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Abstract

The present paper explores the relationship between physical and economic depletion of a nonrenewable natural resource using a decomposition of mining costs akin to the one used in the literature on productivity and technical change. We argue that this decomposition can provide key insights on future availability of nonrenewable natural resources. Using data on slate mining in Galicia (Northern Spain), we provide quantitative evidence of the role played by physical depletion in economic exhaustion but also of the offsetting effects of technical change. Additionally, we provide a measure of the effects on economic depletion of input prices, output, fixed inputs and production scale. Input prices and fixed input misallocation contributes far more to economic depletion than physical depletion while technical change has a remarkable negative contribution to economic depletion. Policy implications are discussed, particularly, the importance of promoting technical change.

JEL classifications: C32, L72, O40, Q30

Keywords: Non-renewable natural resources, Physical depletion, Economic depletion, Mining cost, Slate mining, Technical change, Total Cost Growth decomposition.

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1. Introduction

The canonical model of physical depletion of a nonrenewable natural resource is quite simple. There is a roughly fixed stock of the resource of which a constant quantity gets extracted each year so the remaining reserves will only last for a number of years. The main assumptions of the model are a somehow known stock of the natural resource and a constant yearly consumption rate. As a matter of fact, this seems to be the model behind the calculation of the number of years that the remaining reserves of oil, coal and other minerals will last – which is known as the reserves to production ratio (BP Statistical Review of World Energy, 2014).

However, there is another point of view on the issue of depletion of nonrenewable natural resources: economic depletion (Tilton, 2009). In this case, the focus is not as much in the stock of the resource but in the opportunity cost of extracting it. In other words, the amount of other resources (e.g. capital and labor) required to extract a unit of the nonrenewable resource. In this setting, economic depletion would mean the increasing difficulty and eventual unfeasibility of extracting the natural resource due to mining costs. Economic depletion increases with physical depletion since a reduction of stocks increases the amount of other resources required to mine one unit of the natural resource (Rodríguez and Arias, 2008). However, technical change can alleviate the effects of physical depletion in the cost of extracting the natural resources and, as a result, slow down economic depletion. Economic depletion is a broader concept than physical depletion since mining costs can halt the extraction of the natural resource well before physical scarcity is a pressing concern.

The objective of the present paper is to analyze economic depletion (i.e. the cost of extracting and processing the natural resource) using the cost decomposition behind the analysis of productivity and technical change (Bauer, 1990). The evolution of mining costs can provide a more accurate measure of resource exhaustion than commonly used indexes such as the reserves to production ratio (Feygin and Satkin, 2004) or the real price of the natural resource (Tilton and Lagos, 2007; Tilton, 2009). On the one hand, physical availability as measured by the reserves to production ratio cannot guarantee extraction of the resource if the mining cost increases over a certain level. On the other hand, real prices of the natural resource can be affected by market shocks unrelated to the physical availability of the natural resource. However, a continuous increase in extraction costs is a sure sign of problems to use the non-renewable natural resource in the short or medium run. Furthermore, the cost decomposition provides a measure of the sources of the increase in extraction costs (e.g. input prices or physical depletion). Of particular interest are the role of stock reduction (physical depletion) and the potential offsetting effect of technical change. Additionally, the decomposition shows the effects on economic depletion of factors outside the control of the industry such as input prices and output changes but also the effects of variables that can be changed by management such as fixed inputs and production scale.

The structure of the paper is as follows. In section 2, we review the relationship between economic and physical depletion using a cost function that has reserves of the natural resource as an explanatory variable. In section 3, we propose a decomposition of changes in total cost of extracting the natural resource as a way to analyze the sources of economic depletion. In section 4, we estimate a cost function of mining using data on slate mining and we decompose total cost changes in six components related to economic depletion. The paper ends with some conclusions and policy recommendations in section 5.

