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**Abstract**

This paper empirically analyzes the existence of market power in the global iron ore market during the period 1993-2012 using an innovative Stochastic Frontier Analysis approach introduced by Kumbhakar et al. (2012). In contrast to traditional econometric procedures, this approach allows for the estimation of firm- and time-specific Lerner indices and, therefore, the assessment of the influence of individual firm characteristics on the ability to generate markups. We find that markups on average amount to 20%. Moreover, location and experience are identified to be the most important determinants of the magnitude of firm-specific markups.

*Keywords:* Estimation of market power, Lerner indices, Stochastic Frontier Analysis, Non-renewable resources

*JEL classification: D22, L11, L72*

## 1. Introduction

Steel, sometimes referred to as the backbone of industrialization is an important input in several key economic sectors such as manufacturing and construction. As a result, economic growth in developing countries often goes along with a strong growth of the country's demand for steel. Even in wealthy economies with a lower need for, e.g., infrastructural development, steel constitutes a major economic factor. In Germany, for example, around 20% of all manufacturing inputs are consumed by the steel and metal processing industry (Döhrn and Janßen-Timmen, 2012). Hence, steel prices deviating from prices under perfect competition - either due to exercise of market power in the steel market itself or in one of the key input markets such as coking coal and iron ore – may cause significant losses in in a country's economic welfare.

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In this regard, the sharp increase in iron ore prices in recent years – on average 26% p.a. since 2003– raises the question as to whether this increase is at least partly due to iron ore producers exercising market power (see, e.g., Hilpert and Wassenberg, 2010; Zaklan et al., 2011). While the increase in prices may also be explained by increasing marginal production costs, the conjecture of a non-competitive iron ore market is easily motivated by the high concentration level on the supply side of the market. The three largest producers, VALE, BHP Billiton and Rio Tinto (also called 'Big3'), made up a share of more than 30% of worldwide production, and in the worldwide seaborne trade, of more than 58% in 2010 (UNCTAD, 2011). Furthermore, the iron ore market is characterized by a low degree of demand-side substitutability (Hurst, 2012; Chang, 1994) and high barriers to entry (Asafu-Adjaye and Mahadevan, 2003). Finally, buyers and sellers of iron ore are geographically dispersed and trade costs due to the low value-to-weight-ratio separates markets to some degree. Global iron ore trade may be roughly divided into two areas: the Atlantic-based and the Pacific-based markets, which are linked by suppliers that deliver iron ore to both market areas (Wilson, 2012). Therefore, transportation costs have to be considered as an additional factor that may reduce the availability of cheap supply and could strengthen the exercise of market power.

Despite the warranted interest in scrutinizing firm behavior in the iron ore market, empirical research on the exercise of market power is rather scarce. Most articles concerning the iron ore market deal with market power only indirectly via merger analysis (see, e.g., Lundmark and Nilsson, 2003; Warell, 2007; Lundmark and Warell, 2008; Fiuza and Tito, 2010). To the best of our knowledge, only one article exists that deals empirically with market power in the iron ore market: Smart (2011) finds that producers most likely exhibit Cournot behavior. Overall, including the literature on mergers, the existing literature is supportive of the notion that there is a potential for non-competitive behavior of iron ore producers. However, so far there is no empirical analysis that estimates markups on short-run marginal costs or assesses their main determinants on the firm level, a research gap that this paper intends to close.

In order to do so, we define an empirical model that is based on an innovative estimation approach introduced by Kumbhakar et al. (2012). This approach makes use of a new application of Stochastic Frontier Analysis (SFA) techniques that have been widely applied in quantitative benchmarking studies. Basically, SFA relies on the assumption that the deviation of an individual decision-making unit from the estimated best-practice frontier (in the majority of cases a production or cost frontier) can be divided into two distinctive parts: a classical stochastic noise component and an additional skewed residual that captures individual inefficiency. In the approach given by Kumbhakar et al. (2012), however, it is not a production or cost frontier but rather a frontier of the ratio of revenue to total cost that is estimated, and the additional skewed residual is assumed to represent a firm-specific markup term. This term can easily be transformed into a firm-specific estimate of the familiar Lerner index, which represents the relative markup of price over marginal cost.

This estimation procedure differs significantly from traditional estimation procedures for analyzing market power (see, e.g., Bresnahan, 1989) and bears several advantages. First, Kumbhakar et al.'s approach yields expressions for both time- and firm-specific markups and, hence, provides more detailed information. Furthermore, modifying the original approach by using the SFA model of Battese and Coelli (1995) allows us to analyze the impact of firm-specific and environmental characteristics on the estimated markups. Second, the procedure is not as restrictive as others. An error term that captures noise in the data, such as supply or demand shocks, e.g., as a result of strikes or bad weather conditions, is included. Furthermore, it relaxes some assumptions that are normally necessary to obtain valid estimates, such as constant returns to scale or certain demand conditions. Third, data availability is a crucial factor in empirical analyses. For the estimation procedure applied in this paper, supply data is sufficient and price data is not needed for all inputs and outputs. Instead, total revenue can be used and an input distance function approach can be chosen that relies on (typically) publicly available data on input and output quantities (Coccorese, 2012; Kumbhakar et al., 2012).

Overall, we find that the conjecture of firms exercising market power in the iron ore market is supported by the empirical analysis. Estimated markups are significantly different from zero, with the firms' average markup amounting to 0.20. In addition, starting at the beginning of the 21st century, we find that markups increase over time, which leads us to the conclusion that the recent surge in iron ore prices can at least partially be attributed to an increase in the iron ore producers' exercise of market power. However, heterogeneity of firms seems to be significant as the producer's individual ability to charge markups varies considerably. In particular, the analysis points out that experience, here, measured by years of production, and geographical location are the most important factors influencing the level of firm-specific markups. Yet, due to a potential reverse-causality problem one needs to be cautious with this interpretation. An alternative explanation of our finding may be that more profitable firms, i.e., firms with higher markups, stay in the market for a longer time. However, given that firms, which have a long history in iron ore mining, are more likely to have a more experienced workforce and knowing that labor productivity is an important determinant of marginal production costs, we tend to argue that the increase in the markups with every additional year of production is an indication of experience effects. Finally, we find weak evidence that annual GDP growth helps to explain the markup-levels, albeit the influence is found to be rather small.

The remainder of the paper is structured as follows: The methodology applied is explained in Section 2, and the data and empirical specifications are outlined in Section 3. The results are presented in Section 4, followed by a discussion in Section 5.

## 2. Methodology

The 'SFA estimator of market power' introduced by Kumbhakar et al. (2012) offers a new application of classical SFA techniques that are extensively applied in quantitative benchmarking studies. Basically, SFA relies on the assumption that the deviation of an individual decision-making unit from the estimated best-practice frontier (in the majority of cases a production or cost frontier) can be divided into two distinctive parts: a classical stochastic noise component and an additional residual that captures individual inefficiency. In the approach given by Kumbhakar et al. (2012), however, it is not a production or cost frontier but rather a frontier of the ratio of revenue to total cost that is estimated, and the additional residual is assumed to represent a markup term.

