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A Theoretical Approach for Estimating Learning Curves in the Presence of Administered Prices

Adriana Agapie*, Tony Lima** and Oana Peia***

*Bucharest Academy of Economic Studies, Romania**
adriana.agapie@csie.ase.ro
*California State University East Bay, Hayward,CA,USA***
tony.lima@csueastbay.com
*ESSEC, Cergy, France****
oana.peia@essec.edu

Abstract

It is in general admitted that low administered prices for resources in producing energy conduces to distortions in the input mix, in the sense of the inefficient usage of the resources. The purpose of this research is to provide an enhanced theoretical model for estimating learning curves in the presence of sticky input factor prices. We consider a particular homogeneous functional form for representing the potential distortions in the input-factor quantities in the context of deriving Cobb-Douglas cost functions and such a representation can offer a justification for why the average cost may behave erratically although the technology remains unchanged. In this context it is also possible to determine a theoretical model for the effect of the administered prices on the derivation of the learning curves.

Keywords: *Learning Curves, Administered Prices*

1. Introduction

The presence of flexible returns to scale is acknowledged in several studies (see Isoard and Soria, 2001) in the context of assessing their effects on the renewable energy capital cost reduction. This variability influences the outset innovation deployment and often calls for an institutional commitment in supporting innovation, based on the claimed long term constancy (decreasing) returns to scale. Thus, learning curves often encapsulating R&D annual expenditures are included in the production function as endogenous factors to contribute to the technical change explanations.

While it is widely acknowledged that renewable energy technologies, as an emergent industry, is dependent on the correspondent scale economy (Soete, 1997), this fact is of particular importance for Romania. Although this country has a recognized potential for large windmill parks, the actual investments in such are made more costly by high administered prices for input factors such as land and grid connections. At the same time, the demand side is equally problematic, with low administered prices for classical energy. Moreover, as a member of the EU, Romania's target is to provide 38% of its energy consumption through renewable energy by 2020[1]. Thus important policies ought to be implemented to achieve a technological regime shift from conventional fossil-fuel resources to renewable resources.

An extensive literature has tried to pin-point the factors which explain the "lock-in" on conventional energy resources which is seen in this industry (Kahouli-Brahmi, 2009). By studying the scale economies, learning effects and the process through which technological change occurs, this literature aims to provide important policy directions which can enable a transition to the emerging renewable energy systems. The main methodology employed to uncover all these issues are learning curves. However, previous empirical studies provide little consensus on the size of the learning curves (Soderholm and Sundqvist, 2007). We argue here that the effect of administered prices has a non-negligible impact on the estimations of learning curves.

The findings, enhanced with theoretical considerations of administrated prices built in this research, will be put in perspective and compared with influential econometric estimations of learning curves.

2. Literature review

Broadly speaking, learning curves capture the increased productivity induced by experience, namely a decrease in unit costs as production experience accumulates (Arrow, 1962). This creates a downward shift of the average cost curve.

In capital intensive industries, the technological progress is partly characterized by the use of the learning curves e literature (see Jamasb and Kohler, 2007). The most common representation of learning curves is derived from a Cobb-Douglas cost function as an exponential regression of the form

$$c = aQ^{\alpha} \tag{1}$$

where c is the cost per unit, Q is the cumulative output, a is the cost of the first unit produced and α is the elasticity of the learning by doing (Berndt, 1991). A logarithmic form of equation (1) is usually estimated empirically to determine the learning elasticity:

$$\ln(c_t) = \ln(a_t) - \alpha \ln(Q) + \varepsilon_t \tag{2}$$

There is a significant flow of empirical literature in which it has been estimated the model in equation (2) as well as other enhanced specifications (see, *inter alia*, Kahouli-Brahmi, 2009).

Several methodological concerns have been pointed out in the empirical estimations of learning curves (see Soderholm and Sundqvist, 2007, for an overview). First, issues of endogeneity arise due to the fact that cumulative output is also correlated with unit cost through the fact that decreasing unit costs encourage investments in capacity which will, in turn, lead to higher output.

