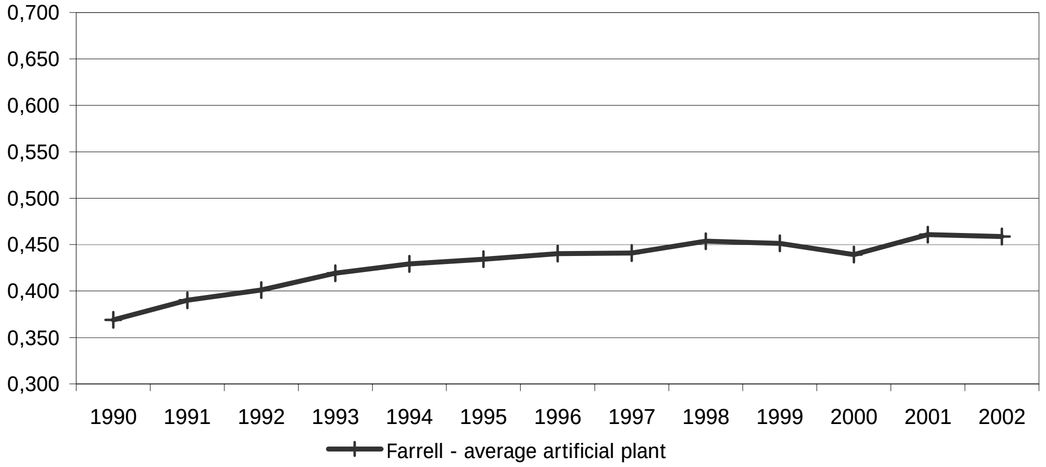
First and last, the application of the non-parametric methodology with sequential Malmquist productivity indexes permits to analyse not only those plants that are on the frontier, but also the ones that are inside the production frontier. Another advantage is that we can measure technological efficiency without aggregating variables and also without giving a monetary dimension to the analysis. This means that we treat data in physical terms, which reflects the microeconomic concept of minimising physical factors instead of the minimisation of costs. Furthermore, traditional approaches assume that according to marginal productivity all inputs adjust instantaneously to changes in prices without taking into account the costs of adjustment. This assumption is not applicable in the power sector since installed capacity cannot be adjusted to demand in every moment. Finally, by applying the sequential method we can measure the productivity efficiency in the limited sample of the Hungarian power plants in a consistent way.

VI.4. RESULTS

The empirical analysis on productivity efficiency was realised on the plants referred to in table 3 that are the base load fossil fuel plants of the Hungarian power system in the period of 1990-2002. As not all the 17 plants were operating in all of the years of the period, we have 12 observations in the first year of the sequential analysis and 181 in the last year. In order to represent the productivity evolution of the base load fossil fuel plants and compare the development of plants with the different fuel types, an average artificial plant was created by taking the arithmetic average of all variables in all years (13 observations) and also taking the arithmetic average of each of the three fuel groups (39 observations). This way we obtain an additional 52 observations that do not alter the construction and position of the production frontiers, but permit to obtain an average productivity for the plants without taking a weighted average of the productivity index. The same method is suggested by Førsund and Hjalmarson (1979) and Arocena and Waddams (2002) who argue that the construction of average artificial plants gives more accurate results on the average performance of the sector than taking the average of results.

As a first approach we represent the results of the basic distance functions with the supposition of constant returns to scale, which is also called Farrell efficiency measure. By calculating the Farrell indexes in an intertemporal[10] scheme all observations (181+52) were used for the construction of the production frontier. In the following figure the results of the average artificial plant are shown where the values can be interpreted as percentage points.

Figure 5. Average of the Farrell indexes of all plants and the Farrell indexes of the artificial average plant



It seems that at the beginning of the 90s the Farrell efficiency of the base load fossil fuel plants was at a very low level (35%) and during the period of 13 years it experienced an increase of about 10%. The tendency of the evolution is increasing at the beginning of the period, while after 1997 it seems to stagnate. Apparently there is no considerable positive effect of regulatory reforms. In the following figure we represent the results of the average artificial plants corresponding to the different groups.