The starting point of Kumbhakar et al.'s approach is rather simple: In the case of market power, the firm's individual output price ($P$) is larger than its individual marginal cost ($MC$): $P > MC$. Augmenting this inequality with the ratio of output to total cost ($Y/C$) and rearranging gives:

$$\begin{aligned} \frac{PY}{C} &> MC\frac{Y}{C} = \frac{\partial C}{\partial Y}\frac{Y}{C} = \frac{\partial \ln C}{\partial \ln Y} = E_{CY} \\ \frac{PY}{C} &> E_{CY} \end{aligned} \tag{1}$$

Hence, the intuition of the approach is to compare the revenue-cost share ($PY/C$) with the cost elasticity ($E_{CY}$). The residual of these two expressions (captured by $u \geq 0$) is related to the markup:

$$\begin{aligned} \frac{PY}{C} &= \frac{\partial \ln C}{\partial \ln Y} + u \\ \frac{PY}{C} &= E_{CY} + u. \end{aligned} \tag{2}$$

Revenue and cost data are usually observable from firm accounting data and, therefore, the revenue-cost share can be directly computed. Thus, in order to estimate Equation 2, an expression for the cost elasticity is needed, which can be obtained by differentiating the cost function in natural logarithm with respect to output in natural logarithm. However, this cost function approach relies on input price data, which is often not available.

As shown by duality theory, in this case a dual input distance function approach can be used instead (Shephard, 1970, p. 159). An input distance function describes a production technology by "looking at a minimal proportional contraction of the input vector, given an output vector" (Coelli et al., 2005, p. 47). That is, in contrast to a traditional cost function approach, the input distance function approach does not rely on a cost-minimization assumption based on observed market input prices. Rather, the input distance approach assumes a shadow cost-minimizing behavior, where the decision-making units minimize their costs relative to the unobserved input shadow prices.

The Lagrangian for this minimization problem can be written as:

$$L(X,Y) = wX + \lambda(1 - D(X,Y)), \tag{3}$$

where $w$ and $X$ represent a vector of input shadow prices and inputs, respectively; $\lambda$ denotes the Lagrangian multiplier; $Y$ is the output and $D(X,Y)$ represents the input distance function.

Using the first-order conditions for the problem, it can be shown that $\lambda = C(w,Y)$ at the optimum (Färe and Primont, 1995, p. 52). In addition, cost minimization and applying the envelope theorem yields the following expression for the log derivatives of the input distance function:

$$E_{CY} = \frac{\partial\, ln\, C(w,Y)}{\partial\, ln\, Y} = -\frac{\partial\, ln\, D(X,Y)}{\partial\, ln\, Y}. \tag{4}$$

Hence, the negative elasticity of the input distance function with respect to the output $Y$ is equal to the cost elasticity of that output.

In order to obtain an explicit formulation for the cost elasticity, the functional form of the input distance function has to be determined. We follow Kumbhakar et al. (2012) and use a translog specification that allows the cost elasticity to vary across time and firms. The translog input distance function for one output $Y$ and $J(j = 1, ..., J)$ inputs can be written as:

$$\begin{aligned} ln\, D(X,Y,T) =& \alpha_0 + \alpha_y\, ln\, Y + \frac{1}{2}\alpha_{yy}\,(ln\, Y)^2 + \sum_{j=1}^{J} \alpha_j\, ln\, X_j \\ &+ \frac{1}{2}\sum_{j=1}^{J}\sum_{k=1}^{K} \alpha_{jk}\, ln\, X_j\, ln\, X_k + \sum_{j=1}^{J} \alpha_{jy}\, ln\, X_j\, ln\, Y \\ &+ \alpha_t\, T + \frac{1}{2}\alpha_{tt}\, T^2 + \alpha_{yt}\, ln\, Y\, T + \sum_{j=1}^{J} \alpha_{jt}\, ln\, X_j\, T, \end{aligned} \tag{5}$$

where $T(t = 1, ..., T)$ is a time trend and the $\alpha$s are unknown parameters to be estimated.

Economic theory requires the input distance function to be non-decreasing, concave and linearly homogeneous in inputs as well as non-increasing and quasi-concave in outputs (Coelli et al., 2005, p. 49). Linear homogeneity in inputs is given if

$$\sum_{j=1}^{J} \alpha_j = 1, \sum_{j=1}^{J} \alpha_{jk} = 0, \sum_{j=1}^{J} \alpha_{jy} = 0, \text{ and } \sum_{j=1}^{J} \alpha_{jt} = 0. \tag{6}$$

Imposing the restrictions in Equation 6 by normalizing the translog input distance function in Equation 5 by one of the inputs (Lovell et al., 1994) and adding a symmetric error term $v$, the model to be estimated becomes:

$$\frac{PY}{C} = -\frac{\partial\, ln\, D(X,Y)}{\partial\, ln\, Y_m} + u + v = -\left[\alpha_y + \alpha_{yy}\, ln\, Y + \sum_{j=1}^{J-1} \alpha_{jy}\, ln\, \widetilde{X}_j + \alpha_{yt}\, T\right] + u + v, \tag{7}$$

where $\widetilde{X}_j$ is the quantity of j-th input factor normalized by the quantity of an arbitrary input factor $(X_1)$.[1]