[1] European Bank for Reconstruction and Development, "Romania Country Profile", available online: http://www.ebrdrenewables.com/sites/renew/countries/Romania/profile.aspx

Second, omitted variable bias also poses methodological issues. Other variables clearly influence costs and, most importantly, in the light of this research proposal, these include input prices and scale effects. Soderholm and Sundqvist (2007) clearly point out the need to derive learning curves such as the ones in equation (1) from a coherent microeconomic framework. Thus, following (Berndt, 1991) and Isoard and Soria (2010) learning curves are estimated from a Cobb-Douglas cost function as a way to accommodate for the effect of input prices and scale effects. Their specification assumes that the impact of input prices is reflected by the GDP deflator so they use the real rather than the current level of unit cost to remove the price terms from the Cobb-Douglas cost function. However, in the case of administered prices this method may not be as efficient. We propose here an enhanced specification which will allow us to directly incorporate any input prices changes through a Cobb-Douglas specification that explicitly allows for variable input prices.

In addition, along with the econometric issues of omitted variables bias and endogeneity, the choice of the variables is also problematic. Production costs and prices (which are taken as proxies for costs in many of the studies), might be affected by other factors apart from production efficiency. For the energy sector, the rate of subsidization is our main focus. In particular, if the rate of subsidization is kept constant for long periods of time, the fluctuations in the unrestricted correspondent market prices are reflected into variable input-factor quantities purchased, often in the form of an inefficient usage of the resources. This will lead to biased and uninformative estimations of the learning curve parameters (Kahouli-Brahmi, 2009).

The set of problems created by administered prices can be thus subsumed to the group of difficulties centred on the usual derivation of learning curves based on a Cobb-Douglas technology and assuming fixed input prices (based on the assumption of perfect competition in factor markets). We argue here that this assumption is not realistic in general and, even more so, in energy sectors which are usually using input factors representing the output of natural monopolies (gas, coal).

All the above caveats reinforce our belief that accurate estimations of learning curves ought to be derived from modified Cobb-Douglas representations, as the one proposed here, which allow for variable factor prices.

The importance of obtaining reliable estimates of learning rates has been recently underlined by Soderholm and Sundqvist (2007). They argue that the significant discrepancies identified in learning rates in empirical estimations are due to methodological and theoretical issues that are not thoroughly addressed. Since these energy models have important implications for the timing and cost of environmental policies, Soderholm and Sundqvist (2007) urge on the need to provide more reliable estimates of the learning rates. Our purpose is to contribute to the theoretical understanding of the learning rate formation by acknowledging that as a counterpart of the learning curve effects, the production can shift to a different cost curve due also due to the effect of a variation in input prices.

In section III we develop a theoretical model to account for the influence of the administered prices on the average cost curves assuming Cobb-Douglas technology. This model is proved to encompass the traditional one claiming the one to one correspondence between returns to scale and economies to scale under fixed input prices. Thus, additionally, issues regarding the possible identification of the pressures on the prices will be theoretically addressed. As a conclusion, the main body of research will provide an enhanced formulation of the learning curves following (Berndt, 1991), Isoard and Soria (2010) and Soderholm and Sundqvist (2007).

3. The economics of learning curves in the presence of administered prices

In this section we will provide an overview of the theoretical framework we will develop in this research and its applicability in estimating learning curves.

3.1. The Effect Of Administered Prices On The Cobb-Douglas Cost Curve

If a firm's technology exhibits increasing returns to scale, then a decrease in factor prices will induce the firm to purchase greater input quantities, and output will increase. By increasing the scale of the operation, the firm can further reduce its average cost simply by moving right on the long-run average cost curve. This happens with fixed technology.

On the other hand, if a firm is aware either about its present returns to scale or about its average cost's monotonicity with respect to the output, then if it observes that for the same input price it may buy more input factors, it might think that it would be a good idea to increase its scale of operations. We'll briefly sketch in this section that the assumption of a fixed technology combined with pressures on the input prices can lead to any behaviour of the average cost with respect to the output. This is necessary to better illustrate how the learning curves will be theoretically derived to accommodate for the effect of administered input factor prices. We'll use as an example a two-variable Cobb-Douglas production function.

