REGIONAL VARIATION IN GLOBAL IRONMAKING COSTS*

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ABSTRACT

This paper investigates the determinants of pig iron production costs in the global steelmaking industry, in particular, economies of scale and raw material prices. Using a sample of 66 integrated steel plants in 27 countries that produce hot rolled coil, a cross sectional translog cost function is estimated to examine the relationship between production costs and the scale of production. The estimates of the cost function suggest that economies of scale are not present in ironmaking. In addition, there is little evidence that the significant variation in raw material prices faced by steel plants affects pig iron production costs in a systematic manner. Instead, the large variation in pig iron production costs among the plants in the sample is primarily driven by variation in conversion costs. Furthermore, these conversion costs appear to be geographically random and also unrelated to the scale of production.

JEL Classification: D24, L61, Q31.

Keywords: Translog cost function, economies of scale, steel.

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INTRODUCTION

Steel companies, like most businesses, have entered an era of increased global competition and sophisticated technology. Much of the growth in global competition in recent times has been a result of continued improvement in the competitive position of Asian and South American steel producers, who enjoy natural cost advantages over the more mature steel industries of Western Europe and North America. Responses by established steel producers to the challenges presented by the changing pattern of global steel production have taken various forms. In 2001, for example, US steel producers successfully lobbied for the implementation of a 40 per cent tariff on low cost steel imports. Other responses have involved bankruptcy of firms and industry-wide restructuring and consolidation of the steel industry in countries struggling to remain competitive.

Other actions have involved more competitive responses involving the adoption or development of sophisticated new steelmaking technologies. Taking various forms, technological change has improved both product quality and worker productivity. These include the development of technology and innovation to improve product design to closer match consumer needs and use of new information technologies from production scheduling and machine control to metallurgical analysis. Competition has also forced steel producers to invest in human capital and undertake development of more specialised product lines.

Given the emphasis on technology development, efficiency improvements and mergers and acquisitions in the steel industry in recent times, an interesting question is to what extent do factors prices and economies of scale contribute to variation in per unit production costs for pig iron. While differences in factor prices are generally beyond the control of producers, economies of scale is an often cited rationale for much of the merger and acquisition activity in recent years that has helped form some of the world's largest steel conglomerates. The purpose of this paper is to measure the impact of plant size on per unit production costs for pig iron produced within integrated steel plants.[1] The economies of scale to be examined in this paper are only those arising from the production side of the process. Of course, economies at larger production scales can be generated from savings resulting from higher scheduling and operating efficiencies, elimination of redundant management and overhead costs and reduced freight costs.

The estimation of a translog cost function allows us to separate the impact of differences in raw material prices across steel plants from scale effects as they relate to per unit pig iron production costs and draw inferences regarding the behaviour of per unit costs as the scale of production increases. This paper uses data for 2003 from a cross section of 66 integrated steel plants in 27 countries for those steel plants producing hot rolled coil. The integrated steelmaking process involves four distinct phases with the one plant; ironmaking, steelmaking, casting and rolling. We focus on the first phase, where the main inputs into steelmaking are capital, labour, raw iron (sourced from fines, pellets, lump, hot-briquetted iron, direct reduced iron and scrap) and coal. The following section examines the current state of the steel industry, with particular focus on steel production and production costs. The third section reviews the translog cost function methodology, while the fourth section presents the empirical results. The fifth section examines the relationship between production costs and raw material prices in greater detail. The final section provides concluding comments.

PRODUCTION AND COSTS IN THE STEEL INDUSTRY

The vast majority of steel is produced using one of two technologies. The more traditional technology involves integrated steel plants, the two main components of which are the blast furnace for the production of pig iron, and the basic oxygen furnace for the production of steel. The raw material inputs used within the integrated plants are iron ore (in the form of fines, pellets, lump) and coke (made from coking coal), with smaller quantities of scrap steel, hot briquetted iron (HBI) and direct reduced iron (DRI) often being used. The alternate technology is