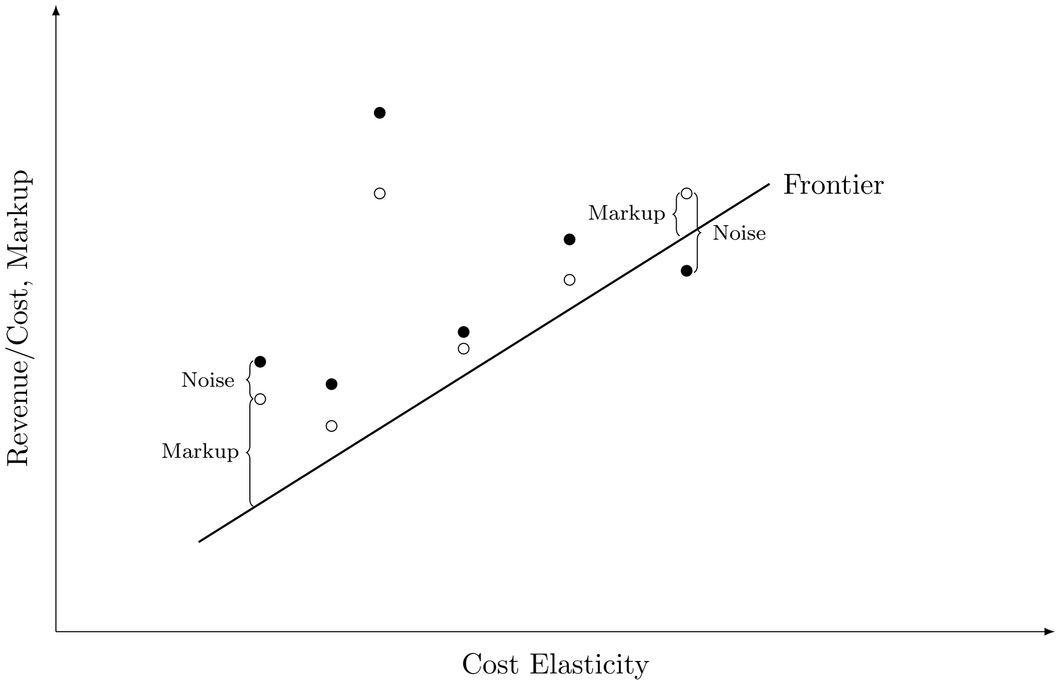


Figure 1: Markups and cost elasticity

This specification is statistically equivalent to a stochastic cost frontier model with two error components, $u$ and $v$. However, as shown in Equation 2, $u$ does not represent cost inefficiency but is instead related to a markup component. Kumbhakar et al. (2012) denominate this approach as a "non-standard application of stochastic frontier models". An illustrative description of the approach is provided in Figure 1. The vertical axis shows the revenue-cost ratio $(PY/C)$, while the horizontal axis shows the cost elasticity $(E_{CY})$. Furthermore, the solid line represents the estimated frontier and the dots indicate some observed revenue-cost ratios. As shown, the deviation of the observed revenue-cost ratios from the minimum revenue-cost ratios on the estimated frontier can be divided into a noise component $v$ and a markup component $u$.

Furthermore, as shown by Kumbhakar et al. (2012), an expression for the familiar Lerner index (Lerner, 1934), which represents the relative markup of price over marginal cost, $((P - MC)/P)$, can be computed from the estimated results as follows: First, the fraction by which $P$ exceeds $MC$ can be written as:

$$\frac{P - MC}{MC} = \frac{P - \frac{\partial C}{\partial Y}}{\frac{\partial C}{\partial Y}} = \frac{\frac{PY}{C} - \frac{\partial ln(C)}{\partial ln(Y)}}{\frac{\partial ln(C)}{\partial ln(Y)}} = \frac{u}{E_{CY}}. \tag{8}$$

[1]The monotonicity and concavity restrictions are tested ex post after the estimation.

Then, multiplying this expression by $MC/P$ and reformulating gives the traditional Lerner index for measuring market power:

$$\begin{aligned}
\frac{P-MC}{MC}\frac{MC}{P} &= \frac{u}{E_{CY}}\frac{MC}{P} \\
\frac{P-MC}{P} &= \frac{u}{E_{CY}}\frac{MC}{P} = \frac{\frac{u}{E_{CY}}}{\frac{P}{MC}-\frac{MC}{MC}+1} \\
LI &= \frac{\frac{u}{E_{CY}}}{1+\frac{u}{E_{CY}}}.
\end{aligned} \tag{9}$$

The range of the Lerner index is between zero and one, with one indicating the maximum possible market power and zero indicating marginal cost pricing. These values will be presented and analyzed in detail in Section 4.1.

## 3. Data and empirical model specifications

This section serves two purposes: First, it provides an overview of the data and the variables used in the analysis. Second, the empirical model to be estimated is outlined and discussed.

### *3.1. Data*

The sample encompasses 10 companies from six countries and covers the period between 1993 and 2012 with 96 observations in total (see Table 1). These companies represent more than 70% of the global trade and 33% of the worldwide production of iron ore in 2010.[2] The data is obtained either from the "Form 20-F" of the Securities and Exchange Commission (SEC) of the United States or from the companies' annual reports.[3]

Although the firms operate in different geographical locations all over the world, five out of the eleven firms have their headquarters and main production based in Australia. Unfortunately, no producers from India and China can be included. For firms in these countries, either no data is available (especially in China) or their definitions of accounting items deviate from other companies in the sample preventing a meaningful comparison (as for Indian companies).[4]

Summary statistics for the variables used to estimate the revenue-cost frontier model described in Section 2 are depicted in Table 2. All monetary variables have been converted to US Dollar (USD) by purchasing power parity conversion rates from the Worldbank (2013) and inflated by the consumer price index from the OECD (2013) for each respective country to 2012 values.[5][6]

[2] For the case of companies operating in multiple countries, the country with the most production activity is chosen.

[3] "SEC Form 20-F" is a necessary form to file with the Securities and Exchange Commission (SEC) of the United States if the company is listed on the stock market in the United States.

[4] For example, for Sesa Sterlite, only data on capital expenditure and total segment assets was available.

[5] For the Ukraine, figures from UKRstat (2013) had to be used instead as data was not available from the OECD.

[6] For 4 of the 10 companies, the fiscal year ends in June instead of December. Hence, without adjustment, different time periods would be compared. To adjust for these cases, two consecutive years are averaged, e.g., the average of

Table 1: Overview - Companies

| Company | Period | Obs. | Company | Period | Obs. |
|---|---|---|---|---|---|
| Atlas Iron | 2009 - 2011 | 3 | Fortescue Metals Group | 2008 - 2011 | 5 |
| BHP Billiton | 2005 - 2011 | 7 | LKAB | 2000 - 2012 | 13 |
| Cliffs Natural Resources | 1993 - 2012 | 20 | Mount Gibson | 2006 - 2011 | 6 |
| Ferrexpo | 2006 - 2012 | 5 | Rio Tinto | 1997 - 2012 | 16 |
| Kumba Iron Ore | 2006 - 2012 | 7 | Vale | 1998 - 2012 | 15 |
| Total | 1993 - 2012 | 96 | | | |

Table 2: Summary statistics - Frontier variables

| Variable | Mean | Median | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Revenue [million USD] | 6,345.44 | 2,368.06 | 9,038.27 | 40.59 | 47,536.23 |
| Total Cost [million USD] | 2,959.36 | 1,499.05 | 3,666.02 | 45.04 | 18,095.00 |
| Revenue Cost Share | 1.82 | 1.79 | 0.58 | 0.90 | 3.62 |
| Capital [million USD] | 5,342.92 | 1,876.21 | 8,272.00 | 9.35 | 37,846.00 |
| Labor [number of employees] | 7,092.67 | 4,470.5 | 8,632.35 | 85.00 | 52,374.00 |
| Reserves [million FE units] | 1,348.96 | 510.89 | 2,076.8 | 22.87 | 9,524.12 |
| Production [million FE units] | 43.12 | 19.81 | 49.68 | 0.55 | 186.59 |

Iron ore can be divided into three different product groups: lumps, fines and pellets. Unfortunately, detailed data on the product groups is often not available. However, although their usage is different, all three products are utilized in the production of steel. Therefore, the products are closely interconnected, at least in the long run. For this reason, the existence of different product groups is neglected in the following, and product differences among iron ore are reflected by differences in their iron content. Product and reserves are converted to FE units by different FE grades. For the production, the FE grade is the production-weighted average of the FE grades of the active mines of the respective firm. In the case of pellet production, the FE grades of the pellets are used. In calculating the FE grade of the reserves, all mines of the respective firm are considered.