Assume a two variable Cobb-Douglas production function

$$f(K, L) = AK^{\alpha}L^{\beta} \tag{3}$$

For reasons that will soon become clear we call this the *unenhanced Cobb-Douglas production* function. This production function is linearly separable, homogeneous of order $r = \alpha + \beta$ and concave iff $0 < \alpha, \beta < 1$. If the price of one unit of K (w_K) or L (w_L) is kept fixed, then all adjustments in the capital/labor markets will be quantity adjustments. This can be equally represented through the assumption that the input prices for capital and labour depend on the quantities of capital and labour, respectively, as in the following notation: $w_K = w_K(K)$, $w_L = w_L(L)$. For instance, in the theory of estimated shadow prices, $w_K = w_K(K) = w_K p_K$.The cornerstone in our approach of modelling adjustments through quantities for the price pressures induced by the administered prices is to consider that these price functions are both homogeneous of orderh_1 and h_2:

$$w_K = w_K(K) = w_K(K \cdot 1) = K^{h_1}w_K(1) \tag{4}$$
$$w_L = w_L(L) = w_L(L \cdot 1) = L^{h_2}w_L(1) \tag{5}$$

In this context, $w_K(1)$ is the price paid for one unit of capital, K, and for brevity we denote this as w_K. Similarly, $w_L(1)$ is the price paid for one unit of labor, L, and we denote this as w_L. If $h_1 = 0$ then the firm will spend $w_K \cdot K$ on capital. However, if $h_1 > 0$, $w_K = w_K(1)$, K^{h_1+1} units of capital will be purchased, and total spending on capital will be$w_K \cdot K^{h_1+1}$. This will model a situation in which the input factor prices $w_K = w_K(1), w_L = w_L(1)$ are subsidized (under the market prices) and therefore the firm think that it is affordable to input more quantities: K^{h_1+1} instead of K and similar, L^{h_2+1} instead of L. On the other hand, if the input factor prices are kept fixed at a higher level than the market prices, then less input factors will be used for production, corresponding to values of h_1 or h_2 less than zero. On the particular application for assessing the quantitative effects of the sticky prices on the learning curves, it has to be mentioned that administered prices (as a particular example of sticky prices) can create increasing, decreasing, or constant long-run average costs *even though returns to scale are constant.* This can also occur in the short run and may be misinterpreted as changes in technology.

Assuming the production function is also quasi-concave, the cost function will be the solution to the minimization problem

$$\min\,(w_K(K)\cdot K + w_L(L)\cdot L) \text{ subject to } f(K,L) = q$$

(6)

In the Cobb-Douglas case, the total cost function is

$$C\big(q, w_K(1), w_L(1)\big) = B\cdot q^{\frac{1}{\left(\frac{\alpha}{h_1+1}\right)+\left(\frac{\beta}{h_2+1}\right)}}\cdot w_K(1)^{\frac{\frac{\alpha}{h_1+1}}{\left(\frac{\alpha}{h_1+1}\right)+\left(\frac{\beta}{h_2+1}\right)}}\cdot\; w_L(1)^{\frac{\frac{\beta}{h_2+1}}{\left(\frac{\alpha}{h_1+1}\right)+\left(\frac{\beta}{h_2+1}\right)}} \qquad (7)$$

with

$$B = \left(\frac{1}{A}\right)^{\frac{1}{\left(\frac{\alpha}{h_1+1}\right)+\left(\frac{\beta}{h_2+1}\right)}}\left[\left(\frac{\alpha}{\beta}\frac{h_2+1}{h_1+1}\right)^{\frac{\frac{\beta}{h_2+1}}{\left(\frac{\alpha}{h_1+1}\right)+\left(\frac{\beta}{h_2+1}\right)}} + \left(\frac{\beta}{\alpha}\frac{h_1+1}{h_2+1}\right)^{\frac{\frac{\alpha}{h_1+1}}{\left(\frac{\alpha}{h_1+1}\right)+\left(\frac{\beta}{h_2+1}\right)}}\right] \qquad (8)$$

It is now clear that the cost function in (7) corresponds to the cost function associated with the fixed input prices $w_L = w_L(1)$, $w_K = w_K(1)$, as if the quantity elasticity with respect to capital and labour were, instead of α and β, respectively $\frac{\alpha}{h_1+1}$ and $\frac{\beta}{h_2+1}$. Other way stated, the cost function assuming the effect of fixed input prices in the homogeneous functional dependence on K and L correspond to the so-called enhanced *Cobb-Douglas production function*:

$$f(K,L) = AK^{\frac{\alpha}{h_1+1}}L^{\frac{\beta}{h_2+1}} \qquad (9)$$

As a consequence, the proposed method of tackling the quantity adjustments in input factors as a result of the sticky administered input-prices allow to regain all the cost-theory available for a firm in perfect competition with fixed input prices under $h_1 = h_2 = 0$.

