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Abstract

This paper analyses productivity growth and the nature of technical change in a sample of Portuguese hydroelectric generating plants over the period 2001 to 2004. In a first step, we employ the Luenberger productivity indicator to estimate and decompose productivity change. The results paint a picture of mixed productivity performance in the Portuguese energy sector. In a second step, we analyse the nature of this technical change by using the recent concept of parallel neutrality (Briec et al., 2006). We observe a global shift in the best practice frontier as well as evidence of input bias in technical change.

JEL: G21, D24

Keywords: hydroelectric energy, Portugal, Luenberger productivity indicator, parallel neutrality.

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1 Introduction

Efficiency at the level of the enterprise is a major issue in contemporary European economics, due to the ever more intense pressure that competition has exerted on prices since the adoption of the E.U.'s Single Market Programme (SMP). This was established in 1992 with the aim of facilitating the free movement of goods and services throughout the Member-States. In the energy industry, this competitive pressure has resulted in two stages of evolution: first, the deregulation of the former national markets (Kleit and Terrell, 2001); a second stage has seen an increase in competition, both internally and across borders, allowing for the entry of other national energy companies into what were formerly national markets. The changes observed in the market have obliged the energy companies to react, but strategic activity requires a sound, efficient basis if it is to yield successful results. Efficiency in energy has been analysed by Førsund and Kittelsen (1998), Edvardsen and Førsund (2003), Jamasb et al. (2004), Estache et al. (2004) and Farsi and Filippini (2004), Managi et al. (2004, 2005) and Nakano and Managi (2008) among others.

The present research is based on our observation of the various threats confronting the Portuguese energy sector at the present time. Among these, the growing number of major Spanish energy companies that have entered the Portuguese market as a result of the SMP has led to the above-mentioned competition with national players. This reveals the small dimension of most Portuguese energy companies, arising from the small size of the national market and the relatively low level of disposable income among Portuguese consumers. This small size restricts the possibility of expansion into the European market, as Portuguese energy producers lack the economies of scale that exist for larger enterprises, which can benefit from operating in several contiguous markets. However, in some but not all cases, the process of mergers and acquisitions has had the effect of increasing the size of energy companies through their purchase of larger shares of the market. Furthermore, a degree of saturation already exists in this energy market, implying that a continuing process of consolidation will serve to rationalise competition in the medium to long term, by removing the weaker players from the market. Another threat stems from the role played by the State and the policy that has prevailed in recent years. Despite the deregulation enforced by the E.U., the State is present in the market in the form of its holding of a golden share in the stock of EDP, which is the largest Portuguese energy company. This policy may restrict the growth of private companies, in addition to protecting EDP from acquisition by Spanish companies, which violates the spirit of the SMP. In addition, competition has been extended to the gas and petroleum sectors, with EDP buying the Portuguese company, Portugas and the Spanish oil company, Repsol-YPF buying Royal Dutch Shell (Gas and Liquid Petroleum) Portugal in 2004, when this company abandoned the Portuguese market. Finally, the regulatory agencies are suspected of collusion with EDP against the producers and consumers. This may result from wrong perceptions of the economic agents, or from the fact that usually personnel related to EDP, and in view of the State's golden share, the company is still managed like a public company. This paper aims to analyse the efficiency of EDP Hydroelectric generating plants[1] with in a new and original procedure. Along this line, the directional distance function and the Luenberger productivity indicator are used to identify the efficient and productivity scores of each unit analysed. This investigation stems from research carried out into an industry's best practices, based on the idea that the widespread application of these can lead to improved performance throughout the whole industry overcoming the above threats (Färe et al., 1983, 1985; Atkinson and Halvorsen, 1986; Pollitt, 1996). A complete survey of the existing literature can be found in Barros (2008). The paper is organised as follows: in section 2, we describe the contextual setting, considering the Portuguese energy sector in order to shed some light on the threats mentioned above; in section 3, we explain the theoretical framework supporting the model used; in section 4, we present the data and results; finally, section 5 is devoted to the discussion and conclusion.

