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Immeuble du Centre de Commerce International d' Abidjan (CCIA)
01 BP 1387, Abidjan 01
Côte d'Ivoire
E-mail: afdb@afdb.org

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Economies of Scale in Gold Mining

Ousman Gajigo[1] and Mouna Ben Dhaou[2]

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[1] Ousman Gajigo (o.gajigo@afdb.org) is Principal Research Economist at the Development Research Department, African Development Bank. The authors are grateful for comments from colleagues from the Development Research Department.

[2] Ms. Mouna Ben Dhaou (m.bendhaou@afdb.org) is a consultant at the Development Research Department, African Development Bank.

Abstract

This paper analyzes the presence of economies of scale in gold mining in Africa. It uses mine level data between 2005 and 2010 and the data is collected from countries that account for 83% of the continent's gold production. Our analysis shows that the gold mining industry in Africa exhibits significant economies of scale. In other words, the unit cost of production falls significantly as mines get larger.

JEL Classification: D24, L72, L250, Q31, Q380.

Keywords: Cost, Gold, Mining, Scale economies, Semi-parametric, Technology.

1. Introduction

Mergers and acquisitions news have become ubiquitous in the mining industry. In some commodities (such as steel and iron ore), global production has become increasingly concentrated within a small number of larger firms. A large part of these concentrations have been driven by vertical integration, especially in steel, to reduce cost for key inputs such as iron, ore and manganese (Crompton and Lesourd 2008; Gajigo et al. 2011). In addition to mergers and acquisitions, the average sizes of mines have become larger. As documented in Crowson (2003), the number of mines has decreased while the average size of mines has increased significantly for a number of minerals, including gold. Since the overall global mineral production is growing over time, this implies that the average output per mine has gone up. It is therefore likely that economies of scale may be present, with the unit costs declining with the level of production.

A lot of evidence would support the hypothesis that scale economies exist in the mining industry. There have been significant advances in the technology, and resulting increases in capacity of machinery (Sullivan 1990). Better technologies tend to lead to increasing automation, and higher efficiencies in machinery. For example, some mining companies have already begun experimenting with driverless trucks. So it would not be surprising if the unit cost declines as output expands over a given mine. However, there are some complicating factors standing in the way of a simple conclusion that economies of scale is inevitable. As explained in Roman and Daneshmend (2000), greater capacity and newer but more complex technology may increase operating cost through higher maintenance. Larger underground mines lead to other costs such as the need for larger ventilation systems and its accompanying energy demand. So whether there is economies of scale, and over which range in a given mining industry is an empirical issue.

Several papers have looked at economies of scale in mining for a number of minerals. Crompton and Lesourd (2008) uses data from 9 steel plants in 27 countries between 2001 and 2003, they found that scale effect is present in the industry. Crowson (2003) examines the relationship between mine size and cost for copper. The author finds that economies of scale is present in the copper industry but not quite strongly. On the other hand, even if scale economies is present, diseconomies of scale could set in at some range of production (Bozorgebrahimi et al. 2005). A number of other papers have examined economies of scale in other industries (Christensen and

Green; Yatchew 1997). The semi-parametric analysis used in Yatchew (1997) is the approach we use in this paper.

This paper focuses on the gold mining industry in Africa. African countries account for 20% of the global gold production of 2500 million metric tons. South Africa is the largest producer of the mineral on the continent but other major producers include Ghana, Guinea, Mali and Tanzania. Overall, about 20 African countries produce at least one ton per annum. The countries represented in our sample account for 83% Africa's gold production. We use a semi-parametric approach that allows us to estimate the relationship between unit cost and production level without imposing any functional form assumption that would be required under a fully parametric approach. Our results suggest that economies of scale is present in the gold mining industry. This means that the trends observed in large-scale mining, as well as mergers and acquisitions in the industry are likely driven by economies of scale.