Average cost is

$$AC = \frac{C}{q} = B\cdot q^{\frac{1}{\left(\frac{\alpha}{h_1+1}\right)+\left(\frac{\beta}{h_2+1}\right)}-1}\, g\big(w_K(1), w_L(1)\big) \qquad (10)$$

with $g(w_K(1), w_L(1))$=$w_K(1)^{\frac{\frac{\alpha}{h_1+1}}{\left(\frac{\alpha}{h_1+1}\right)+\left(\frac{\beta}{h_2+1}\right)}} \cdot w_L(1)^{\frac{\frac{\beta}{h_2+1}}{\left(\frac{\alpha}{h_1+1}\right)+\left(\frac{\beta}{h_2+1}\right)}}$ and the sign of the average cost curve's slope is therefore the sign of the exponent $\frac{1}{\left(\frac{\alpha}{h_1+1}\right)+\left(\frac{\beta}{h_2+1}\right)} - 1$.

For example, suppose the unenhanced production function exhibits increasing returns to scale ($\alpha = 0.5$, $\beta = 0.75$). If $h_1 = 0.125, h_2 = 0.25$ then the enhanced production function will exhibit economies of scale (decreasing average costs). On the other hand, if $h_1 = 0.5$, $h_2 = 1.1$ diseconomies of scale (increasing average costs) occur. This happens because homogeneity in input prices now has an impact on the effective production function's capital and labor elasticity. If a researcher assumes $f(K, L) = AK^{\alpha}L^{\beta}$, the estimated production function will have incorrect parameters. And even though $\alpha + \beta > 1$, there will always be values of h_1 and h_2, that can cause the average cost function to slope upward, slope downward, or be horizontal.
Administrated input prices may be "sticky"(Blinder, 1982, Gordon, 1981, Hall, 1980, Mortenson, 1970, Phelps, 1968). With sticky prices, the signal of changes in the input factors is a change in quantity of the input purchased. This may induce changes in average cost caused by either returns to scale or price pressures. Such average cost changes may be regarded as random when, in fact, they are signalling pressures on input prices. As an application, these findings will be further integrated in the theoretical derivation of the learning curves for the particular case of the renewable energy sector, accounting for the effect of the administered prices in this domain.

3.2 The Derivation Of A Learning Curve Accounting For The Effect Of Administered Prices: Differences With Respect To The Mainstream Bottom-Up Models In The Field

In the following we will briefly mention the main steps of the economic model which incorporates the learning curves into a Cobb-Douglas production function. We will do so with the specific purpose to precisely formulate what will be the theoretical differences in deriving learning curves addressed in this research.

Let $(x_i)_{i=1,..,M}$ represent the set of all inputs required to produce and operate the wind turbines, while $(P_i)_{i=1,..,M}$ are the correspondent input prices. Assume the output Q- as being the level of wind generated electricity –is produced according to a Cobb-Douglas production function

$$Q = A \prod_{i=1}^{M} x_i^{\delta_i} \quad (11)$$

where δ_i is the output elasticity with respect to the input factor x_i and

$$r = \sum_{i=1}^{M} \delta_i \quad (12)$$

is the returns to scale parameter, while A is a parameter reflecting the current state of knowledge.