[1]See Barros and Peypoch (2007, 2008) for an efficiency analysis using alternative methods.

2 Institutional Setting

EDP accounts for 82% of the installed capacity of energy production and 30% of the distribution capacity in Portugal, with 5.3 million clients. Therefore, it is a highly representative energy enterprise in the national market. EDP was created in 1975, when the country embarked on a process of nationalisation following the revolution of 25th April 1974. The enterprise was the product of the merger of several small private enterprises which were in the market before the nationalisations. On Portugal's entry into the EEC in 1986, the nationalisation process was reversed in many sectors. In 1991, EDP was transformed from a public enterprise into a limited liability company. Three years later, the company was divided into two parts, namely, production and distribution, constituting the EDP group. In 1997, the privatisation process saw the company's floatation on the stock exchange. 70% of its capital was dispersed. In the same year, EDP sold 70% of the distribution company to the State, retaining 30% of its stock. In order to produce energy, EDP operates electricity plants all over the country. The electricity production capacity by EDP in 2005 was estimated at 7,588 MW, of which 3,954 MW are from hydro plants, 3,505 MW are from thermoelectric plants (40% coal and 50% gas and heavy-fuel oil (HFO). Gas is used in combination with fuel and 29 MW are from wind plants. EDP is currently managed by a CEO appointed by the State, which retains this right by virtue of its golden share. The aim of the enterprise is to be representative in the Iberian Peninsula, and to this end, it has bought Hidrocantabrico (Hidroelectric del Cantábrico), the fourth-largest Spanish energy player, active in northern Spain. In addition, EDP has an African presence, owning Electra-Cabo Verde, the electricity enterprise of the Cabo Verde islands. In Central America, it owns the Guatemalan enterprise, EEGSA, while in Asia, it has CEM in Macau. Finally, the EDP has several enterprises in Brazil: Peixe Angical, Lajeado, Bandeirantes, Escelsa, Enersul, Enertrade and CERJ. As can be inferred, the company's global expansion strategy is almost exclusively restricted to countries with strong historic, economic and cultural ties to Portugal and with a common language. The governments of Spain and Portugal have agreed to establish a common energy market in the Iberian Peninsula, under the name, MIBEL (Mercado Ibrico de Energia Elctrica), which was initially planned to start in January 2002. The launch was then postponed until January 2005, and then in only a partial form. Under the MIBEL, all clients with very high voltage, high tension or medium tension consumption will be able to choose their suppliers. This will increase the competition for market share among the electricity enterprises. The principal cause for the postponement of the MIBEL is the strategic delay of common market practice by the two Iberian governments. This is due to the fact that they seek achieve a national leadership advantage for the national energy companies, based on a market solution, which would safeguard the national interest, but at the same time slows down the energy regulation harmonisation. National interest is a political concept and hence, the causes for the delay are political. The most recent allocation of energy licences for electricity production in Portugal (energy plants of combined cycle), the results of which were announced on 23rd February 2005 by the Ministry of Economy, has awarded two plants to EDP - one in Figueira da Foz and the other in Sines - amounting to 860 MVA, which corresponds to 27.5% of all power allocated. The Spanish energy company, Iberdrola was also granted a licence to construct a plant of 457 MVA in Figueira da Foz. Another Spanish company, Endesa received a licence to build a plant with a capacity of 430 MVA, also in Sines. Galp, the Portuguese oil company received a licence to built a plant with a capacity of 430 MVA, initiating this company's activity in electricity production. Finally, Tejo Energia received a licence for a plant with a capacity of 940 MW. This enterprise currently exploits a thermoelectric plant in Pego, near Lisbon. All of the new plants are due to be operational by 2008.

EDP has dispersed in stock exchange the capital of a new company named EDP Renovaveis, on May 2008, focusing on wind energy after buying the USA company Horizon Wind.