2. Physical and economic depletion of a nonrenewable natural resource

Physical depletion of a nonrenewable natural resource refers simply to the continuous decrease in stock as a result of extracting it. It is commonplace to measure physical depletion by the number of years remaining of the stock at current rates of extraction. The simplicity of the proposal no doubt contributes to its popularity. However, besides the difficulties of estimating the stock and the oversimplification of projecting current extraction rates into the future, Tilton (2009) lists a number of shortcomings of this approach. Namely, the physical approach to depletion cannot account for the role played by technical change in mining, recycling or development of substitutes for the natural resource.

Tilton and Lagos (2007) and Tilton (2009) propose an economic perspective for the analysis of depletion of nonrenewable natural resources. More precisely, he proposes to measure economic depletion by the opportunity costs of mining the natural resource. In this setting, physical depletion contributes to economic depletion by increasing the cost of extracting the natural resource. The relationship between the level of reserves and extraction costs has been analyzed by Zimmerman (1981), Harris (1990), Epple and Londregan (1993) and Cuddington and Moss (2001). The rationale is that easy to extract veins of the resource are mined first while more costly to extract veins are mined later on. On the other hand, technical change could offset the effects of physical depletion by reducing the cost of extracting the natural resource. In other words, technical change can alleviate economic depletion (Rodriguez and Arias, 2008). In the same manner, recycling and substitutes for the natural resources operate by putting a cap on the cost of extracting the natural resource and, as a result, limiting economic depletion.

In the present paper we take on the proposal of measuring depletion by the opportunity cost of mining a nonrenewable natural resource. Further, we extend this idea by linking changes in mining costs over time to decreases in stock of the natural resource (physical depletion), technical change, changes in inputs prices, fixed inputs and scale of operation. For that purpose, we use the cost decomposition from the literature on productivity and technical change following the proposal to analyze the relationship between resource depletion and technical change of Rodríguez and Arias (2008).

The starting point is the cost of extracting a non-renewable natural resource that can be written as:

$$C = C\left(W, Q,\ t, R\right)$$

Where C is the cost of extracting the natural resource, W is a vector of input prices, Q is the quantity of the resource extracted, t is a time trend that accounts for technical change over time and R is the stock of the natural resource.

It is common to assume that technical change reduces the cost over time $\frac{\partial C}{\partial t} < 0$ and that a larger stock of resources decreases mining costs $\frac{\partial C}{\partial R} < 0$. The stock R decreases over time due to extraction following the rule: $\frac{\partial R}{\partial t} = -Q$. Therefore, mining costs are going to increase over time due to the reduction of the stock. In other words, there is economic depletion linked to the reduction of the stock. However, technical change can reduce the cost of extracting the natural resource offsetting the effects of the reduction of the stock (physical depletion) on mining cost (economic depletion). Moreover, inputs prices and output can play a role too in economic depletion.

In the next section, we present a decomposition of mining cost that provides a measure of the effect of different factors on economic depletion.

3. A decomposition of economic depletion

In this section we propose a decomposition of the total cost of mining a non-renewable natural resource in order to assess the contribution to economic depletion of input prices, quasi-fixed inputs, output, production scale, technical change and the level of reserves of the natural resource. The starting point is the production function:

$$Q = f\left(X_L, X_E, X_M, X_K,\ t, R\right) \quad (1)$$

where Q is the quantity of the natural resource mined using three variable inputs: Employment (X_L), Energy (X_E) and Materials (X_M). We assume that Capital (X_K) is a quasi-fixed input. In other words, we assume that the industry is in a short-run competitive equilibrium where some inputs cannot be changed instantaneously. In addition, the technology represented by a time trend (t) and the level of reserves of the natural resource denoted by R affect the mining of the natural resource. Finally, assuming cost-minimizing behaviour and certain regularity conditions of the production function (Lau, 1976) we obtain a dual variable cost function containing all relevant information of the technology such as:

$$VC = h\left(W_L, W_E, W_M, X_K, Q, t, R\right) \quad (2)$$

Where VC denotes variable cost and W_L, W_E and W_M are the input prices of labour, energy and materials. The total cost function can be written as:

$$C = h\left(W_L, W_E, W_M, X_K, Q, t, R\right) + W_K X_K \quad (3)$$

where W_K is the user cost of capital.