### *3.2. Specification of the empirical model*

The Lerner index should only be used if the underlying assumption of static profit maximization is valid (Kutlu and Sickles, 2012). In a dynamic context, marginal cost has to be adjusted to "full marginal cost", which includes a user cost describing "the sum of discounted future costs or benefits that result from current production decisions" (Pindyck, 1985). Otherwise, a high value for the Lerner index could result even if the firm behaves competitively. In a nonrenewable resource

the results for July 2004 to June 2005 and for July 2005 and June 2006 would form the value for the year 2005. A consequence of this adjustment is that the second half of 2004 and the first half of 2006 are included in the value for 2005. Furthermore, it reduces the number of observations from 100 to 96.

industry, the user cost will be positive if either the resource is completely exhausted or production costs are increasing with cumulative production. The former refers to a scarcity rent in style of Hotelling (1931), while the latter points to a so-called 'Ricardian stock rent' in line with Levhari and Liviatan (1977). As 4.6% of the earth's crust consists of iron ore (European Commission, 2001), the physical availability should not pose a problem in our estimations. The average of the reserves-to-production ratio of firms in the sample is, with more than 32 years, relatively high. Therefore, the existence of a scarcity rent is not very likely and is therefore not included in the analysis. The 'Ricardian stock rent', however, may be of more relevance. Pindyck (1978) mentions that while the exact transmission channel is not clear, it is reasonable to assume for mineral resources that the amount of reserves influences the level of production cost. One explanation may be that lower cost deposits are extracted first and, therefore, higher production costs must be met in the future. Following this argument, we include the iron ore reserves of each company in our empirical model specification. Given the methodology outlined in Section 2 as well as the variable description in Section 3.1 and this paragraph, the following equation is estimated:

$$\frac{PY_{it}}{C_{it}} = - \left[ \alpha_y + \alpha_{yy} \, ln \left( production_{it} \right) + \alpha_{1y} \, ln \left( \frac{capital_{it}}{labor_{it}} \right) + \alpha_{2y} \, ln \left( \frac{reserves_{it}}{labor_{it}} \right) + \alpha_{yt} \, t \right] + u_{it} + v_{it}. \tag{10}$$

Several stochastic frontier models for panel data can be used to estimate Equation 10. We modify the original approach of Kumbhakar et al. (2012) by including variables assumed to directly influence the markup component. This is done by using the SFA model of Battese and Coelli (1995). Within this model, the markup term $u_{it}$ in Equation 10 can be defined as:

$$u_{it} = z'_{it}\beta + W_{it}, \tag{11}$$

where $z'_{it}$ is a vector of explanatory variables and $W_{it}$ is a random component. The model can be estimated in a single stage by maximum likelihood techniques in which the stochastic term is assumed to follow a normal distribution $v_{it} \sim iidN(0, \sigma_v^2)$ and the markup term is assumed to follow a truncated normal distribution $u_{it} \sim N^+(z'_{it}\beta, \sigma_u^2)$. Since only the composed error term $\epsilon_{it} = u_{it} + v_{it}$ is observed, the firm's markup is predicted by the conditional mean $\widehat{u}_{it} = E[u_{it}|\epsilon_{it}]$ (Jondrow et al., 1982).

Two specifications of the model are estimated. The first specification is the traditional Battese and Coelli (1995) model as presented above. The model has been used in a number of SFA applications with panel data. However, it is not a real panel data model but rather a pooled model that considers all observations as independent. Hence, the model may suffer from an unobserved heterogeneity bias that, in particular, may lead to an overestimation of markups. For this reason, we additionally estimate a second specification in which the traditional Battese and Coelli (1995) model is augmented by individual firm dummy variables as in Filippini and Wetzel (2014). These variables capture any time-invariant firm-specific unobserved heterogeneity and hence avoid the unobserved heterogeneity problem. However, a drawback of this specification is that any persistent firm-specific markups will also be attributed to the unobserved heterogeneity. Therefore, firm-specific markups may be underestimated.

In the following, we discuss the firm-specific and environmental factors that are assumed to influence a firm's ability to exert markups. Altogether, six factors are included in Equation 11 as explanatory variables: amount of reserves, FE grade of reserves, years of production, location, market share, a change in the pricing system and the year on year growth rate of the world GDP. Thereby, the first four of these factors, *ceteris paribus*, reduce short-run marginal costs, which typically leads to increasing markups. Hence, these factors may explain potential variations in markups across firms.

As stated by Tilton (2001), labor is an import factor in the mining industry. One-third to one-half of variable costs are related to labor. Furthermore, Tilton (2001) finds that labor productivity positively depends on the amount of reserves. He assumes that this relationship holds because the incentive to invest in new technology or in the latest equipment may be larger for a mine with a long expected lifetime. Hence, a mine with a large amount of reserves may be extracted more efficiently. Following this argument, we, first, expect a positive influence of the amount of reserves on the markups.

Moreover, a firm that owns reserves with high FE grades will be able to produce the same quality of iron ore at lower cost compared to a competitor with reserves of lower quality: Either the firm is able to extract a smaller amount of iron ore than the competitor to produce the same amount of iron ore in FE units, or the competitor may need to further process the crude iron ore (e.g., by pelletizing) to achieve the same quality of the firm's final product. Hellmer (1996) provides empirical evidence for this relationship as he finds a negative relationship between the FE grade and average cost for iron ore producers. Hence, second, a positive impact of the FE grade of reserves on the markups is expected.

Third, experience may serve as an advantage for firms operating in the iron ore market for a long time. This is particularly interesting for the period under observation as some firms have just recently entered the iron ore market. More experienced firms could have an advantage due to long lasting sales relationships and, therefore, more efficient sales divisions. Another aspect is the possible existence of individual learning effects: Learning by doing could lead to higher labor productivity.

Fourth, producers and customers are regionally dispersed. Therefore, advantages of one firm over another could result from a favorable geographical location of the main production area with respect to the main demand centers. Hobbs (1986) states that significant transportation costs and economies of scale can lead to spatial price discrimination or, in other words, to geographic market power. In all likelihood, this applies to the iron ore industry. As transportation costs depend to a large extent on the distance shipped, Australian producers should benefit from lower transportation costs to the main demand centers located in the close-by Asia-Pacific region (Galdon-Sanchez and Schmitz, 2002). Hence, Australian producers may capture the freight cost differential to more distant suppliers and thus, generate higher markups (Smart, 2011). In order to capture this location factor, we include country dummies in our analysis.

Fifth, there is only a small number of active firms in the iron ore market (Sukagawa, 2010). In the economic literature, a positive correlation between industry concentration and profitability has been observed (Bain, 1951). However, there has been a debate over the causal direction. On the one hand, the Structure-Conduct-Performance-Paradigm states that high concentration facilitates collusion and, therefore, leads to the exercise of market power which is 'proxied' by high profitability of firms in a concentrated industry (Bain, 1951). On the other hand, this explanation may suffer from a reverse causality problem as the positive correlation could result from firms with higher efficiency levels that grow faster and, consequently, expand their market shares (Demsetz, 1973; Peltzman, 1977). Thus, while there is no consensus on the causal relationship, the firm's individual market share is a potential factor to explain different markups across firms. For our analysis, we define a firm's individual market share as the ratio of its own production to global production. A positive influence of the market share on markups is expected.