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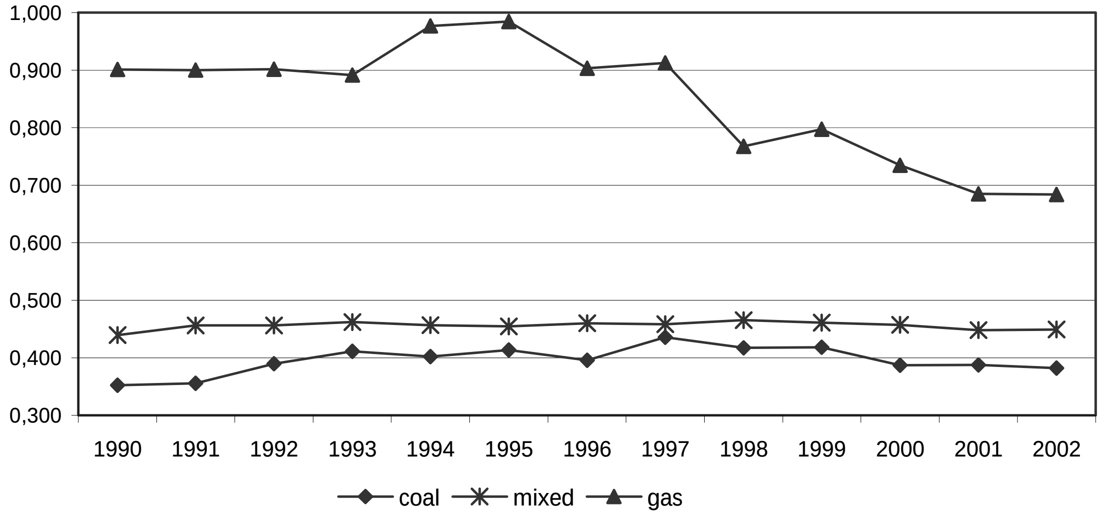
[10] For more details see Tulkens and Van der Eeckaut (1993).

Figure 6. Farrell indexes of the artificial average plant in each group



According to the Farrell efficiency index the most efficient group is formed by the gas turbines, as we were expecting it. However it is surprising that their efficiency reduces after 1995. The explication might be that in the following years there were more gas turbines put into operation and the overcapacity of the system was augmenting, while the relatively low utilisation of gas turbines caused the drawback of their results.

Now we turn to the dynamic Malmquist productivity indexes determined by Ray and Desli (1997) and apply the sequential $(MPI^{RD})^S$ described in the previous chapter. It should be noted that the $(MPI^{RD})^S$ is not transitive, so the indexes show year-to-year changes. Here we represent the annual changes of the average artificial plant and the growth rate of factors of the individual plants for the whole period.

It seems that productivity of base load fossil fuel plants increased especially at the beginning of the period reaching an annual 11% growth in 1990 and 7-8% in the following two years. This important increment is due, first of all, to the shift of the production frontier and to the more intensive utilisation of input resources as a consequence of import reduction. From 1995, the year when privatisation started, the sector seems to get stagnated; there is practically no shift of the production frontier, the technical efficiency term, which reflects the catching up effect, shows that in the mid 90s and in the last two years of the decade the heterogeneity of efficiency of the plants increased. This might be an affect of the reserves growing at a higher rate than national production, consequently the utilisation of potentially high efficient plants decreased. This phenomenon was also strengthened by the PPAs that might have made an influence on the establishment on the merit order of the plants, which not necessarily relied on the incremental cost principal.

Table 5. Decomposition of MPI^{RD}. Average artificial plant.

	ΔT^{s}	ΔTE^{s}	ΔSE^{s}	$(MPI^{RD})^{s}$
1990-91	1,123	0,965	1,021	1,106
1991-92	1,034	1,029	1,012	1,076
1992-93	1,056	1,012	1,005	1,074
1993-94	1,124	0,901	1,003	1,015
1994-95	1,169	0,872	1,005	1,025
1995-96	1,031	0,934	0,994	0,956
1996-97	1,004	1,023	1,009	1,036
1997-98	1,027	1,028	0,975	1,029
1998-99	1,000	0,991	1,004	0,994
1999-00	1,000	0,895	1,087	0,973
2000-01	1,007	1,062	0,982	1,049
2001-02	1,003	1,003	0,989	0,995

Studying the annual averages of $(MPI^{RD})^{S}$ a similar result is obtained by applying the Farrell efficiency indexes, that is to say that the gas turbines have the highest productive efficient indexes. However, it should be taken into account that most of the gas turbines were not operating at the beginning of the period and the three most efficient ones (Dunamenti Gt2, Debrecen and Csepel) were operating together only in the last two years of the period. In the case of Dunamenti Gt2 and Debrecen the decomposition factor of scale efficiency dominated the productivity efficiency scores reflecting that their utilisation permitted to reach high levels of productivity. At the same time, the utilisation of Csepel could have been potentially improved.