Differentiating the total cost function with respect to time we have that:

$$\frac{\partial C}{\partial t} = \sum_i \frac{\partial h}{\partial W_i}\frac{\partial W_i}{\partial t} + \frac{\partial h}{\partial X_K}\frac{\partial X_K}{\partial t} + \frac{\partial h}{\partial Q}\frac{\partial Q}{\partial t} + \frac{\partial h}{\partial t} + \frac{\partial h}{\partial R}\frac{\partial R}{\partial t} + X_K\frac{\partial W_K}{\partial t} + W_K\frac{\partial X_K}{\partial t} \qquad (4)$$

$$i = L, E, M$$

Applying Shephard lemma's in expression (4) and rearranging terms suitably we have that[4]:

$$C = \sum_i S_i W_i + Q + \left(W_K - Z_K\right)\frac{X_K}{C}X_K + Q\left(\varepsilon_{CQ} - 1\right) + \frac{1}{C}\frac{\partial h}{\partial t} + \frac{R}{C}\frac{\partial h}{\partial R}R \qquad (5)$$

$$i = L, E, M, K$$

where, C is the rate of change of total cost, S_i is the cost share of input i, W_i the rate of change of the price of input i, $Z_K = -\frac{\partial h}{\partial X_K}$ is the shadow price of capital, X_K is the rate of change of Capital, $\varepsilon_{CQ} = \frac{Q}{C}\frac{\partial h}{\partial Q}$ is the elasticity of cost with respect to output, Q is the rate of change of output and R is the rate of change of reserves.

As it was argued in section 2, mining costs can be interpreted as an index of economic depletion. As such, equation (5) shows a decomposition of the evolution of economic depletion into six components. The first component measures the effects of changes in input prices ($\sum_i S_i W$) on total cost. This component raises an intriguing possibility: the economic exhaustion of a non-renewable natural resource due to an increase in the price of the factors required to extract it rather than to its physical scarcity. The second component measures the effects of changes in output (Q) on total cost. The third component measures the effects of a non-optimal allocation of fixed factors − $\left(W_K - Z_K\right)\frac{X_K}{C}X_K$ − on total cost. This term vanishes in a competitive equilibrium when the shadow value of the fixed factor (Z_K) is equal to its market price (W_K). The fourth component − $Q\left(\varepsilon_{CQ} - 1\right)$ − measures the effects of changes in the scale of production on total cost. This term vanishes when there are constant returns to scale (

[4] See Rodríguez and Arias (2008) for details.

$\varepsilon_{CQ} = 1$). The fifth component ($-\frac{1}{C}\frac{\partial h}{\partial t}$) measures the effects of technical change on total cost. Finally, the last term ($\frac{R}{C}\frac{\partial h}{\partial R}R$) measures the effects of physical depletion of reserves on total cost.

4. Empirical application

In this section, we explore the relationship between economic depletion and its main components using data on slate mining in Galicia (Northern Spain) by decomposing the changes in the total cost of mining into the six components described in expression (5). For that purpose, we estimate a Variable Cost function in which the level of resource depletion is included as an explanatory variable. Therefore, a key issue of the decomposition is the definition of a variable that measures the reserves of slate available for extraction at each period of time.