Furthermore, a change in the pricing system, which occurred in 2010, is empirically analyzed. The prices given in the long-term contracts consist of a (regional) benchmark price as a basis and a discount or premium contingent on quality, product group and transport distance (Hellmer and Ekstrand, 2013). In the past, the benchmark price was determined annually by so-called 'champion negotiations' (Sukagawa, 2010, p.56), in which the largest producers and largest buyers engaged in 'a form of an oligopoly-oligopsony negotiation' (Wilson, 2012). This pricing procedure, however, changed in the beginning of 2010 when the top three producers enforced a transition from annual price negotiations to a quarterly revised index price system based on spot market prices (Wilson, 2012). Iron ore producers face a highly inelastic demand in the short run. Hence, a change in the pricing system from annual negotiations to quarterly index based pricing should support iron ore producers under increasing demand, as is the case in the time period considered in this paper (Sukagawa, 2010). We therefore include a dummy variable equal to one for the years with the new pricing system and zero otherwise. We expect the sign of the corresponding coefficient to be positive, indicating the ability of the firms to generate higher markups within the new pricing system.

Finally, the year on year change in the world's real GDP (IMF, 2014) is included in order to analyze the impact of general economic conditions during the sample period. A positive growth of the world's real GDP should be accompanied by a surging demand for iron ore. In this case, a tighter market could make it easier for producers to generate higher markups.

Summary statistics for the markup variables are presented in Table 3. As for the frontier variables, the descriptive statistics show significant variance regarding all variables. Reserves and years of production, in particular, differ significantly among producers.

Table 3: Summary statistics - Markup variables

| Variable | Mean | Median | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Reserves [million tons] | 2,486.43 | 1,223.46 | 3,620.46 | 39.57 | 17,538.22 |
| Years of production | 81.23 | 69.50 | 51.25 | 1.00 | 162.00 |
| FE grade of reserves | 0.49 | 0.56 | 0.14 | 0.26 | 0.70 |
| Market share | 0.05 | 0.02 | 0.05 | 0.00 | 0.17 |
| GDP change | 3.62 | 3.94 | 1.69 | -0.38 | 5.35 |

## 4. Results

This section comprises the results from the empirical analysis and is divided into two parts. The first subsection presents the results of the frontier estimation and the firm- and time-specific estimates for the Lerner index. In the second subsection, the influence of the outlined firm-specific and environmental factors on markups are illustrated.

### *4.1. Lerner indices of iron ore producers*

As outlined in Section 2 and Section 3.2, the firm- and time-specific Lerner indices can be derived from the estimation results of the stochastic frontier model defined in Equation 10. Two specifications of the model are estimated: one encompassing individual firm fixed effects (BC95 FE) and one without (BC95). The estimated model is a semi-log or level-log model in which all independent variables are normalized by their sample median. Furthermore, Equation 10 without the error terms is an expression for cost elasticity with respect to output, i.e., the relative change in cost given a relative change in output. This means that the estimated coefficients represent the absolute change in cost elasticity for a one-percent change in the respective variables evaluated at the sample median.

In addition to our stochastic frontier model, we also estimate a conventional ordinary least squares (OLS) model for the two specifications. Using likelihood ratio (LR) tests, we evaluate whether a markup component exists at all. The LR tests have the null hypothesis: $\lambda = 0$ with $\lambda = \sigma_u/\sigma_v$ (Coelli et al., 2005). For both specifications, the null hypotheses that the OLS model is sufficient can be rejected at any conventional level of significance. Hence, the stochastic frontier model is preferred.

All coefficients in the stochastic frontier models except the ones for the linear time trend in the BC95 specification and the constant in the BC95 FE specification are statistically significant at least at the five percent level. However, the magnitude of the coefficients varies significantly

Table 4: Estimation Results[a,b,c,d]

| Variable | Parameter | OLS | OLS ID | BC95 | BC95 FE |
|---|---|---|---|---|---|
| Ln(production) | $\alpha_{yy}$ | 0.151*** | 0.201 | 0.451*** | 0.460*** |
| | | (0.044) | (0.160) | (0.104) | (0.068) |
| Ln(capital/labor) | $\alpha_{y1}$ | 0.114* | −0.218** | −0.198** | −0.247*** |
| | | (0.065) | (0.108) | (0.081) | (0.050) |
| Ln(reserves/labor) | $\alpha_{y2}$ | −0.083 | −0.211*** | −0.110** | −0.092*** |
| | | (0.068) | (0.073) | (0.049) | (0.029) |
| Time | $\alpha_{yt}$ | 0.056*** | 0.061*** | 0.007 | −0.035*** |
| | | (0.010) | (0.018) | (0.006) | (0.012) |
| Constant | $\alpha_y$ | 1.885*** | 1.596** | 0.877*** | −0.011 |
| | | (0.048) | (0.621) | (0.123) | (0.012) |
| Fixed effects | | No | Yes | No | Yes |
| Log-likelihood | | −52.756 | −8.878 | 0.763 | 28.782 |
| $\sigma_u$ | | | | 0.304*** | 0.299*** |
| $\sigma_v$ | | | | 0.076*** | 0.083*** |
| $\lambda$ | | | | 3.979*** | 3.621*** |
| No. of observations | | 96 | 96 | 96 | 96 |

[a] Standard errors are in parentheses.
[b] *, **, *** indicate significance at the 10, 5 and 1% level, respectively.
[c] Estimates for the fixed effects coefficients are available from the authors upon request.
[d] All estimations have been performed in R using the "frontier" package by Coelli and Henningsen (2013).

between the two specifications. This indicates the existence of an unobserved heterogeneity bias in the BC95 specification without fixed effects. In fact, applying an additional LR test to choose between the BC95 and the BC95 FE specification indicates that as a group the firm dummy variables are statistically significantly different from zero. Hence, the BC95 FE is found to be the appropriate specification and is discussed more thoroughly in the following. Nevertheless, the specification without fixed effects is presented for comparison reasons.

Unfortunately, a limited number of the cost elasticity estimates yield negative values. This result is not consistent with economic theory since a well behaved cost function is required to be non-decreasing in outputs. Negative cost elasticity estimates are observed for five observations in the BC95 and seven observations in the BC95 FE specification. Four of the observations within the BC95 specification belong to Mount Gibson and one to Atlas Iron. The seven observations in the BC95 FE specification belong to BHP Billiton. Given this anomaly, the respective observations are excluded from the following analysis of the Lerner indices.[7]

[7] In case of BHP Billiton the estimated negative cost elasticities are in all likelihood due to the fact that we had to approximate the capital variable. Data on capital was only available on the total company level but not on the iron ore business segment level. Therefore, we used two alternative approximation approaches based on asset and revenue shares to proxy the capital variable. The estimation results for the two approaches do not differ significantly. Furthermore, all models were also estimated without the respective observations. The estimated coefficients are very similar to the coefficients presented in Table 4 and all cost elasticity estimates show positive values as required by economic theory. Therefore, in order to have more degrees of freedom, we opted to leave all observations in the frontier estimation and exclude the ones with negative cost elasticity estimates from the second-stage Lerner indices analysis. All estimation results are available from the authors upon request.