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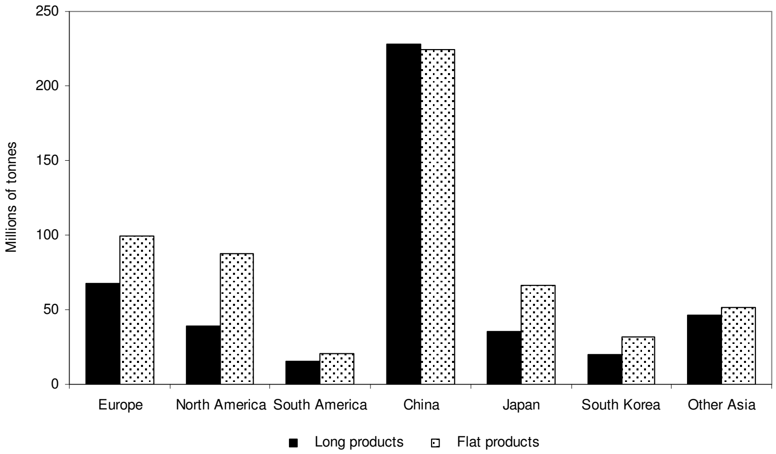
[1] The production of pig iron from raw iron is the first stage in the steelmaking process.

incorporated within electric arc furnace (EAF) based mills or minimills. Production generally occurs on a smaller scale than the larger integrated plants. The raw material inputs used by minimills are scrap steel, with electricity being used to melt the scrap into a liquid form for processing. Minimills also use quantities of pig iron, HBI and DRI to dilute residual impurities contained in the scrap and improve the quality of the final steel products.

Steel can be divided into two broad product categories, flat and long products. Long products include various forms of bar, rod, wire and structural shapes, and are used primarily in construction and manufacturing. Since growth in these sectors is largest in developing economies, consumption of long products is most intensive in these regions. Flat products include sheet, strip and plate steel, and are used in sectors such as consumer goods, shipbuilding and transportation. Requiring higher levels of consumer income, the consumption of goods from these sectors tends to be more heavily concentrated in developed economies. Traditionally, production of flat shapes has been the domain of integrated steel producers. The operational introduction of thin slab casting technology by Nucor in the United States however, has made it economically viable for minimills to produce flat products. The vast majority of flat product production however, still occurs within the larger integrated plants.

Figure 1 shows the geographical distribution of hot rolled steel production for both flat and long products for the major steel producing regions. In 2006, production of flat products accounted for 56.2 per cent of total hot rolled production. Interestingly, flat production accounts for 69.2 per cent of total hot rolled production in North America and 65 per cent in Japan. These figures compare to only 49.6 per cent in China. These differences in the geographical mix of production between flat and long products reflects, to a large extent, differences in regional consumption patterns.

FIGURE 1: GLOBAL PRODUCTION OF HOT ROLLED STEEL IN 2006



Source: International Iron and Steel Institute (2007)

The data used in our analysis of pig iron production costs cover 66 integrated steel plants in 27 countries. The data set is limited to only those plants producing flat products, in particular hot rolled coil, to ensure the highest degree of comparability of inputs, technology and processes across all plants. Table 1 provides a summary of the plant operations for 2003 by presenting country averages for production, labour and capital. The plants included in the data set are not a complete list of all integrated steel plants, but include the majority of major producers and accounted for 327 Mt, or 78 per cent, of global production of flat products in 2003. The largest steel plants in the sample are located in Russia, China, South Korea and Taiwan, often with annual production in excess of 10 Mt per annum. Plant scale in Western Europe and North America however, averages around 50 per cent of this figure. The value of capital used in the ironmaking stage of production is, as expected, highly correlated with the level of production with a correlation coefficient of 94 per cent. This measure of capital only includes that capital within the integrated facility associated with ironmaking, thus it ignores capital used in the steelmaking, casting and rolling stages of the overall steel production process.