To the best of our knowledge, there is no annual estimation of reserves of slate in the area of analysis in Northern Spain. However, several reports published by Instituto Tecnológico GeoMinero de España (ITGE, 1976, 1979, 1982, 1985)[5] and Xunta de Galicia (1991) quote 109 million metric tons of reserves of ornamental slate[6] in Galicia (Northern Spain) for the year 1985. Additionally, we have data on the quantities of slate mined from 1974 to 2010. Therefore, following Rodríguez and Arias (2008) an annual time series of reserves can be estimated using the following expression:

$$R_t = R_0 - \sum_{i=1}^{t} Q_{t-i} \qquad (6)$$

where R_t denotes slate reserves in year t and (Q_1, … , Q_{t-1}) the quantities of slate mined in previous years. R_0 represent the level of reserves the year before the period of analysis starts. It can be calculated using the reserves in any given year (1985 in the present paper) and the amount of slate mined in previous years. The accuracy of the

[5] A research branch of the Ministry of Industry and Energy. Its name was changed to Instituto Geológico y Minero de España (IGME) in December, 2000.

[6] The type of slate with the highest commercial value.

estimation of the reserves R_t depends on the reliability of the 1985 estimate but also on extractions of slate being the main force in the evolution of reserves. In other words, we implicitly assume that there were no new discoveries of the resource in the area and period of analysis. We believe that this assumption is realistic for slate mining in Galicia (Northern Spain) in the period of analysis[7].

We estimate a variable cost function using aggregate yearly data on slate production, input prices and quantities reported in Mining Statistics (Estadística Minera), an annual publication of the Spanish Ministry of Economy[8]. The dataset contains aggregate data on slate mining operations in Galicia (Northern Spain) from 1974 to 2010. Some descriptive statistics of the variables used for the estimation are shown in Table 1.

[7] In fact, the number of active mines went from 69 in 1974 to 53 in 2010. This decrease is due to the closing of mines that reach the point in which reserves are not economically recoverable.

[8] These data were previously published by the Spanish Ministry of Industry and Energy.

Table 1. Descriptive statistics (1974-2010)

Variables	*Units*	*Maximum*	*Minimum*	*Mean*	*Std. Dev.*
Labor (X_L)	Hours (thousands)	3,929	1,758	3,240	588
Price of Labor (W_L)	Euro/hour	21.35	1.93	9.35	6.70
Capital (X_K)	Hours (thousands)	2,713	870	1,568	532
User cost of Capital (W_K)	Euro/hour	7.97	1.22	5.74	2.21
Materials (X_M)	Tons	1,351	346	747	261
Price of Materials (W_M)	Euro/Ton	24.4	0.75	11.81	6.88
Energy (X_E)	Tons of coal equivalent (TEC)	46,718	4,565	23,273	13,418
Price of Energy (W_E)	Euro/ TEC	0.49	0.05	0.25	0.12
Output (Q)	Tons of mineral (thousands)	485	95	299	113
Output price (P)	Euro/Ton	466.17	31.47	225.85	135.99
Variable cost (CV)	Euro (Millions)	102.43	3.93	48.37	34.66
Total Cost (C)	Euro (Millions)	119.88	5.05	58.24	40.44
Reserves (R)	Tons of mineral (thousands)	110,846	100,055	106,499	3,374

The definition of variables follows closely Rodríguez and Arias (2008). Variable and Total Cost include only items directly related to extraction and preparation of slate and do not include other costs (e.g. marketing costs). The hours of Labor (X_L) are weighted by the cost share of each labor qualification, the tons of Materials (X_M) are weighted by the cost share of each type of material, Capital is measured as hours of machinery use weighted by the power of each type of machinery and output is measured in Tons of mineral extracted.

The user cost of Capital (W_K) is defined as:

$$W_{Kt} = \frac{S_0}{H_0}\left(r + d\right) I_t \qquad (7)$$

where S_0 is an estimate of the value of the stock of Capital in the base year (Gómez, 1987), H_0 is the stock of capital in the base year measured as hours of machinery use, r is the interest rate, d a depretiation rate and I_t is an index of price of machinery. We choose the interest rate charged in the base year to mining firms for medium and long term loans (12%) and the rate of depreciation provided for tax and accounting purposes in the mining industry by the Ministry of Economy of Spain.