In the case of the coal plants the results show that Inota and Tiszapalkonya were loosing productivity efficiency along the period; Inota got closed in 2001 and Tiszapalkonya is going to be closed as well due to falling short of hitting the emission targets. The best coal plant is Mátra where a general retrofit reconstruction took place, which is reflected by its relatively high technological efficiency score. The rest of the plants are maintaining more or less their efficiency level, although in many cases their utilisation might be due to their heat production.

In the group of the mixed plants are those that have blocks that use both fuel oil and gas as combustion material. It should be noted that Dunamenti I. was closed in 2000 for finishing its economic life. The annual average productivity increase of Tisza II. and Dunamenti II. at the level of 3% and 4%, respectively, is basically due to the period of 1990-1994.

Table 6. Decomposition of MPI^{RD}. Individual results.

(annual average)

	plants	ΔT^s	ΔTE^s	ΔSE^s	$(MPI^{RD})^s$
Coal	Ajka	1,090	0,961	0,982	0,999
	Bánhida	1,059	0,969	0,993	1,012
	Borsod	1,049	0,921	1,019	0,979
	Inota	1,030	0,983	0,925	0,937
	Mátra	1,038	0,998	0,994	1,030
	Oroszlány	1,026	0,972	0,999	0,995
	Pécs	1,052	0,946	1,013	0,998
	Tiszapalkonya	1,040	0,928	1,020	0,969
Mixed	Tisza II	1,029	0,988	1,028	1,046
	Dunamenti I	1,070	1,072	0,922	0,944
	Dunamenti II	1,038	0,985	1,013	1,037
Gas	Dunamenti Gt1	1,035	0,988	0,995	1,017
	Dunamenti Gt2	1,003	1,001	1,185	1,132
	Kelenföldi	1,104	0,985	0,973	1,057
	Kelenföldi Kombi	1,004	0,994	0,997	0,994
	Debrecen	1,000	0,948	1,157	1,097
	Csepel	1,014	1,406	0,802	1,067

It is rather difficult to separate the effects of privatisation and regulatory reforms since they are too close in time. What seems to be reasonable is to compare, on one hand, the productivity efficiency results of public and private plants, and on the other hand, the results in the monopoly structure (1990-1996) with the scores during the single buyer model (1997-2002). According to the fact that non-parametric results do not have an interpretable distribution, we apply the non-parametric statistical tests of Wilcoxon / Mann-Whitney[11] and X^2.

Table 7. Results of non-parametric tests

	ΔT^s	ΔTE^s	ΔSE^s	$(MPI^{RD})^s$
Privatisation effect				
Wilcoxon/Mann-Whitney (Z)	**4.2852***	1.2627	0.1184	0.8190
Probability	**0.0000**	0.2067	0.9057	0.4128
X^2	**12.7448***	0.0000	0.0000	0.4213
Probability	**0.0004**	1.000	1.0000	0.5163
Single buyer model effect				
Wilcoxon/Mann-Whitney (Z)	**7.7834****	0.1832	0.8532	**2.8750****
Probability	**0.0000**	0.8546	0.3935	**0.0040**
X^2	**49.7528****	2.9729	1.9901	**7.1005****
Probability	**0.0000**	0.0847	0.1583	**0.007**

Note: In case of * public plants had significantly higher scores than private ones. In the case of ** the plants in the monopoly structure provide significantly higher scores than the ones in the single buyer model.

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[11] For further details see Brockett and Golany (1996).

According to the results of the non-parametric tests we have no clear evidence that the privatised plants have higher productivity efficiency scores than public plants. However, the technological change effect highlights that public plants reached higher scores than private ones. At the same time testing the effects of the introduction of the single buyer model shows that during the monopoly structure the productivity efficiency was higher than in the single buyer model when incentive regulatory tools were applied. This was due to the higher indexes of the technological efficiency in the monopoly model than in the other. Both testing procedures demonstrate that the production frontier has developed more at the beginning than at the end of the 90s that might indicate that neither privatisation nor the regulatory reform had the expected effects on productivity efficiency performance of the firms. This result can be explained by the fact that the PPA contracts might have diminished the effects of the introduced economic incentives.

The merit order of the power system is supposed to be based on the incremental costs in order to minimise the incurred costs of the system. In the incentive based regulatory framework the availability payments meant an annual fixed amount paid by the transmission company to the generation units in order to cover fixed costs of the plants, while the energy payments were to cover variable costs of generation. In this sense the merit order of the plants were determined basically by the energy payments. Taking into account that in the PPAs the parts contracted the quantity and price of power purchased by the single buyer from each generation company. This means that the PPAs could have had an influence on the establishment of payments for generation companies and could have made a distorting effect on the merit order; which did not necessarily reflect the technical and economic efficiency circumstances of the units dispatched. By realising the dispatch of generation units, the single buyer minimised its own costs taking into account not only the incremental cost principal of the system but also the possible penalties that it should have paid for the generation companies in case of lagging behind the contracted power generation.