TABLE 1: SUMMARY STATISTICS

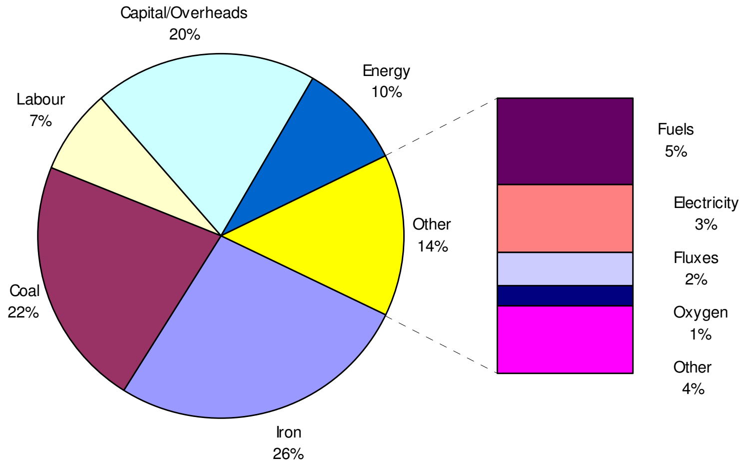
Country	Number of plants	Production (Mt)	Labour (hours/tonne)	Capital ($USm)
Austria	1	4.2	0.58	285
Belgium	3	2.3	0.60	228
Finland	1	2.7	0.40	200
France	3	4.4	0.89	308
Germany	5	5.9	0.76	447
Hungary	1	1.7	0.52	145
Italy	1	6.2	1.60	750
Netherlands	2	6.2	0.71	440
Poland	1	2.3	1.61	225
Russia	1	10.2	3.99	750
Slovak Republic	1	4.2	1.20	255
Spain	1	3.4	0.44	255
Sweden	1	2.2	0.55	175
UK	2	3.1	0.54	240
Canada	4	2.5	0.79	195
Mexico	1	3.0	1.29	285
USA	13	3.1	0.72	246
Australia	1	5.3	0.84	360
China	2	9.0	4.45	595
India	1	4.2	2.96	285
Japan	13	5.4	0.66	458
South Africa	1	2.7	2.07	225
South Korea	2	12.4	1.35	770
Taiwan	1	10.8	2.09	750
Turkey	1	3.1	0.96	225
Argentina	1	2.4	0.48	175
Brazil	4	4.6	1.16	304

Source: BHP Billiton.

Interestingly, labour usage appears to be highest in Russia, China and India, that is, countries with the lowest unit production costs. Offsetting higher labour utilisation rates of course, are lower unit labour costs in these countries. A correlation of 49 per cent between labour and steel production suggests that labour can be classified as a non-essential input as defined by Shephard (1970, 1981). Essential inputs are those used in direct proportions to output, in the present context, according to key metallurgical relationships and steelmaking technologies. Examples include iron ore and coke, the use of which are all highly correlated with production.[2] Given the nature of these inputs they are generally used extremely efficiently, making costs reductions through factor substitution or economies of scale from this source virtually impossible.

Figure 2 provides a decomposition of unit production costs, using the sample average from all 66 integrated plants. In the sample, sinter accounts for 58.2 per cent of total raw iron inputs, with a range of 0 to 98.3 per cent across all plants in the data set. Pellets are the next most common source of raw iron, accounting for 27.4 per cent of raw iron inputs, followed by lump with a share of 13.6 per cent. Scrap, DRI and HBI account for the remaining 0.7 per cent. Raw iron, from all sources, accounts for 26 per cent of unit production costs, making access to cheap sources of iron ore a primary concern for steelmakers. Coking coal accounts for a further 22 per cent of unit production costs on average. Capital maintenance/overheads, labour and other forms of energy are the next most important factors in ironmaking, accounting for an additional combined 37 per cent of unit costs.

FIGURE 2: COMPOSITION OF PIG IRON PRODUCTION COSTS



Source: BHP Billiton.

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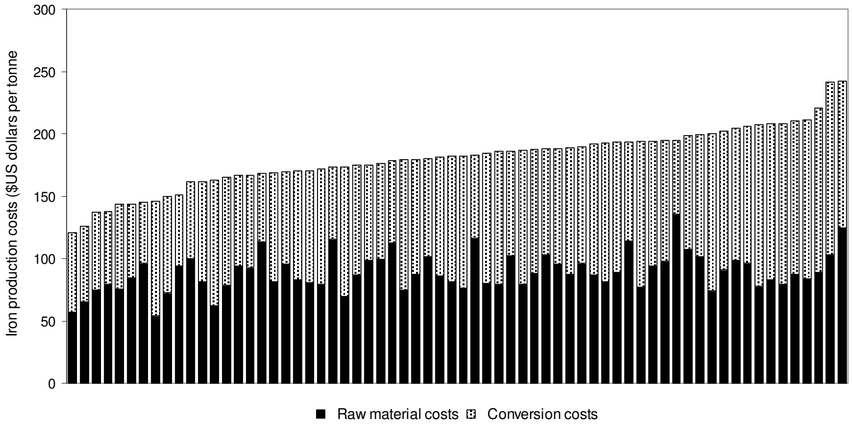
[2] The correlation coefficients for these essential inputs all exceed 95 per cent.