The variable cost function using a Translog functional form can be written as:

$$
\begin{aligned}
\ln CV &= \alpha_0 + \alpha_Q \ln Q + \tfrac{1}{2}\alpha_{QQ}(\ln Q)^2 + \sum_i \alpha_i \ln W_i + \beta_k \ln X_k \\
&+ \tfrac{1}{2}\beta_{kk}(\ln X_k)^2 + \alpha_t t + \tfrac{1}{2}\alpha_{tt} t^2 + \alpha_R \ln R + \tfrac{1}{2}\alpha_{RR}(\ln R)^2 + \alpha_{QR}\ln R \ln Q \\
&+ \alpha_{Qt}\ln Q \; t + \tfrac{1}{2}\sum_i \sum_j \alpha_{ij}\ln W_i \ln W_j + \sum_i \alpha_{iQ}\ln W_i \ln Q + \sum_i \delta_{ik}\ln W_i \ln X_k \\
&+ \sum_i \alpha_{it}\ln W_i t + \sum_i \alpha_{iR}\ln R \ln W_i
\end{aligned} \qquad (8)
$$

where *i,j* refer to the three variable inputs - Labor (*L*), Energy (*E*) and Materials (*M*) - while *R* is the measure of reserves in expression (6). All variables in the translog cost function are in natural logarithms with the exception of the time trend (*t*) [9]. This practice is standard for the time trend since the passing of time (and not its "growth rate") is the interesting feature here.

Using Shephard's lemma in equation (8) we have that:

$$
\mathrm{S_i} = \frac{\partial \ln CV}{\partial \ln W_i} = \alpha_i + \sum_j \alpha_{ij}\ln W_j + \alpha_{iQ}\ln Q + \delta_{ik}\ln X_k + \alpha_{it} t + \alpha_{iR}\ln R \qquad i = L,\ E,\ M \qquad (9)
$$

where S_i denotes the cost share of input *i*. In addition, we impose optimizing behaviour in the output market (Morrison and Schwartz, 1996) by including the equilibrium condition:

$$
P = \frac{\partial CV}{\partial Q} = \frac{CV}{Q}\left(\alpha_Q + \alpha_{QQ}\ln Q + \sum_i \alpha_{iQ}\ln W_i + \alpha_{QR}\ln R + \alpha_{Qt} t\right) \qquad (10)
$$

The system of equations (8), (9) and (10) is estimated after imposing parametric restrictions of symmetry and homogeneity of degree one on input prices. Additionally, we have dropped the share equation of materials to avoid singularity of the system. Homogeneity of degree one on input prices of the Variable Cost function is imposed by dividing Prices and Variable Cost by the price of Materials. As a result, the coefficients

[9] It is well known that when a variable is introduced into the model in levels, the associated coefficient measures the effect of a unitary change in this variable on the dependent variable. However, if the variable is introduced in logarithmic terms, the coefficient measures the effect on the dependent variable of a unitary increase *in the growth rate* of the variable in question.

associated with the price of Materials are not estimated directly although they can be recovered using the linear homogeneity restriction. The resulting system of equations is estimated by the Generalized Method of Moments (GMM) to avoid potential endogeneity issues. Additionally, we use a Heteroskedasticity and Autocorrelation Consistent (HAC) Covariance Matrix robust to heteroskedasticity and autocorrelation (Newey and West, 1987).

The quadratic terms of the cost function were dropped since we could not reject the null hypothesis that they were jointly equal to zero. By doing so, we reduce the number of coefficients to estimate with limited data that could lead to problems of multicollinearity. The final results of the estimation are shown in Table 2.