2. Data

We assemble a panel data set at the level of mines that were in production between 2005 and 2010 in Africa (the full list of mines is provided in Table A1 in the appendix). The data was compiled using publicly available information stored in annual reports of mining companies, and filed with the System for Electronic Document Analysis and Retrieval (SEDAR). It covers 30 gold mines in 7 African countries. The 7 countries (Botswana, Burkina Faso, Ghana, Guinea, Mali, Niger and South Africa) account for 83% of Africa's total gold production over the 2005-2010 period (US Geological Survey 2011). The summary statistics of the key variables used in the analysis are presented below in Table 1.

The median gold output per mine is about 143,217 ounces per year and is lower than the average of 245,511. This is due to the presence of some very large mines in the data. Figure 1 provides the full distribution of the annual mine output in our sample. About half of the mines are open-pit mines[3]. The grades of the mines also vary significantly, not only across mines but also over time in the same mine. Most of the mines in our sample are profitable. In fact, only about 5% of the

[3] An open pit mine is the type of mining where the surface ground is removed in a large pit to extract the mineral, as opposed to an underground mine where tunnels are dug deep below the surface.

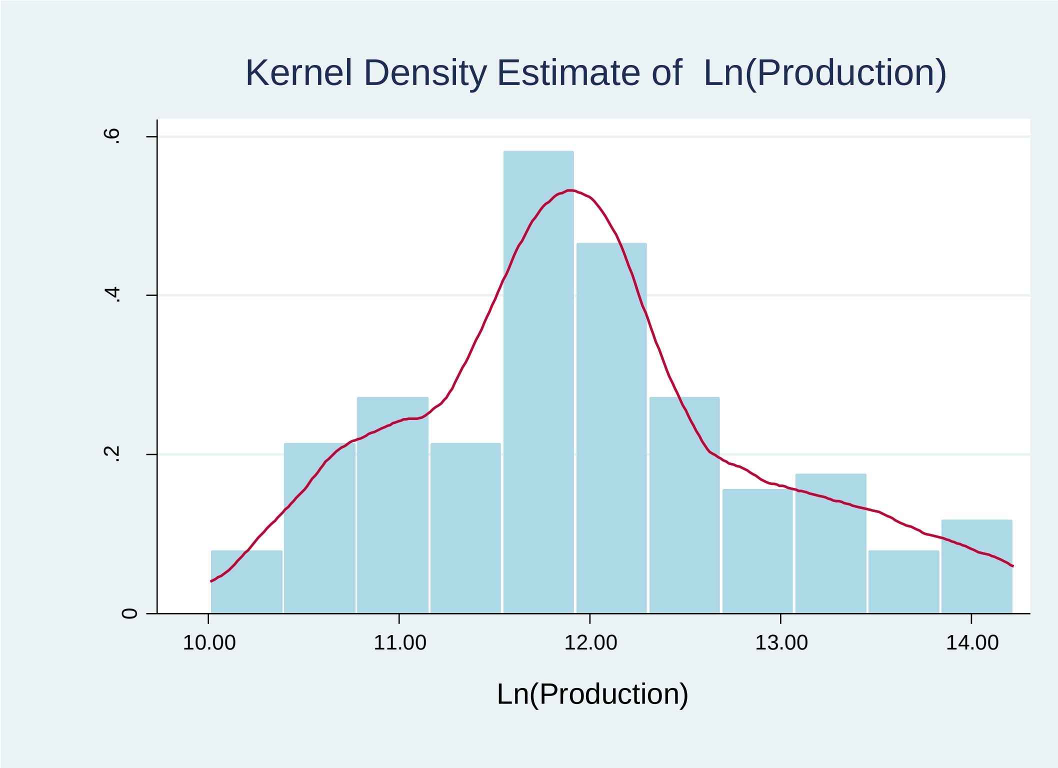
mines registered losses in the period covered by our sample. This is not surprising because gold prices went from USD 444 per ounce in 2005 to USD 1220 in 2010 - an annual growth rate of 20% (World Gold Council 2013). So this was a period when gold prices were increasing at a high rate. Our key dependent variable is cost per ounce of gold produced. Cost is defined as the full operating cost, and it includes expenses that are normally excluded from "cash cost" such as depreciation and payments to governments (including tax, fees and royalties). The production variable is the actual quantity of ounces of gold produced rather than the capacity of the mine.