Globally, steel production costs vary significantly, which in turn affects the geographical location of production, the direction of trade flows and the source of demand for raw materials. Figure 3 shows pig iron production costs per tonne (separated into raw material costs and conversion costs) for the 66 steelmaking plants in the sample. Costs range from US$120 to $244 per tonne. Furthermore, across the sample, there is substantial variation in both the raw material costs and conversion costs.

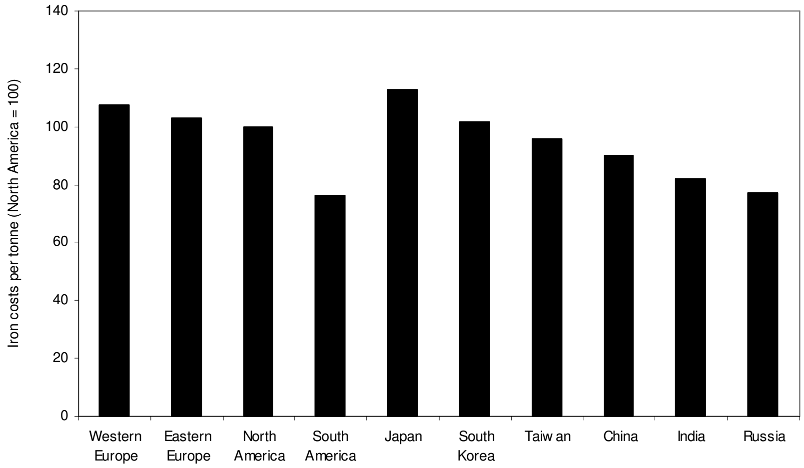
FIGURE 3: GLOBAL PIG IRON PRODUCTION COSTS



Source: BHP Billiton.

Figure 4 shows regional differences in these unit production costs. Japan and Western Europe steel producers face the highest production costs, while the developing regions of South America, China, India and Russia are the lowest cost producers. For example, production costs in South America are 68 per cent of those in Japan, while India is only marginally higher at 73 per cent. It is important to remember that these costs represent the production costs of the ironmaking stage of the steelmaking process only. The final unit production cost of hot rolled coil steel is also affected by the costs of the steelmaking, casting and rolling stages of the process. The ironmaking phase of the process was selected because costs in this phase of production are most directly affected by variation in raw material costs and potential economies of scale.

FIGURE 4: REGIONAL VARIATION IN PIG IRON PRODUCTION COSTS



Source: BHP Billiton.

There are four possible sources of variation in pig iron production costs across the plants consider in this paper: (i) differences in raw material prices, (ii) differences in conversion costs, (iii) differences in the plant efficiency, and (iv) economies of scale. In the following sections we consider two sources of global variation in production costs, namely differences in raw material prices and economies of scale.[3] Differences in the delivered prices of raw materials, particularly iron ore and coking coal, are heavily influenced by the distance from the load to discharge port and the associated daily cost of seaborne freight vessels. In the following sections we incorporate the main raw materials prices in ironmaking into a translog cost function to investigate whether any residual economies of scale are present.

THE TRANSLOG COST FUNCTION

Consider a production technology $S = F(X)$, where X is a vector of n inputs; $X_1, X_2, \ldots, X_n$ and there exists a corresponding price vector P. Provided that inputs are rented in competitive factor markets and output levels are determined exogenously, then,

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[3] Exchange rate fluctuations can also significantly affect unit production costs and the comparability of these costs across regions. To minimise the effect of exchange rate movements on the cost data used in this study, the average exchange rate for 2003 was used in the conversion of domestic units of currency to US dollars. Differences in technology and productive efficiency can also contribute to variation in unit production costs, although in the estimation of the translog cost function we assume a common technology and levels of efficiency.