3 Methodology

3.1 The Luenberger Productivity Indicator

Represent inputs by $x \in \mathbb{R}^n_+$ and outputs by $y \in \mathbb{R}^p_+$. The production set T_t is the set of all the input-output vectors $(x, y) \in \mathbb{R}^{n+p}_+$ such that

$$T_t = \left\{(x, y) \in \mathbb{R}^{n+p}_+ : x \text{ can produce } y \text{ at } t\right\}. \tag{3.1}$$

Let $L_t : \mathbb{R}^p_+ \longrightarrow 2^{\mathbb{R}^n_+}$ denote the input correspondence that maps all $y \in \mathbb{R}^p_+$ to input sets capable of producing them

$$L_t(y) = \left\{x \in \mathbb{R}^n_+ : (x, y) \in T_t\right\}. \tag{3.2}$$

The output correspondence $P_t : \mathbb{R}^n_+ \longrightarrow 2^{\mathbb{R}^p_+}$ maps all $x \in \mathbb{R}^n_+$ into sets of outputs that can be produced by those inputs:

$$P_t(x) = \{y \in \mathbb{R}^p_+ : (x, y) \in T_t\}. \tag{3.3}$$

We have

$$(x, y) \in T_t \iff x \in L_t(y) \iff y \in P_t(x). \tag{3.4}$$

For all vectors z, w in $\mathbb{R}^m$ we denote $z \leq w$ if $z_l \leq w_l$ for all $l = 1 \cdots m$.

We impose standard properties on the technology:
T1: $(0, 0) \in T_t$, $(0, y) \in T_t \Rightarrow y = 0$ i.e., no fixed costs and no free lunch;
T2: the set $A(x) = \{(u, y) \in T_t : u \leq x\}$ of dominating observations is bounded $\forall x \in \mathbb{R}^n_+$, i.e., infinite outputs cannot be obtained from a finite input vector;
T3: T_t is closed;
T4: For all $(x, y) \in T_t$, and all $(u, v) \in \mathbb{R}^{n+p}_+$, we have $(x, -y) \leq (u, -v) \Rightarrow (u, v) \in T_t$ (free disposability of inputs and outputs);
T5: T_t is convex.

Assumptions T1-T5 imply that for all $(x, y) \in T$, the subsets $L_t(y)$ and $P_t(x)$ are closed, convex and satisfy free disposability.

The directional distance function $D_t : \mathbb{R}^{n+p}_+ \times \mathbb{R}^{n+p}_+ \longrightarrow \mathbb{R} \cup \{-\infty\} \cup \{+\infty\}$ is defined by:

$$D_t(x, y; h, k) = \begin{cases} \sup\{\delta : (x - \delta h, y + \delta k) \in T_t\} & \text{if } (x - \delta h, y + \delta k) \in T_t \text{ for some } \delta \in \mathbb{R} \\ -\infty & \text{otherwise} \end{cases}$$

The definition implies $D_t(x, y; 0) = +\infty$. However, the direction $g = (h, k)$ is fixed, and hence we suppose that $g \neq 0$. Detailed properties of the directional distance function can be found in Chambers et al. (1996, 1998).

The directional distance function is a function representation of the technology, namely

$$(x, y) \in T_t \Leftrightarrow D_t(x, y; g) \geq 0.$$

$D_t(\cdot; g)$ is also concave and continuous on the interior of $\mathbb{R}_+^{n+p}$.

If $h \neq 0$ and $k \neq 0$ then:

$$D_t(x, y; h, 0) \geq 0 \iff x \in L_t(y) \quad \text{and} \quad D_t(x, y; 0, k) \geq 0 \iff y \in P_t(x). \tag{3.5}$$

Following Chambers (1996) one can introduce a Luenberger productivity indicator to measure the productivity changes between two time periods. This Luenberger productivity indicator is defined by

$$\begin{aligned} L(x_t, y_t, x_{t+1}, y_{t+1}; g) = \frac{1}{2} [\, & D_{t+1}(x_t, y_t; g) - D_{t+1}(x_{t+1}, y_{t+1}; g) \\ & + D_t(x_t, y_t; g) - D_t(x_{t+1}, y_{t+1}; g) \,] . \end{aligned} \tag{3.6}$$