Table 2: Restricted Translog Variable Cost Function

Parameters	*Estimate*	*Std. Error*	*t-Statistic*	*Prob.*
α_0	0.042119	0.010616	3.967367	0.0001
α_Q	1.031336	0.008623	119.6092	0.0000
α_L	0.677785	0.002601	260.5383	0.0000
α_E	0.133993	0.001637	81.86768	0.0000
β_k	0.571803	0.072170	7.922965	0.0000
α_t	-0.071290	0.007419	-9.608961	0.0000
α_R	-12.34791	1.914205	-6.450676	0.0000
α_{QR}	8.288787	0.884802	9.367962	0.0000
α_{LL}	0.152117	0.007285	20.88185	0.0000
α_{EE}	0.036177	0.014237	2.541098	0.0123
α_{QQ}	0.174643	0.023145	7.545517	0.0000
α_{LE}	-0.086109	0.004529	-19.01489	0.0000
α_{LQ}	-0.042759	0.016464	-2.597122	0.0105
α_{EQ}	-0.094610	0.014242	-6.642837	0.0000
δ_{LK}	-0.017646	0.032632	-0.540751	0.5897
δ_{EK}	0.143792	0.027241	5.278571	0.0000
α_{Lt}	-0.010431	0.003719	-2.804916	0.0059
α_{Et}	-0.002950	0.002780	-1.061192	0.2907
α_{LR}	-2.022994	0.883407	-2.289993	0.0237
α_{ER}	-1.491775	0.625118	-2.386390	0.0185
α_{Qt}	0.002331	0.000812	2.869712	0.0048

Estimation Method: Generalized Method of Moments (HAC option) using Eviews 7.0

The R-squared of the estimated equations are 0.97 for the Variable Cost function, 0.95 for the Labour Cost share equation, 0.70 for the Energy Cost share equation and 0.98 for market equilibrium equation. We obtain a small value for J-statistic (0.23) showing there is no evidence of instrument mis-specification.

All variables appearing in natural logarithms were divided by their geometric mean prior to estimation. The time trend was set at zero in 1992. As a result, the coefficients of the first order terms of the variables in natural logarithms can be interpreted as cost elasticities in that year evaluated at the geometric mean of the explanatory variables. These cost elasticities have the expected signs and are significantly different from zero at conventional levels of significance.

The coefficient of the first order term of the time trend (α_t) is negative and significantly different from zero. The negative value (-0.07) can be interpreted as the average annual growth rate of total variable cost keeping all other explanatory variables constant. This cost decrease can be attributed to technical change. Of particular interest is the value of the coefficient of the first order term of the variable that represents the level of slate reserves (α_R). The negative value (-12.3) is quite large and significantly different from zero. It means that a 1% decrease in reserves is associated with a 12.3% increase in total cost.

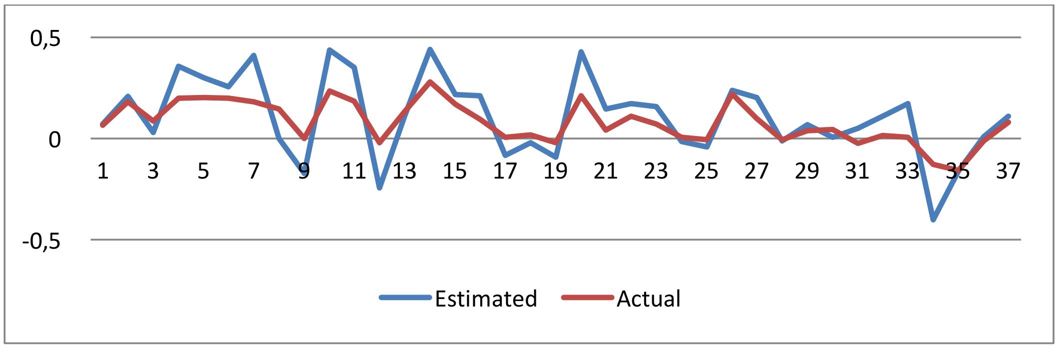
The decomposition of total cost growth (TCG) following equation (5) is shown in Table 3. The six components of TCG (index of economic depletion) in equation (5) are shown in the first six columns of Table 3 while the estimated value of TCG appears in the seventh column.