according to the theory of duality between production and cost, the production function can be represented by a unique cost function taking the general form:

$$C\left(P,S\right)=\min_{X}\left(P'X;\, S=F(X)\right), \tag{1}$$

which minimizes the total cost of production of the output level S. The cost function is assumed to be increasing in S, and nondecreasing, linear homogenous, continuous and concave in P. The cost-minimising conditional input demand for the ith input X_i^* is expressed as a function of P and S using Shephard's lemma, $X_i^*(P,S)=C_i(P,S)$ where $C_i = \partial C/\partial P_i$ is the first-order partial derivative of the cost function with respect to factor prices. The conditional input demand equations are homogenous of degree zero in prices. Using a flexible function form, the production technology described in equation (1) can be approximated by a transcendental logarithmic (translog) second order, twice differentiable and nonhomothetic cost function taking the following form:[4]

$$\begin{aligned}\ln(C)=&\,\alpha_0+\alpha_S\ln S+\frac{1}{2}\alpha_{SS}\left(\ln S\right)^2\\&+\sum_i\beta_i\ln\left(P_i\right)+\frac{1}{2}\sum_i\sum_j\delta_{ij}\ln\left(P_i\right)\ln\left(P_j\right)\\&+\sum_i\lambda_{Si}\ln S\ln\left(P_i\right),\end{aligned} \tag{2}$$

where C is total production cost and the subscripts i, j denote elements of the price vector P. An important feature of this function is that it places no *a priori* restrictions on the substitution possibilities between inputs, which are captured by the cross price terms δ_{ij}. Furthermore, it permits scale economies to vary with production levels. Shepard's lemma is expressed in logarithmic form as $\partial \ln C/\partial \ln P_i = P_iX_i/C = Z_i$ where the last expression represents the share of the ith input in the total cost of production. Thus, by partially differentiating equation (2) with respect to the log of

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[4] The translog cost function was introduced by Christensen, Jorgenson and Lau (1973) and has since be used in numerous empirical applications.

factor prices separately, we can conveniently express the cost-minimising input share equations as:

$$\frac{\partial \ln(C)}{\partial \ln(P_i)} = Z_i = \beta_i + \lambda_{Si} \ln S + \sum_j \delta_{ij} \ln P_j . \tag{3}$$

It is customary to estimate the cost function and share equations simultaneously as a system in order to improve the efficiency of the estimates. Since $\sum_i Z_i = 1$ by definition, and are thus linearly dependent, one share equation is dropped during estimation of the translog cost function.

There are several restrictions that must hold if the cost function is to represent a well behaved function. The most important restriction is linear homogeneity in factor prices which implies the following initial parameter restrictions:

$$\sum_i \beta_i = 1 , \tag{4}$$

$$\sum_i \lambda_{Si} = 0 , \tag{5}$$

$$\sum_i \delta_{ij} = 0 , \tag{6}$$

which together ensure that a proportionate increase in factor prices results in a proportionate increase in production costs, and that this effect is independent of the scale of production. The assumption of output homotheticity requires $\lambda_{Si} = 0$, which ensures that the cost function can be written as a separable function in output and factor prices. The more restrictive assumption of homogeneity requires that the elasticity of cost with respect to output is constant which is achieved by $\alpha_{SS} = 0$.[5] The cost function must also satisfy the conditions of monotonicity and concavity to represent a well behaved production technology. Monotonicity requires that the fitted shares in equation (3) be non-negative at all points. Concavity requires that the Hessian matrix of second derivatives of the cost function be negative semi-definite.

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[5] See Diewert (1974) for a formal discussion of the restrictions for homotheticity and homogeneity.

A common use of cost functions is the investigation of the presence of economies of scale and the measurement of input substitutability. Caves, Christensen and Swanson (1981) define economies of scale as the proportionate increase in total cost arising from a proportional increase in production. In terms of the translog cost function, economies of scale can be calculated as the reciprocal of the value of the cost elasticity (*Ec*) with respect to production which is expressed as:

$$E_C = \frac{\partial \ln(TC)}{\partial \ln S} = \alpha_S + \alpha_{SS} \ln S + \lambda_{SL} \ln P_L + \lambda_{SK} \ln P_K + \lambda_{SM} \ln P_M + \lambda_{SA} \ln P_A, \tag{7}$$

so that an estimate of the economies of scale are then calculated as $E_S = 1/E_C$. An industry is said to exhibit economies (diseconomies) of scale if E_S is greater (less) than unity. Since the level of production directly affects the cost elasticity, it is clear from equation (7) that the economies of scale estimate will be sensitive to the scale of production.