Positive growth (decline) is indicated by positive (negative) value. The Luenberger productivity indicator is additively decomposed as follows

$$\begin{aligned} L(x_t, y_t, x_{t+1}, y_{t+1}; g) =& [\, D_t(x_t, y_t; g) - D_{t+1}(x_{t+1}, y_{t+1}; g) \,] \\ & + \frac{1}{2} [(\, D_{t+1}(x_{t+1}, y_{t+1}; g) - D_t(x_{t+1}, y_{t+1}; g) \,) \\ & + (\, D_{t+1}(x_t, y_t; g) - D_t(x_t, y_t; g) \,)] , \end{aligned} \tag{3.7}$$

where the first term (inside the first brackets) measures efficiency change between periods t and $t + 1$. Hence, we denote:

$$EFFCH = D_t(x_t, y_t; g) - D_{t+1}(x_{t+1}, y_{t+1}; g). \tag{3.8}$$

The second term (inside the second brackets) captures the technical change component and represents the shift of technology between periods t and $t+1$. Thus, technical change is denoted as:

$$\begin{aligned} TECH = \frac{1}{2} [\, & (\, D_{t+1}(x_{t+1}, y_{t+1}; g) - D_t(x_{t+1}, y_{t+1}, g) \,) \\ & + (\, D_{t+1}(x_t, y_t, g) - D_t(x_t, y_t, g) \,) \,] . \end{aligned} \tag{3.9}$$

This decomposition was proposed in Chambers and Pope (1996) and inspired from the decomposition of the Malmquist index in Färe et al. (1994). Figure 1 shows the Luenberger productivity indicator.

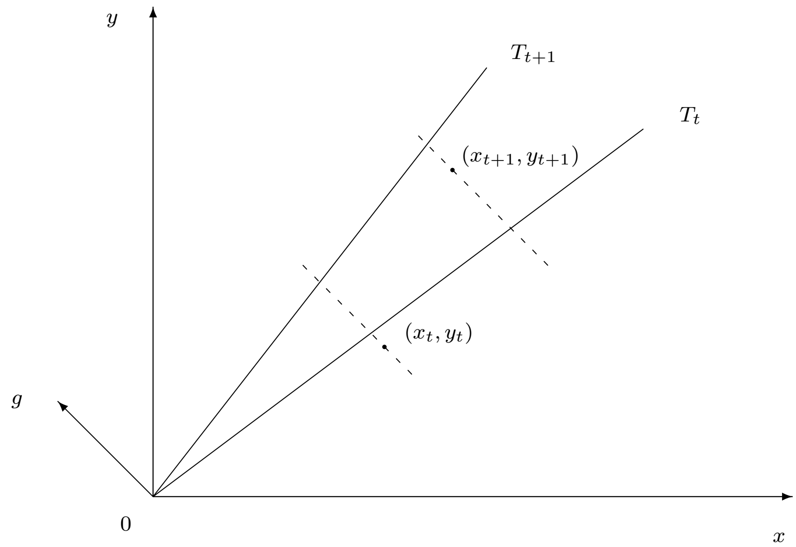

Figure 1. Luenberger productivity indicator.

3.2 Biased and Neutral Technical change

Briec et al. (2006) have introduced a notion of input-neutral technical change that requires the input set to be representable as a translation in the direction of h of an input set that is independent of the state of technology. Output-neutral technical change requires that the output set be representable as a translation in the direction of k of an output set independent of the state of technology.

Namely, the production technology exhibits *parallel input-neutral technical change* in the direction h if:

$$L_t(y) = \hat{L}(y) + A(y, t)h. \tag{3.10}$$

Figure 2 shows the parallel input-neutral technical change.