Table 3: Decomposition of Total Cost Growth (Equation 5)

Years	Effect of input prices growth	Effect of output growth	Fixed factors	Scale	Technical Change	Physical Depletion	Total Cost Growth
1975	0,0290	0,0648	0,0458	-0,0018	-0,0825	0,0174	0,0726
1976	0,0545	0,2165	0,0022	-0,0006	-0,0831	0,0196	0,2091
1977	0,0530	0,1595	-0,1313	0,0065	-0,0794	0,0219	0,0302
1978	0,0589	-0,0128	0,3619	0,0003	-0,0748	0,0244	0,3579
1979	0,0767	0,1928	0,0722	0,0054	-0,0717	0,0259	0,3012
1980	0,1520	0,0441	0,0978	0,0030	-0,0665	0,0237	0,2541
1981	0,1832	0,1625	0,0901	0,0159	-0,0645	0,0221	0,4094
1982	0,1850	-0,0246	-0,1189	-0,0031	-0,0661	0,0281	0,0005
1983	0,1430	-0,0720	-0,1970	-0,0083	-0,0633	0,0260	-0,1715
1984	0,1194	0,1547	0,1793	0,0252	-0,0610	0,0202	0,4377
1985	0,0322	0,0666	0,2804	0,0080	-0,0624	0,0247	0,3495
1986	0,0696	-0,0312	-0,2431	-0,0042	-0,0625	0,0267	-0,2448
1987	0,1423	0,1157	-0,1330	0,0272	-0,0617	0,0229	0,1134
1988	0,1522	0,0627	0,2464	0,0156	-0,0640	0,0254	0,4384
1989	0,1061	-0,0192	0,1714	-0,0043	-0,0651	0,0281	0,2169
1990	0,0381	0,1524	0,0336	0,0305	-0,0695	0,0273	0,2123
1991	0,0978	-0,0499	-0,0870	-0,0088	-0,0695	0,0330	-0,0843
1992	0,0673	-0,0663	0,0261	-0,0105	-0,0678	0,0307	-0,0207
1993	-0,0364	-0,1292	0,1225	-0,0085	-0,0690	0,0290	-0,0915
1994	0,1169	0,2580	0,0547	0,0433	-0,0674	0,0233	0,4288
1995	-0,0021	-0,0084	0,1883	-0,0010	-0,0672	0,0347	0,1445
1996	0,0145	0,1258	0,0605	0,0121	-0,0710	0,0296	0,1715
1997	0,0999	0,1133	-0,0303	0,0163	-0,0695	0,0283	0,1580
1998	-0,0100	-0,0130	0,0461	-0,0012	-0,0705	0,0332	-0,0155
1999	-0,0276	-0,0111	0,0355	-0,0005	-0,0703	0,0335	-0,0405
2000	0,1525	0,0049	0,1198	0,0000	-0,0771	0,0389	0,2389
2001	0,0414	-0,0199	0,2178	0,0011	-0,0778	0,0407	0,2033
2002	0,0684	0,0538	-0,0935	-0,0011	-0,0739	0,0340	-0,0123
2003	0,0229	0,0645	0,0202	-0,0032	-0,0751	0,0398	0,0691
2004	0,0559	-0,0203	0,0066	0,0017	-0,0753	0,0365	0,0049
2005	0,0553	0,0855	-0,0378	-0,0102	-0,0759	0,0350	0,0519
2006	0,0255	0,0141	0,1083	-0,0023	-0,0740	0,0373	0,1090
2007	0,0130	-0,0551	0,2334	0,0133	-0,0722	0,0396	0,1719
2008	0,0193	-0,0888	-0,3208	0,0230	-0,0780	0,0448	-0,4005
2009	-0,0045	-0,4653	0,1439	0,1865	-0,0778	0,0576	-0,1597
2010	-0,0118	0,0444	0,0337	-0,0169	-0,0739	0,0328	0,0083
Average	*0,0654*	*0,0297*	*0,0446*	*0,0097*	*-0,0709*	*0,0305*	*0,1089*

The relationship between actual TCG and TCG obtained by adding-up the different components of equation (5) is shown in Figure 1. The quite similar patterns of actual and estimated TCG are the result of the high correlation between these two variables (0.87) due to the good fit of the cost and cost-share equations. As a result, the average yearly estimated TCG (10.96%) is close to the actual figure (7.98%).