A COST FUNCTION FOR THE GLOBAL STEEL INDUSTRY

The translog cost function is estimated using cross sectional data for 66 integrated steelmaking plants for 2003. We include four factor prices in the pig iron cost function; labour, capital, iron ore, and coal, and in addition a price index presenting the cost of the other minor inputs in the production process.[6] The system of equations comprising equations (2) and (3) is jointly estimated using Zellner's (1962) iterative seemingly unrelated regression estimation (SURE) technique. Since the share equations sum to one we arbitrarily omit Z_O, the share equation for the other inputs, during estimation because Barten (1969) has shown that estimates of a system of share equations are invariant to which equation is omitted. Furthermore, because the estimates of the system have been shown by Kmenta and Gilbert (1968) to be equivalent to maximum likelihood estimates, the likelihood ratio test can be used to test the validity of the various restrictions placed on the cost function.

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[6] The cost of labour, capital, iron ore and coal on average account for 76% of total production costs of steel plants used in this study. The price of other factors used in the steelmaking process are not included in equation (1) in order to retain the necessary degrees of freedom for the estimation of the cost function.

TABLE 2: ESTIMATES OF TRANSLOG COST FUNCTIONS

	Initial restrictions		Homothetic		Homogenous	
	Coefficient	t value	Coefficient	t value	Coefficient	t value
α_0	1.1641	11.22	1.2203	12.59	1.2262	13.38
α_S	1.0100	18.61	1.1006	22.33	1.0963	30.14
α_{SS}	0.0186	0.68	-0.0030	-0.12		
β_L	0.0968	9.31	0.0927	10.43	0.0928	10.49
β_K	-0.0046	-0.60	0.0068	0.99	0.0069	1.01
β_I	0.3470	25.22	0.3371	25.93	0.3371	25.95
β_C	0.1665	12.37	0.1669	12.38	0.1669	12.40
β_O	0.39419	13.41	0.3964	14.03	0.3962	14.07
δ_{LL}	-0.0171	-2.70	-0.0214	-3.90	-0.0214	-3.91
δ_{KK}	-0.0233	-2.54	-0.0117	-1.47	-0.0116	-1.46
δ_{II}	0.1152	15.75	0.0989	24.57	0.0987	25.88
δ_{CC}	0.1175	16.71	0.1142	17.66	0.1141	17.74
δ_{OO}	-0.1903	-8.31	-0.2087	-9.89	-0.2089	-9.92
δ_{LK}	-0.0359	-7.35	-0.0317	-6.91	-0.0317	-6.92
δ_{LI}	-0.0154	-4.09	-0.0195	-6.42	-0.0195	-6.43
δ_{LC}	-0.0273	-6.72	-0.0305	-7.72	-0.0305	-7.75
δ_{LO}	0.0958	10.42	0.1031	16.14	0.1032	16.19
δ_{KI}	-0.0170	-3.20	-0.0097	-2.04	-0.0097	-2.05
δ_{KC}	-0.0073	-1.43	-0.0140	-3.16	-0.0141	-3.19
δ_{KO}	0.0836	7.83	0.0673	6.97	0.0671	6.98
δ_{IC}	-0.1044	-12.82	-0.1014	-13.43	-0.1014	-13.46
δ_{IO}	0.0216	2.58	0.0317	4.01	0.0320	4.06
δ_{CO}	-0.0108	-0.43	0.0065	0.32	0.0065	0.32
λ_{LS}	-0.0117	-0.57				
λ_{KS}	0.1017	3.37				
λ_{IS}	-0.0737	-2.41				
λ_{CS}	0.0238	0.80				
λ_{OS}	-0.0399	-1.08				
Log likelihood	759.78		754.57		754.56	

Table 2 presents the estimates of three translog cost functions for the global steel industry with various restrictions imposed on the parameter values. The estimates in the first column are for equation (2) with only the initial restrictions of linear homogeneity in factor prices imposed on the estimated coefficients. In the second and third columns, the successive restrictions of homotheticity and homogeneity are imposed on the cost function. The log likelihood values suggest that the restrictions imposed beyond the first column can be rejected at the 5 per cent level of significance. As a result, the model with only the initial restrictions imposed was accepted as the final one.