The summary statistics of the Lerner index estimates are presented in Table 5. The estimates are derived from the estimation results of the two stochastic frontier specifications as outlined in Equation 9. The two specifications provide a range of possible values. The estimates from the BC95 specification are most likely upward-biased and hence may be considered as an upper bound. In contrast, the more reliable BC95 FE specification provides relatively conservative estimates. Any time-persistent markup components are captured by the fixed effects and hence are excluded from the Lerner index estimates.

Table 5: Summary statistics of Lerner index

| Model | Mean | Median | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| BC95 | 0.38 | 0.43 | 0.25 | 0.02 | 0.99 |
| BC95 FE | 0.20 | 0.12 | 0.21 | 0.01 | 0.75 |

The BC95 specification shows a high mean value for the Lerner index estimates of 0.38. In the specification with fixed effects, the estimates are considerably lower with a mean of 0.20 and a median of 0.12. This means that half of the observations in the sample do not achieve a Lerner index of more than 0.12. It also hints at some firms having very large Lerner indices, which is consistent with the high maximum value of 0.75 compared to the mean or median.[8]

The figures shed light on the degree of competition in the iron ore market. Whereas a mean value of 0.38 is a rather high value, it is difficult to conclude whether a mean value of 0.20 indicates serious competition issues in the iron ore market or not. To facilitate interpretation, we compare our figures with those obtained by Kumbhakar et al. (2012) and Coccorese (2012) who use the same methodological approach. Although these two do not deal with the iron ore market, a comparison may help to conclude whether our estimates are low or high, relatively speaking. In the analysis by Kumbhakar et al. (2012), the mean values of the Lerner index vary among specifications between 0.07 and 0.10 and can therefore be considered as relatively low. Nevertheless, Kumbhakar et al. (2012) state that the Norwegian sawmilling firms, which were under investigation in their analysis, exercised some market power. Coccorese (2012) estimates Lerner indices of banks in various countries with an overall mean of 0.15 and a maximum mean in one country of 0.54. The results presented here are therefore more in the range of Coccorese (2012) and, hence, seem to be relatively high.

The second important finding that can be concluded from Table 5 is the wide range between the minimum and maximum values of the time- and firm-specific Lerner indices. This suggests that the firms' individual abilities to generate markups differs considerably, also across time. A

[8]Given the differing magnitude between the two model specifications, the overall correlation of Lerner indices across specifications should be examined. The calculated Pearson correlation coefficient of 0.38 illustrates only a moderate correlation of Lerner indices across both specifications. This further stresses the importance of considering unobserved heterogeneity in the analysis.

graphical representation of the development of Lerner indices over time and the differences across firms is given in Figure 2.

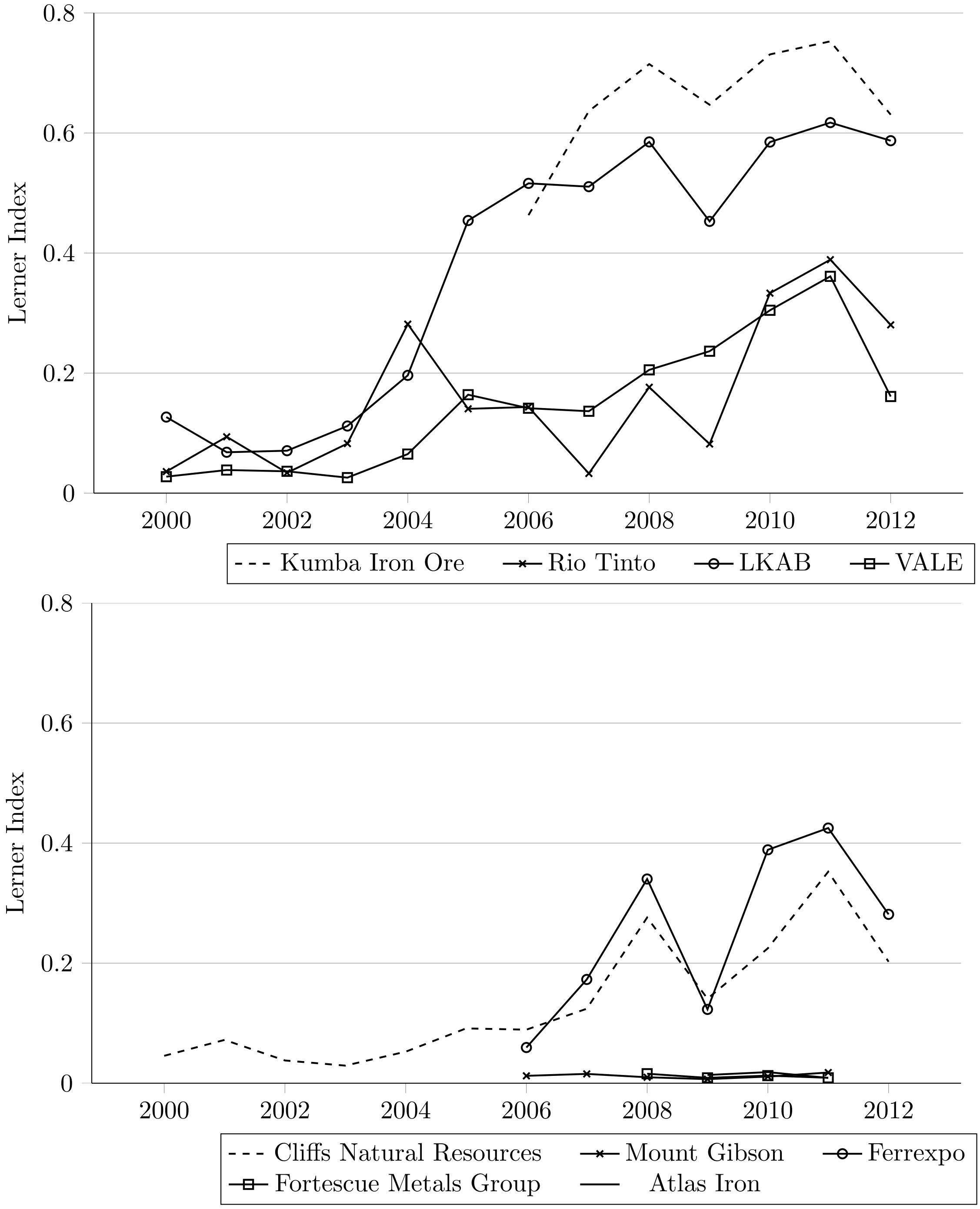


Figure 2: Firm-specific Lerner index estimates from the BC95 FE specification

Interestingly, the second-highest Lerner index in the fixed effects specification belongs to the Swedish producer LKAB, which is considered to incur rather high production costs.[9] It is, however, in line with Hellmer and Ekstrand (2013), who state that producers in the USA and Sweden may have been able to generate economic rents during the recent rapid iron ore demand expansion as those companies were not able to raise production but nevertheless benefited from higher prices. The average annual growth rate of production over the period 2000 to 2012 is 1.8 percent for LKAB, whereas it is, e.g., 7.6 percent for VALE.[10] Therefore, the hypothesis may be supported in the case of LKAB.[11]

Furthermore, LKAB's high values may be explained by their high quality pellets, favorable geological conditions and their strong focus on Europe as a sales market.[12] In supplying this market, LKAB does not incur high transportation costs, in contrast to, e.g., VALE whose production is located mainly in Brazil. Given the demand increase in China starting in the early 2000's and the price correlation between the European and Asia-Pacific markets, LKAB probably benefited from the price increase on the European market. This development is in line with the increase in the Lerner index from 2003 onwards.