Figure 1. Estimated and Actual Total Cost.



The last row of Table 3 shows the average over the period of analysis (1975- 2010) of the components of TCG. The average TCG over the period of analysis is 10.89%. A substantial part of such cost increase is due to the increase in the price of inputs (6.54%) and to the increase in output (2.97%). We consider these two components the results of market forces outside the control of the industry. Non-optimal allocation of the fixed factor (capital) contributes another 4.46% and the scale component a further 0.97% to TCG. The effect of misallocation of fixed inputs on total cost seems fairly large. Additionally, firms do not seem to have chosen the correct scale of operation in order to produce at the minimum of the average cost although this component has a small effect on TCG. Finally, the reduction of reserves, the physical depletion of the resource, contributes 3.05% to TCG. The high cost elasticity of variable cost with respect to the level of reserves (-12.3) results nonetheless in a moderate contribution of physical depletion to the increase in cost due to the small change in reserves each year (0.28% on average).

An interesting feature is that input prices and fixed input misallocation contributes far more to our measure of economic depletion than physical depletion. Another interesting result is that technical change has a remarkable negative contribution to TCG (-7.09%). This means that technical change more than offsets the effects of physical depletion on TCG. In fact, technical change is a factor contributing to the economic viability of slate extraction in the face of increasing costs due to stock reduction. Historically, new technology and innovation have offset the negative effects of physical depletion on the cost of producing mineral commodities (Espi and Moreno, 2010; Tilton, 2013).

In summary, a 10.89% yearly TCG hardly looks like a sustainable pattern. However, the view is quite more optimistic if we use the qualitative and quantitative information on economic depletion provided by the TCG decomposition. If we deduct the effects of input prices and output growth, the TCG is a more moderate 1.38%. This result is due mainly to the compensating effects of decreasing reserves and technical change on TCG. Additionally, better management of fixed inputs and scale could lead to a nil TCG. This detailed analysis of depletion is an advantage of the analysis performed in the present paper.

5. Conclusions

In this paper, we analyze changes in mining costs as a very general measure of depletion of a non-renewable natural resource. Mining costs as an index of economic depletion can be used to assess the future viability of extracting the natural resource. As such, we propose a decomposition of changes in mining cost to analyse the relationship between physical and economic depletion of a non-renewable natural resource. Additionally, the decomposition proposed here allows to explore the role played in economic depletion not only by the level of physical reserves but also by technical change and other variables related to market events and management of firms in the industry.

We find quite high yearly average cost increases. The decomposition of Total Cost Growth shows that components not under the control of the industry such as input prices and output changes account for most of the increase in total cost. The remaining components of economic depletion increase Total Cost Growth in less than 1.5% per year on average. However, capital misallocation contributes substantially to TCG while the scale effect plays a minor role. These results suggest that the industry is not well managed in terms of fixed inputs and to a less extent of scale of operation. On the other hand, the role of physical depletion of the resource in explaining economic depletion is substantial but lower than other factors. On the other hand, technical change can reduce extraction costs enough to offset the effect of physical depletion. Therefore, technical change is clearly the main driver of economic sustainability of the extraction of slate.

Finally, we conclude with some policy consequences of the results in the present paper. Resource management is important not only on environmental grounds but also in terms of its effect on the evolution of the extraction cost of the natural resource (economic depletion). Second, the relevance of reserves for total cost suggests the convenience of gaining a better knowledge of reserves. Third, our results suggest that technical change is the main driver of economic sustainability of the slate industry. This overlooked insight can provide some guidance to mining policy although some management issues could be relevant too.

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