The coefficients on factor prices and production are broadly consistent with those reported in two studies by Truett and Truett (1996, 1997) focusing on the Mexican and Korean steel industries. The coefficient on αs of 1.01 indicates that no economies of scale are present for ironmaking in the data set. The variation in pig iron production costs must therefore be a result of a combination of the other three possibilities mentioned above. These are differences in factor prices, differences in conversion costs or differences in plant efficiency. In the following section we consider the relationship between factor prices and pig iron production costs.

PRODUCTION COSTS AND RAW MATERIAL PRICES

The translog cost function in the previous section suggested that there are no economies of scale in the ironmaking stage of the steelmaking process. Another potential source of variation in iron production costs is raw material prices, primarily iron ore and coking coal. Figures 5 and 6 show the relationship (measured in terms of deviations from the mean and in US dollars) between raw material prices and production costs. If raw material prices were responsible for the variation in iron production costs we would expect to see positive correlations. The correlation between iron ore prices and iron production costs is 0.29, and is only 0.01 for coal prices. The absence of a clear positive relationship between raw material prices and iron production costs suggest that either conversion costs or plant efficiency that is responsible for the variation in production costs.

FIGURE 5: IRON ORE PRICES AND IRON PRODUCTION COSTS

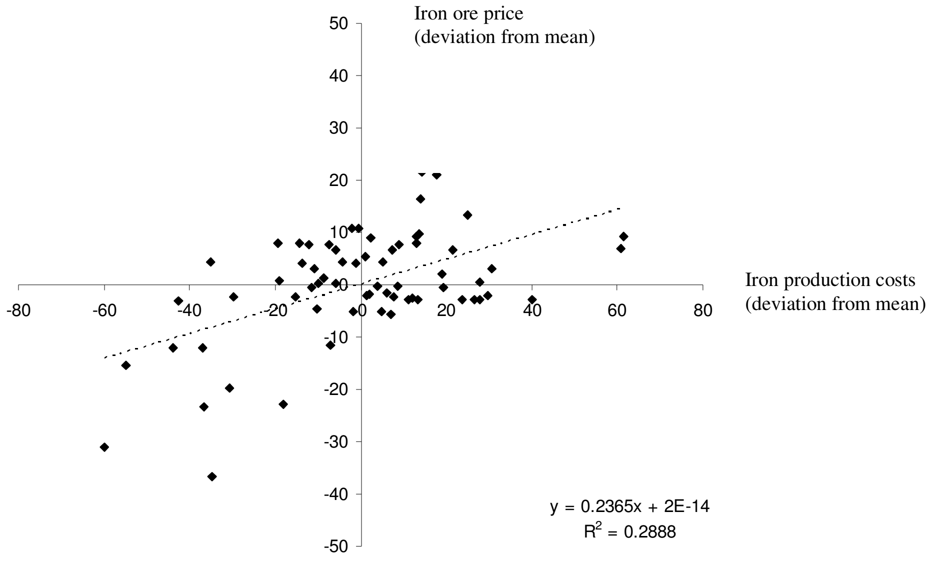


FIGURE 6: COAL PRICES AND IRON PRODUCTION COSTS

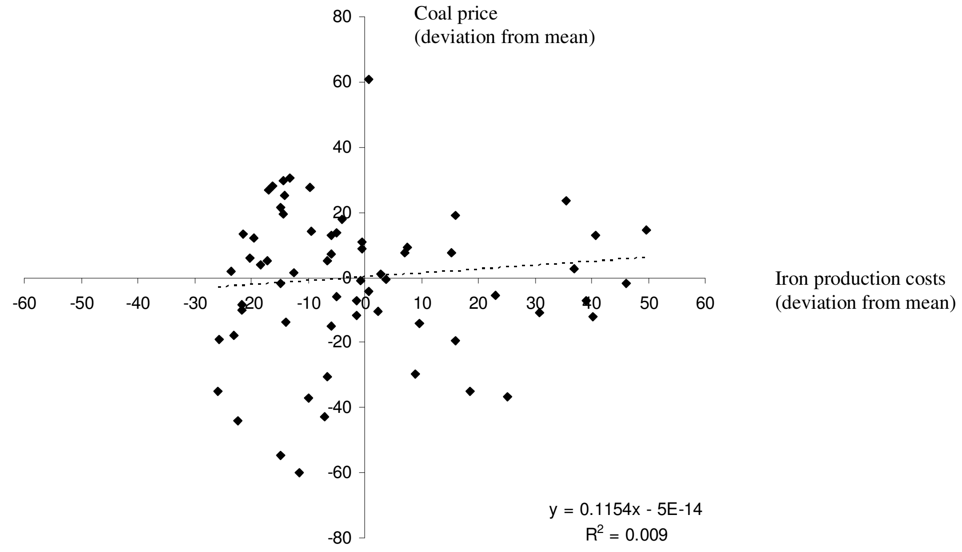
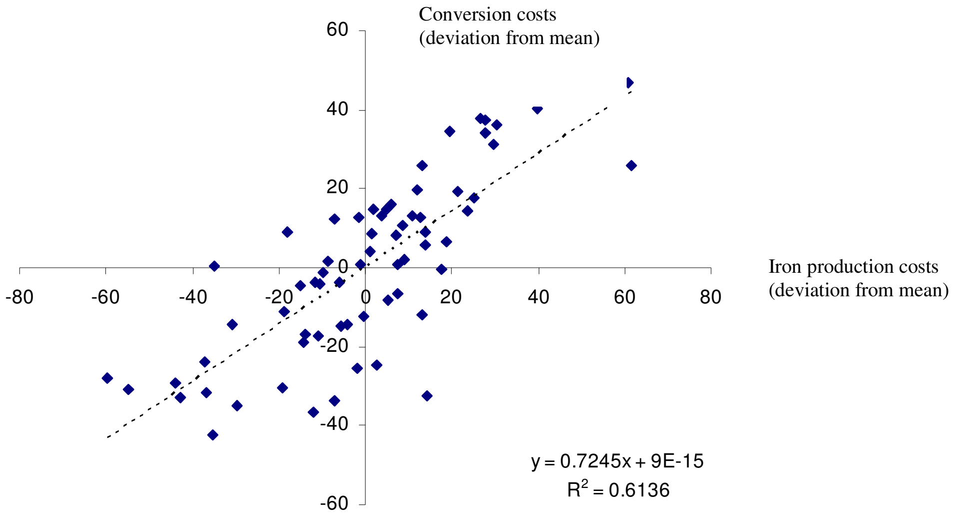


Figure 7 shows a strong positive relationship between conversion costs and iron productions costs. While the correlation between conversion costs and total production costs is 0.61, the correlation between raw material costs and total production costs is only 0.18. The importance conversion costs as a key determinant of total production costs is also evident in Figure 3, where conversion costs clearly appear to increase with production costs. Conversion costs include factors such as labour, various types of energy, fluxes, oxygen, inert gases, recycled materials, maintenance materials, general supplies and overhead expenses.