*4.2. Influence of firm-specific and environmental characteristics on markups*

The firm-specific and environmental characteristics assumed to influence a firm's ability to exert markups have been discussed in Section 3.2. Given these characteristics, Equation 11 in Section 3.2 can be explicitly written as:

$$\begin{aligned} u_{it} = \beta_0 &+ \beta_1\, ln(\text{FE grade of reserves}_{it}) + \beta_2\, ln(\text{reserves in ton}_{it}) + \beta_3 \,\text{years of production}_{it} \\ &+ \beta_4 \,\text{market share}_{it} + \beta_5 \,\text{price change}_{it} + \beta_6 \,\text{GDP change}_{it} + \sum_{j=6}^{10} \beta_j \,\text{country}_j + W_{it}. \end{aligned} \tag{12}$$

The estimated coefficients are presented in Table 6. Among the first six evaluated firm-specific and environmental factors, a statistically significant impact on the markup component is only observed for years of production and GDP change. Years of production is the proxy variable for experience. As expected, the respective coefficient in both specifications is positive and statistically significant at the 1% level. This is in line with the hypothesis formulated in Section 3.2 and hints at the existence of possible learning effects in production or in the marketing and sales division for iron ore producers.

[9] LKAB is the only company (with large scale operations) that is engaged in underground mining, which is associated with higher costs than production in open pit operations (Hellmer, 1996).

[10] Note that these figures are calculated in FE units in order to allow for comparison.

[11] The main producer in the USA, Cliffs Natural Resources, however, does not seem to follow this hypothesis. Its average annual growth rate of production over the period 2000 to 2012 amounts to 10.3 percent and is therefore even larger than the rate for VALE. The time-varying Lerner indices, however, remain rather flat.

[12] Hence, LKAB's cost disadvantage may be outweighed by lower pelletizing costs due to a high magnetite fraction in the deposit (Hellmer, 1996).

The sixth factor, location, is evaluated by five country dummy variables: USA (Cliffs Natural Resources), Ukraine (Ferrexpo), South Africa (Kumba Iron Ore), Sweden (LKAB) and Brazil (VALE).[13] The reference group is Australia (Rio Tinto, Mount Gibson, Fortescue Metals Group, Atlas Iron). With all other things being equal, it is expected that companies operating mainly in Australia are able to enjoy a higher markup because of lower transportation costs, resulting from its geographical proximity to the main demand areas. As expected, all coefficients are negative and, with the exception of the one for Ukraine, also statistically significant at least at the 5% level in the fixed effects specification.

Table 6: Markup component - influencing variables[a,b]

| Variable | Parameter | BC95 | | BC95 FE | |
|---|---|---|---|---|---|
| Ln(FE grade of reserves) | $\beta_1$ | 1.001 | (1.316) | −1.010 | (1.718) |
| Ln(reserves in ton) | $\beta_2$ | −0.143* | (0.078) | 0.061 | (0.231) |
| Years of production | $\beta_3$ | 0.006*** | (0.002) | 0.143*** | (0.054) |
| Market share | $\beta_4$ | −0.046** | (0.069) | −0.127 | (0.179) |
| Price change | $\beta_5$ | 0.455*** | (0.104) | −0.050 | (0.240) |
| Change GDP | $\beta_6$ | 0.000 | (0.023) | 0.066* | (0.040) |
| Constant | $\beta_0$ | 1.307*** | (0.320) | 5.109*** | (1.639) |
| Country dummies (Reference: Australia) | | | | | |
| USA | $\beta_6$ | −1.731* | (0.970) | −18.346*** | (6.521) |
| Ukraine | $\beta_7$ | 0.492 | (0.827) | −2.130* | (1.282) |
| South Africa | $\beta_8$ | −0.222 | (0.218) | −4.385*** | (1.619) |
| Sweden | $\beta_9$ | −0.810** | (0.328) | −11.271*** | (4.139) |
| Brazil | $\beta_{10}$ | −0.755** | (0.329) | −3.538** | (1.510) |

[a] Standard errors in parentheses.
[b] *, **, *** indicate significance at the 10, 5 and 1% level, respectively.

The results given in Table 6 hint at the direction and significance of markup influencing factors. However, the magnitude of the coefficients is difficult to interpret. Therefore, marginal effects of the factors influencing the Lerner index are calculated. In order to analyze to what extent a small change in factor $z_l$ leads to an absolute change in the Lerner index, the partial derivative of the Lerner index defined in Equation 9 with respect to $z_l$ has to be derived:[14]

[13] Note that this specification is not equivalent to individual fixed effects in the markup term, although each country is represented by one firm only. In contrast to individual fixed effects the reference group consists of a set of firms sharing the same characteristic (i.e., production in Australia) instead of one individual firm as in the fixed effects specification.

[14] Time and firm indices are dropped for notational convenience.

$$
\begin{aligned}
\frac{\partial LI}{\partial z_l} &= \frac{1}{E_{CY}}\frac{\partial u}{\partial z_l}\left(1+\frac{u}{E_{CY}}\right)^{-1} - \frac{u}{E_{CY}}\left(1+\frac{u}{E_{CY}}\right)^{-2}\frac{1}{E_{CY}}\frac{\partial u}{\partial z_l} \\
&= \frac{1}{E_{CY}}\frac{\partial u}{\partial z_l}\left(1+\frac{u}{E_{CY}}\right)^{-1}\left[1-\frac{u}{E_{CY}}\left(1+\frac{u}{E_{CY}}\right)^{-1}\right] \\
&= \frac{\frac{1}{E_{CY}}\frac{\partial u}{\partial z_l}}{1+\frac{u}{E_{CY}}}(1-LI)
\end{aligned}
\tag{13}
$$

Since $u$ and $E_{CY}$ are positive and $LI$ is between zero and one, the sign of the marginal effect depends only on the sign of $\partial u/\partial z_l$, i.e., the partial derivative of $u$ with respect to the $l$-th $z$ variable. While the variables in this expression only have to be replaced by their empirical counterparts ($\widehat{u}$, $\widehat{E_{CY}}$ and $\widehat{LI}$), an expression for $\partial u/\partial z_l$ is needed. Two suggestions are made in the literature: Wang (2002) derives an expression based on the unconditional expectation $E(u)$, whereas, more recently, Kumbhakar and Sun (2013) develop an expression based on the conditional expectation $E(u|\epsilon)$. The latter argue that their formulation is methodologically more coherent since the conditional expectation is already used to predict the markup component $u$ (cp. Section 3.2). Following this argument, Table 7 displays the average marginal effects computed via the approach by Kumbhakar and Sun (2013).[15].