Accordingly, the Cobb-Douglas average cost function specifying the unit cost of wind power capacity in a particular country at a particular time period AC is as follows:

$$AC = kQ^{\frac{1-r}{r}} \prod_{i=1}^{M} P_i^{\frac{\delta_i}{r}} \quad (13)$$

with

$$k = r\left[A \prod_{i=1}^{M} \delta_i^{\delta_i}\right]^{-\frac{1}{r}} \quad (14)$$

The learning curve is introduced in the Cobb-Douglas cost function through the parameter A, according to the next specification:

$$A = TIWP^{\delta_{TIWP}} R\&D^{\delta_{R\&D}} \quad (15)$$

where TIWP is totally installed wind power, R&D is the knowledge stock and δ_{TIWP} is the learning by doing elasticity, while $\delta_{R\&D}$ is the learning by searching elasticity.
This yields a modified version of the Cobb-Douglas average cost function accommodating for the learning effects as follows:

$$AC = \bar{k}\, TIWP^{\frac{\delta_{TIWP}}{r}} R\&D^{\frac{\delta_{R\&D}}{r}} Q^{\frac{1-r}{r}} \prod_{i=1}^{M} P_i^{\frac{\delta_i}{r}} \quad (16)$$

with

$$\bar{k} = r\left[\prod_{i=1}^{M} \delta_i^{\delta_i}\right]^{-\frac{1}{r}} \quad (17)$$

In the usual derivation of the cost functions accommodating for the learning effects as in (16) a last step is taken by removing input-factor prices from (16) through the assumption that the shares of the inputs in the production function are the same as the weights used in the GDP deflator and therefore the next equation (in logarithms), considering real rather current average cost of wind power capacity AC is estimated:

$$AC = k' TIWP^{\frac{\delta_{TIWP}}{r}} R\&D^{\frac{\delta_{R\&D}}{r}} Q^{\frac{1-r}{r}} \quad (18)$$

or equivalent,

$$\ln(AC) = \beta_0 + \beta_1 \ln(TIWP) + \beta_2 \ln(R\&D) + \beta_3 \ln(Q) \quad (19)$$

Equation (19) above has two major theoretical drawbacks for which this research formulate a potential answer. The first one also mentioned in Soderholm and Sundqvist (2007) refers to the implicitly assumed constant returns to scale. The second one is the way in which the authors chose to tackle one methodological issue mentioned in this paper-namely the omitted variable bias. They argue that, due to the fact that there must be other variables apart of the learning curve, most notably input prices and scale effects influencing the dependent variable, one needs the consideration of the so called feed-in price (P_{nt}^{F}) as an extra explanatory variable to be added in the econometric estimation of the equation (5) (with the coefficient β_4).

We think that the feed-in price might induce higher input-factor prices (for land, grid connections, poor wind conditions) and in the situation in which the input factor prices are administered, the adjustment might be performed through the lowering of the quantities of the input factors involved in the production of the wind energy. So, although the weights in the computation of the GDP deflator do not change-since the input factor prices are sticky, the shares of the inputs in the production factors vary. So, in other words, in the presence of the administered input-price factors might be a correlation between the feed in price and the unit costs of wind capacity.

Therefore, we are going to drop the inclusion of the feed-in price in the equation (19) and estimate rather (16). Furthermore, in the equation (16) we will also drop the implicit assumption of fixed returns to scale and we'll use the enhanced Cobb-Douglas cost function briefly presented in subsection 3.1.

The effects for the administered input factor prices can further be separately estimated through the design of a customized test for

$H_0: h_1 = h_2 = \dots = h_M = 0$ against

$H_0: h_1 \neq 0, h_2 \neq 0, \dots h_M \neq 0$ using sequences of minimal two observations and some intelligent techniques (like Simulated Annealing) to allow for nonlinear estimators.

4. Implications for investors and Conclusions

If, for some existent data in hand there is evidence of the effects of the administered prices in the data regarding the average cost of the wind power capacity, then is advisable either not to invest or to determine some intervals for the input factor prices which generate acceptable variations of the average cost, given some fixed technology.

Starting from the general assumption that sticky low input factor prices reflect in higher quantities acquisition of the input factors (as a reflection of the resulted allocative inefficiency) and assuming that the induced effect can be modelled by a homogeneous function on the input factors, this paper theoretically illustrate that administered prices, particularly in the energy sector can further induce any behaviour in the average costs. Thus, through these findings, we challenge the usual claims for institutional support by setting boundaries through which such an aid is profitable.

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