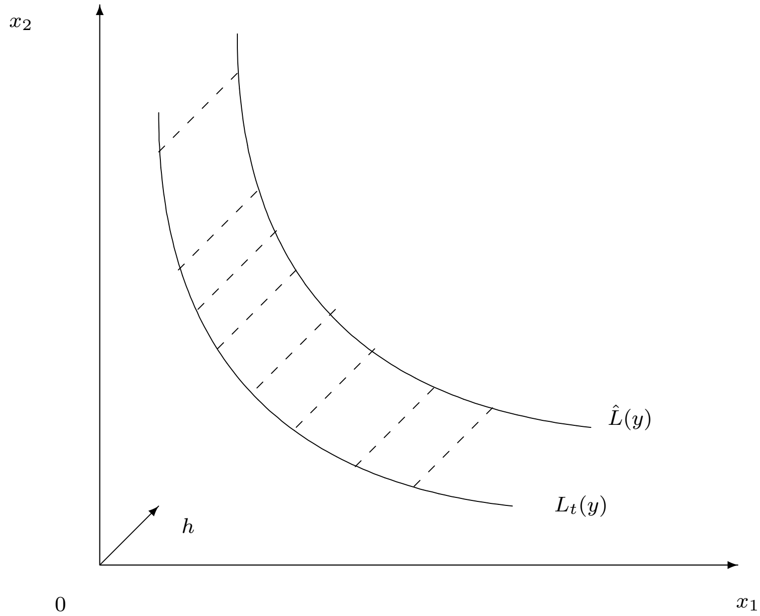

Figure 2. Parallel input-neutral technical change.

The technology exhibits *parallel output-neutral technical change* in the direction k if:

$$P_t(x) = \hat{P}(x) + B(x,t)k. \tag{3.11}$$

Following Färe and Grosskopf (1996), it can be stated that, without simultaneous neutrality, we must consider the possibility of both input and output biased technical change.

According to Briec and Peypoch (2007), the output biased technical change is defined by:

$$\begin{aligned} OBTECH = \frac{1}{2}\,[\ (\ D_t(x_{t+1}, y_{t+1}; g) - D_{t+1}(x_{t+1}, y_{t+1}; g)\ ) \\ +\ (\ D_{t+1}(x_{t+1}, y_t; g) - D_t(x_{t+1}, y_t; g)\ )\ ]\,. \end{aligned} \tag{3.12}$$

Holding the input vector fixed at x_{t+1}, $OBTECH$ is the arithmetic mean of the technical change in the direction of g with respect to y_{t+1} and y_t, and measures the output bias of technical change.

Symmetrically, the input biased technical change is defined by:

$$\begin{aligned} IBTECH = \frac{1}{2}\,[\ (\ D_{t+1}(x_t, y_t; g) - D_t(x_t, y_t; g)\ ) \\ +\ (\ D_t(x_{t+1}, y_t; g) - D_{t+1}(x_{t+1}, y_t; g)\ )\ ]\,. \end{aligned} \tag{3.13}$$

Holding the output vector constant at y_t, $IBTECH$ is the arithmetic mean of the technical change in a direction g with respect to x_{t+1} and x_t. Therefore, it measures the input bias of technical change.

It is then possible to provide a decomposition of the technical change. Combining equations (3.12) and (3.13) the technical change component can be expressed as

$$TECH = OBTEC + IBTECH + MATECH, \tag{3.14}$$

where

$$MATECH = D_t(x_t, y_t; g) - D_{t+1}(x_t, y_t; g) \tag{3.15}$$

$MATECH$ measures the magnitude of technical change in the direction g through period t data.

Technology is Hicks neutral whenever the marginal rate of substitution between any inputs is unaffected by technical change. This corresponds to an "homothetic shift" in the isoquants. Conversely, technical change is Hicks biased if it is not Hicks neutral, i.e. if the marginal rate of substitution between any inputs (outputs) is affected by technical change. This corresponds to a "non-homothetic shift" in the isoquants. Hence, if technical change is biased then it tends to influence the relative contribution of each input to the production process.