Table 7: Average marginal effects[a]

| Variable | BC95 FE | Variable | BC95 FE |
|---|---|---|---|
| Ln(FE grade of reserves) | -0.019 | USA*** | -0.351 |
| Ln(reserves in ton) | 0.001 | Ukraine* | -0.041 |
| Years of production*** | 0.003 | South Africa*** | -0.084 |
| Market share | -0.003 | Sweden*** | -0.215 |
| Price change | -0.001 | Brazil*** | -0.068 |
| GDP Change* | 0.001 | | |

[a] *, **, *** indicate significance at the 10, 5 and 1% level, respectively.

Concerning years of production, the average marginal effect indicates that on average one additional year of production increases the median firm's Lerner index by 0.003, holding all other variables fixed. Against the background that the mean value of years of production in the sample is 78, one may conclude that the years of production is the single most important determinant for the ability of iron ore producers to exercise market power. Yet, caution must prevail by interpreting the years of production as a proxy for experience. An alternative explanation of our finding may be that more profitable firms, i.e., firms with higher markups, stay in the market for a longer time. However, we do not observe firms leaving the market in our sample and therefore cannot relate the markup level to market exit. Given that labor productivity is an important determinant of

[15] As the marginal effects in the model without fixed effects (BC95) are negligible, we do not discuss them in the following. The results are available from the authors upon request.

marginal production costs, firms that have a long history in iron ore mining should profit from their experienced miners. Hence, we tend to argue that the increase in the Lerner index for every additional production year is also an indication of experience effects. Nevertheless, we are not able to unambiguously disentangle the two interpretations.

Turning now to the country dummies, one has to keep in mind that Australia is used as the reference point. Hence, the calculated effects represent one-off shifts in the Lerner index compared to Australia rather than the marginal effects. The largest significant negative shift is observed for the USA (-0.351) and the smallest for Ukraine (-0.041). The second largest is exhibited by Sweden (-0.215). Given that Cliffs Natural Resources (USA), VALE (Brazil) and LKAB (Sweden) all have comparably long shipping distances to the main demand areas in the Asia-Pacific region, the differences in the values are considerably large. In particular, at first view, the relatively low negative value for VALE (Brazil) is surprising. As Kumba Iron Ore (South Africa) has the shortest distance to the Asia-Pacific region after Australia, one would expect the country dummy for South Africa to indicate the lowest negative shift. Instead, the negative shift of Kumba Iron Ore (South Africa) is 0.016 higher than that of VALE (Brazil). This result suggests that distance is only one determinant of transportation costs.

According to Heij and Knapp (2014), vessels for iron ore are mainly of 'capesize' (60-100 thousand deadweight tonnes (DWT)) and 'panamax size' ($\geq$ 100 thousand DWT)[16]. However, there are significant differences among producers. In particular, VALE owns its own fleet of ships and is known to have one of the largest ship sizes named after the company ('valemax size' with a size of 380-400 thousand DWT). Since VALE uses larger ships than its Australian counterparts, the difference in (shipping) transportation costs between VALE and Australian companies has traditionally been smaller than the difference in distances would suggest (Sukagawa, 2010). Furthermore, in relation to Kumba Iron Ore (South Africa), our results suggest that VALE's transportation cost advantage due to the usage of its own and larger ships even outweighs the disadvantage of the larger shipping distance to the Asia-Pacific demand centers. Altogether, our results provide evidence that, in addition to distance, other factors such as size and control of the fleet are also important factors for the firm-specific transportation cost level and, hence, for the individual ability of firms to generate markups.

Finally, the third factor found to have a significant influence on the firm's Lerner Index is annual growth in the world's real GDP, with, ceteris paribus, an additional percentage point of GDP growth resulting in an increase of the median firm's Lerner index by 0.001. An explanation for this results may be that high economic growth drives iron ore demand, which reduces the price elasticity of demand and, consequently, strengthens the position of the suppliers in the market. However, given that the median annual GDP growth rate in the period from 1993 to 2012 amounts

[16]This definition is used by Heij and Knapp (2014) and stem from the ship broker Braemar Seascope.

to 3.9%, the importance of GDP growth in determining the level of the Lerner indices is found to be rather small.

## 5. Discussion

The objective of this study was to analyze the potentially non-competitive behavior of iron ore producers during the past decade. For this purpose, Lerner indices for ten iron ore producing companies during the period 1993-2012 were estimated using an innovative SFA approach introduced by Kumbhakar et al. (2012). The approach was further extended by using a model framework that allows to analyze the (potential) influence of firm-specific and environmental characteristics on firm-specific markups.

The conjecture that iron ore producers exercise market power is supported by the empirical results. The estimated Lerner indices are significantly different from zero and indicate that the markups on average amount to 20% of the price. However, producer's individual ability to charge a markup varies considerably, also across time. On the firm-level, we find evidence that experience and geographical location of the main production area are the most important factors that influence firm-specific markups. Distance to the main demand areas, however, seems not to be the only factor that determines whether a firm benefits from its production region. For example, although Brazil is further away from the main demand centers in the Asia-Pacific region than South Africa, producing in Brazil has a weaker decreasing influence on markups than producing in South Africa, both compared to Australia. This may be due to different shipping costs among producers, with some, in particular VALE in Brazil, even controlling their own fleets with extremely large bulk carriers.

Although Lerner index estimations are frequently used in the economic literature to measure the degree of (non-)competitive behavior, the level of the estimates must be treated with caution: Whereas a low level of an estimated Lerner index can be interpreted as the absence of market power (Elzinga and Mills, 2011), finding a high Lerner index does not translate equally well into evidence for the exercise of market power. Economies of scale or the need to recover fixed cost may also be captured in the estimates (Lindenberg and Ross, 1981). Consequently, although we do find empirical evidence for increasing markups over time, in particular beginning with the early years of the century's first decade, i.e., from 2004 onwards, this indicates only an increase in market power under the assumption that capital costs of investment projects did not increase significantly.

Summing up, our research shows that the innovative approach for measuring market power introduced by Kumbhakar et al. (2012) and utilized in this study can provide valuable insights into the competitive environment of markets that are prone to the exercise of market power. In particular, the possibility of analyzing factors that most likely influence firm-specific markups is promising for applications to other markets, e.g., the electricity, pharmaceuticals or telecommunications market. In doing so, one may be interested in comparing the importance of the similar characteristics across different markets. Furthermore, because of the relatively low data requirements, the utilized approach may pose a valuable tool for political and legal institutions interested in (empirically) assessing the abuse of market power by firms. Yet, as pointed out in the previous paragraph the estimation of the Lerner index needs to be accompanied by further analyses putting the estimated values in perspective, e.g., by relating it to the level and the development of fixed costs.

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