In order to measure the losses assumed by the system in this circumstances, in the following table we present the real merit order in 2001 compared with two hypothetical merit orders, the first reflects an order according to the established energy payments of the units and the second takes our productivity efficiency findings as references for the establishment of the merit order. In the first column the generation units are shown with their corresponding utilisation rate in 2001. The generally low rate of utilization of the system, which oscillated between 0,25-0,75 in 2001 indicates that plants with low technical efficiency were also included in the merit order that at the same time did not leave enough free capacity for more efficient plants. In order to simulate an ideal case where only the efficient plants could function, we assume that the units that enter in the merit order should operate at a 0,9 utilisation rate level. This implies that in a merit order determined by the energy payments of the plants four aged coal plants (Ajka, Inota, Tiszapalkonya and Borsod) and a secondary reserve plant (Dunamenti II.) would not enter. Taking into account our $(MPI^{RD})^S$ results two coal plants and the same secondary reserve plant would drop out the merit order.

Table 8. Merit order according to different ranking and the variable costs of operation in 2001

	2001	Merit order according to incremental costs ranking	$(MPI^{RD})^S$
Plants entering in the merit order	Mátra (0.75)	Dm Gt1 (0.90)	Csepel (0.90)
	Dm Gt2 (0.72)	Mátra (0.90)	Kföld (0.90)
	Ajka (0.69)	Kföldi (0.90)	K.Kombi (0.90)
	Dm Gt1 (0.67)	K.Kombi (0.90)	Ajka (0.90)
	Bánhida (0.67)	Dm Gt2 (0.90)	Mátra (0.90)
	Csepel (0.63)	Csepel (0.90)	Tpalk. (0.90)
	Oroszlány (0.64)	Bánhida (0.90)	Dm. Gt1. (0.90)
	K.Kombi (0.45)	Pécs (0.90)	Inota (0.90)
	Borsod (0.44)	Oroszlány (0.90)	Bánhida (0.90)
	Pécs (0.43)	Tisza II (0.30)	Dm.Gt2. (0.90)
	Kföldi (0.42)		Pécs (0.90)
	Tisza II (0.35)		Tisza II (0.3)
	Inota (0.33)		
	Dm II. (0.28)		
	Tpalk. (0.25)		
Plants not entering in the merit order		Dm. II. Borsod Tiszapalkonya Inota Ajka	Dm. II. Oroszlány Borsod
Total variable costs	147653 million HUF	131666 million HUF	138564 million HUF

Note: 1) energy payments are published in the yearly modification of the Ministerial decree 55/1996. 2) In 2001 1 euro = 2568,68HUF. 3) The plant Debrecen is not included in the table.

Besides showing the plants that would not enter, the results highlight that according to the real merit order in 2001 the energy price payments were 12,14% higher than it would have been if the merit order had been set according to the established energy payments. Taking into account the efficiency scores of $(MPI^{RD})^S$, it would have resulted in saving 9089 million HUF on energy payments that makes a 6% of the amount paid in reality.

VII. CONCLUSIONS

Regulatory reforms in the Hungarian power sector studied in this paper comprise the unbundling of the monopoly structure and the establishment of a single buyer model, which is a transitory period before market conditions are met with. The efforts by the regulator-aimed efficiency improvements for which an incentive based regulatory framework was introduced after the restructuring and the privatisation process were finished.

Our results show that productivity efficiency was even higher during the monopoly structure than in the single buyer model. It demonstrates that at the beginning of the 90s the effect of intensively growing production in response to the reduction of imports had a more positive impact on productivity efficiency than regulatory reforms in the second half of the 90s. This might be explained that the long run PPAs could have narrowed effects of incentives introduced. According to the magnitude and time span of these contracts economic risks were eliminated for the majority of generators and as a consequence incentives put by price caps to reduce costs were considerably shrunk. In this scheme the exploitation of the system became rigid and was not necessarily determined by the incremental cost principal but by the obligations included in the contracts. This way the low utilisation rate of the overall system was also influenced by the PPAs because it contributed to maintain aged plants in operation and retain overcapacity in the system.

Regarding future developments, the opening of the electricity market in Hungary in 2003 and the fact that the share of PPAs is expected to fall in the coming few years might have a positive impact on productivity efficiency of the base load fossil fuel plants.

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