Following, Briec and Peypoch (2007), it can be stated that technical change is output parallel neutral if and only if technology exhibits graph translation homotheticity and $OBTECH = 0$. Then, there is no output biased technical change if and only if the technology exhibits implicit directional Hicks output neutrality. Hence on the output side, bias is measured against this type of neutral technical change. Moreover, technical change is input parallel neutral if and only if technology exhibits graph translation homotheticity and $IBTECH = 0$.[2]

Along this line, we use a non-parametric approach (Charnes et al, 1978) for estimating each distance function. Therefore, the subset

$$\hat{T} = \left\{ (x, y) \in \mathbb{R}_+^{n+p} : (-x, y) \leq \sum_{j=1 \ldots J} \theta_j(-x^j, y^j) + \mu(h, k), \theta_j \geq 0 \right\}. \tag{3.16}$$

[2]Details of the proofs are in Briec and Peypoch (2007).

is introduced, where $A = \{(x^1, y^1), \cdots, (x^J, x^J)\}$ is a set of J observed activities such that $y^j \neq 0$ for all $j \in J$.

The subset $\hat{T}$ of $\mathbb{R}_+^{n+p}$ defined in equation (3.16) is a closed convex set satisfying free disposability and graph translation homotheticity.
Hence, an empirical analysis is then possible by calculating the Luenberger productivity indicator and its components. This we do using the following linear programming model that calculates each directional distance function:

$$\begin{aligned} D_{t+1}(x_{t+1}, y_t; h, k) = &\max \ \delta \\ \text{s.t.} \quad & x_{t+1} - \delta h \geq \sum_j \theta_j x_{t+1}^j - \mu h, \\ & y_t + \delta k \leq \sum_j \theta_j y_{t+1}^j + \mu k, \\ & \theta_j \geq 0, \quad \delta \geq 0. \end{aligned} \tag{3.17}$$

In this program, technology is defined from period $t + 1$, the output observation from t and the input observation is from $t + 1$; symmetrically, it is possible to obtain linear programs for each directional distance function constituting the technical change component.

4 Data and Results

4.1 Data

Frontier models require the identification of inputs (resources) and outputs (transformation of resources). Several criteria can be used in their selection. The first of these, an empirical criterion, is availability. Secondly, the literature survey is a way of ensuring the validity of the research and thus represents another criterion to be taken into account. The last criterion for measurement selection is the professional opinion of relevant individuals. In this paper, we abide by all three of the above-mentioned criteria and take into account the overview by Pollitt (1995). To estimate the production frontier, we used panel data for the years 2001 to 2004, obtained from EDP, on 25 hydroelectric plants (4 years 25 plants = 100 observations). The hydroelectric plants that are considered in this analysis are listed in Table 3. We respected the DEA convention that the minimum number of DMUs is greater than three times the number of inputs plus output (100 observations > 3(2+1)) (Vassiloglou and Giokas, 1990; Dyson et al., 2001). We measured energy production according to a production function. We measured output by: (i) energy production in MWh, which is a common form of output measurement in electricity research. The inputs are: (ii) labour, measured by the number of equivalent workers; (iii) capital proxied by the book value of physical assets.

In this study the technology produces only one output, thus $OBTECH = 0$.

Table 1. Characteristics of inputs and outputs, 2001-2004

Variables	Minimum	Maximum	Mean	Stand. Dev.
Output				
Production in MWh	40963	1394705	444468	360571
Inputs				
Number of workers	2	39	14	10.10
Capital (Euros 2001=100)	26859445	694798106	253029654	182844098.2

We note that the average EDP hydroelectric generating plant is characterised as having a high level of heterogeneity.

4.2 Results

The Luenberger productivity indicators are calculated using linear programming techniques. The results are presented in Table 3, with the productivity indicators decomposed into its constituents: technical efficiency change (the diffusion or catch-up component - EFFCH); and technical change (the innovation or frontier-shift component - TECH). EFFCH represents the diffusion of best-practice technology in the management of plants and it is attributable to investment planning, technical experience, and management and organization. TECH results from innovations and the adoption of new technologies by best-practice plants in each country.