FIGURE 7: CONVERSION COSTS AND IRON PRODUCTION COSTS



Not surprisingly, given the absence of economies of scale in ironmaking, the correlation between conversion costs and plant steel production is only 0.01, indicating that there is no evidence that large plants have substantially different per unit conversion costs to smaller plants.

CONCLUSIONS

This paper considered the important question of variation in pig iron production costs at the plant level in the global steelmaking industry. Using a sample of 66 integrated steel plants that produce hot rolled coil, we estimate a translog cost function. Annual iron production for the plants in the data set ranges from a little over 1 Mt to 16.8 Mt. The results suggest that there is no evidence of economies of scale in ironmaking, suggesting that larger plants do not have a cost advantage over smaller plants. Although there are significant differences in the raw material prices faced by these plants, surprisingly, there is little evidence that these prices are systematically related to production costs. In other words, higher raw material prices do not appear to result in higher iron production costs. Instead, conversion costs appear to drive much of the variation in iron production costs in the plants examined in this paper.

Our finding that it is primarily conversion costs that account for much of the global variation in pig iron production must be qualified by one point. In our analysis we did not investigate difference in the overall level of plant efficiency and its effect on production costs. Some of the variation in production costs across plants could be driven by each plant's ability to efficiently use the resources at its disposal. While investigation of plant efficiency and its relationship with production costs is beyond the scope of this study it is a fruitful area for future research.

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