Table 2. Average technically efficient change and technological change observed in Portuguese hydroelectric plants: 2001-2004

Hydroelectric Plants	EFFCH Efficiency Change	TECH Technological Change	Productivity Change
Cvado-Lima River Dams			
Alto Lindoso	0	0,0611	0,0611
Touvedo	0,0248	0,0601	0,0849
Alto Rabagão	0,0423	0,0696	0,1119
Vila Nova	0,0252	0,0687	0,0939
Salamonde	0	0,0307	0,0307
Vil. Furnas	0	0,0252	0,0252
Caniçada	0	0,0231	0,0231
Douro Dams			
Miranda	0,0421	0,0307	0,0728
Picote	0	0,049	0,049
Bemposta	0,0298	0,0419	0,0717
Pocinho	0,0223	0,0254	0,0477
Valeira	0	0,0451	0,0451
Tabuaço	0	-0,0105	-0,0105
Régua	0	0,0252	0,0252
Carrapatelo	0	0,0418	0,0418
Torrão	0	0,0217	0,0217
Crestuma	0	0,0096	0,0096
Tejo-Mondego Rivers Dams			
Caldeirão	-0,0059	0,0423	0,0363
Aguieira	-0,0039	0,0307	0,0268
Raiva	-0,0042	0,0269	0,0228
Cabril	-0,0084	0,0425	0,0341
Bouçã	-0,0105	0,0428	0,0324
Castelo do Bode	-0,0062	0,0281	0,0219
Fratel	0	-0,0059	-0,0059
Pracana	0,0926	0,0428	0,1355
Mean	**0,0096**	**0,0347**	**0,0443**
Median	**0**	**0,0307**	**0,0341**
Std. Dev	**0,0231**	**0,0198**	**0,0348**

In Table 2, we can see that the productivity change score is positive for almost all plants, except for Tabuaço and Fratel, showing that a large proportion of the hydroelectric plants experienced gains in total productivity in the period considered. The mean Luenberger score is 0.0443, which, since it is higher than zero, signifies that for the majority of the plants, productivity increased in the period. However, there are fifteen plants with an indicator lower than the mean, signifying that these plants must improve their productivity. The change in the technical efficiency score is defined as the diffusion of best-practice technology in the management of the activity and is attributed to investment planning, technical experience and management and organisation in the energy production sector. For the period under analysis, we can see that it is positive for nineteen hydroelectric plants, signifying that there was an increase in technical efficiency in the period. However, for a proportion of plants, the change in technical efficiency is negative, signifying that there was a regression in this respect in the period. Technological change is the consequence of innovation, i.e. the adoption of new technologies, by best-practice hydroelectric plants. Its mean value is 0.0347, and this indicator is higher than zero for almost every plant, with the exception of only two plants out of the 25 analysed. This indicates that innovation improved in the period for almost all plants, meaning that there was investment in new technologies (methodologies, procedures and techniques) and in the commensurate skills upgrades related to this. However, regarding the two plants showing a downward movement in terms of technological change, this is a primary area of concern. Overall, we observe four combinations of technical efficiency change and technological change: (i) In the first group, we find sixteen plants in which improvements in technical efficiency co-exist with improvements in technological change. These are the best-performing hydroelectric plants in the period, with improvements registered in technical efficiency, denoting upgraded organisational factors associated with the use of inputs and outputs, as well as the relationship between inputs and outputs. It includes all plants with exception of Tabuaço, Caldeirão, Aguieira, Raiva, Cabril, Bouçã, Castelo do Bode and Fratel. (ii) In the second group, we find two hydroelectric plants in which improvements in technical efficiency co-exist with deterioration in technology. These are plants with upgraded organisational factors, but without the innovation inherent in investment in new technology, which would provide leverage for the organisational factors. These plants need to acquire new technology and the necessary commensurate skill upgrades in order to improve their performance. The group includes the two plants, Tabuaço and Fratel. (iii) In the third group, we find six hydroelectric plant in which improvements in technological efficiency co-exist with deterioration of technical efficiency. This plant needs to upgrade its managerial skills and scale in order to improve its performance. This includes Caldeirão, Aguieira, Raiva, Cabril, Bouçã and Castelo do Bode. (iv) In the fourth possibility, in which deteriorating technical efficiency co-exists with deteriorating technology, we find no hydroelectric plants. Hence, our findings encompass several combinations of efficiency change, signifying that there is room for adjustment in almost all plants in order to achieve best-practice procedures in energy production.

The total productivity improvement results from technological change, rather than efficiency change. Technical improvement is attributed to management skills and therefore, the results suggest that this attribute is lacking in the management of EDP's hydroelectric generating plants. Now, we examine the nature of the technological change and then we test the assumption of parallel neutrality (Briec et al., 2006).

Table 3 shows that technical change in the majority of Portuguese plants is captured by the input biased variable (IBTECH), which suggests there is not a global neutral shift in the best practice frontier between 2001 and 2004. Roughly speaking, except for some plants which have IBTECH scores close to 0, the others had almost biased technical change. Then, on average, the marginal rate of substitution between plant inputs is affected by technical change, which in the present case is the marginal rate of substitution between labour (number of workers) and capital. Therefore, the assumption of parallel neutrality is rejected. This implies that the traditional growth accounting method cannot be used in Portuguese energy sector since growth accounting assumes the Hicks neutrality of technological change.

Table 3. Technical Change Decomposition

Hydroelectric Plants	IBTECH	MATECH	TECH
Cvado-Lima River Dams			
Alto Lindoso	0,0432	0,0179	0,0611
Touvedo	0,0498	0,0103	0,0601
Alto Rabagão	0,0501	0,0195	0,0696
Vila Nova	0,0518	0,0169	0,0687
Salamonde	0,0153	0,0154	0,0307
Vil. Furnas	0,0098	0,0154	0,0252
Caniçada	0,0099	0,0132	0,0231
Douro Dams			
Miranda	0,0123	0,0184	0,0307
Picote	0,0318	0,0172	0,049
Bemposta	0,0321	0,0098	0,0419
Pocinho	0,0115	0,0139	0,0254
Valeira	0,0297	0,0154	0,0451
Tabuaço	0,0005	-0,011	-0,0105
Rgua	0,0101	0,0151	0,0252
Carrapatelo	0,0196	0,0222	0,0418
Torrão	0,0088	0,0129	0,0217
Crestuma	0,0025	0,0071	0,0096
Tejo-Mondego Rivers Dams			
Caldeirão	0,0167	0,0256	0,0423
Aguieira	0,0122	0,0185	0,0307
Raiva	0,0099	0,0170	0,0269
Cabril	0,0208	0,0217	0,0425
Bouçã	0,0264	0,0164	0,0428
C.Bode	0,0073	0,0208	0,0281
Fratel	0,0011	-0,007	-0,0059
Pracana	0,0301	0,0127	0,0428

5 Discussion and Conclusion

The general conclusion is that based in the Luenberger productivity indicator, there are room for the hydroelectric companies to improve their productivity in the period in order to upgrade their performance toward the frontier of best practices. This situation applies to plants in which improvement in technical efficiency co-exists with deterioration in technological change (Tabuaço and Fratel) and plants in which improvement in technological efficiency co-exists with deterioration of technical efficiency (Caldeirão, Aguieira, Raiva, Cabril, Bouçã and Castelo do Bode). These results signify that the average hydrolelectric Portuguese dam is catching up with the industry best practice, but there is room for inefficient plants to adjust to the industry best practice frontier.

How do we explain these results? DEA does not explains the causes of efficiency, and only identifies the inefficient plants and slacks on inputs and outputs (Talluri, 2000). Assuming that management is relatively homogenous among different hydroelectric plants, what differentiate it is rainy conditions on the geographical area they are located, a result that is validated by the plants in the northern rainy region of Cvado-Lima displaying higher productivity change. Furthermore, age may play a role in efficiency, since older plants may be less efficient in transforming water in energy (Barros, 2008).

From the application of the technical change decomposition, there appears to have been a global shift in the best practice frontier, and this is the overall driver of technical change. The input bias identified signifies that the EDP hydroelectric plants substituted labour by capital in the period, a policy that has contributed to productivity improvement. This implies that technical change has affected the marginal rate of substitution between hydroplants inputs. For those plants, the production technology is not Hicks neutral.

Future research should focus on the determination of the trend directions of technical change biases in order to show if this last is labour-using or capital-using (Weber and Domazlicky, 1999; Färe et al., 2001; Managi and Karemera, 2004).

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