Table 1: Summary statistics of key variables.

Variable	**Observations**	**Mean**	**Standard Deviation**	**Median**	**Min**	**Max**
Revenue per Ounce (USD)	132	817	257	857	105	1,371
Cost per Ounce (USD)	132	538	188	502	217	1,036
Production (ounces)	136	247,511	290,014	143,217	4,024	1,500,000
Profit per Ounce (USD)	132	279	187	266	-196	942
Mine Grade[†]	121	3.27	1.79	3.29	0.64	7.80
Open Pit Mine dummy	138	0.5	0.5		0	1

[†]Grams of gold per ton of ore.

Figure 1: Distribution of annual mine output (in ounces of gold).



3. Estimation and Results

To analyze the presence of economies of scale in the gold mining sector, we adopt a cost approach to determine if the average or unit cost falls with a higher level of output. The key variables in the cost function are prices and the level of output. We therefore estimate the following semi-parametric equation:

$$Cost_{\,ijt} = f\left(LnQ_{ijt}\right) + \gamma\ Grade_{ijt} + Openpit_i + Year_t + Country_j + \varepsilon_{ijt} \qquad (1)$$

Where $Cost_{\,ijt}$ is the annual cost per ounce of gold for mine i in country j at time t, LnQ_{ijt} is the natural log of annual gold production of the mine, $f(\cdot)$ is a flexible function, $Grade_{ijt}$ represents the grade of the mine[4], $Openp_{it}$ is dummy on whether the mine is an open-pit and ε_{ijt} is the error term. The variables *Year* and *Country* are the year and country fixed effects respectively.

[4] The grade signifies the richness of the ore, and it is measured in grams (of gold) per ton of ore extracted. The higher the grade, the richer the mine in gold, and consequently, the lower the cost of production per unit of gold extracted. The grade varies between mines, and also over time within the same mine.

Our data set is suited to the task of analyzing economies of scale. The price of gold is exogenous to mining firms given the large number of producers[5] and the fact that it is an internationally traded commodity. In fact, the average revenue per ounce of gold does not vary across firms in a given year in our sample. So we used the year fixed effect to control for both time and price. Grade and country-specific characteristics are controlled for since the former is an exogenous and important determinant of cost and the latter helps us to control for other country-specific costs such as quality of infrastructure. Given that the data is captured at the mine level, it avoids the aggregation challenges that would be present in a dataset where the unit of observation is a firm with multiple mines.

The above semi-parametric estimation allows us to estimate the relationship between unit cost and output level without imposing any functional form assumption, while at the same time allowing for other controls to enter linearly. Equation (1) can be written as

$$Cost_{ijt} = f\left(LnQ_{ijt}\right) + X'_{ijt}\beta + \varepsilon_{ijt}, \tag{2}$$

where X is a vector of independent variables that enter linearly. The semi-parametric procedure estimates the parametric component first

$$Cost_{ijt} = X'_{ijt}\beta + \varepsilon_{ijt} \tag{3}$$

and then smoothes

$$\widehat{Cost}_{ijt} - \left[X'_{ijt}\hat{\beta}\right] = f\left(LnQ_{ijt}\right) + \epsilon_{ijt} \tag{4}$$

(where $\hat{\beta}$ is a vector of the estimated parameters for mine grade, open pit, country fixed effects and year fixed effects). The non-parametric component, $f(\cdot)$, is estimated in this paper using locally weighted scatter-plot regression (LOWESS). The use of LOWESS (as opposed to polynomial smoothing) is advantageous in that it is robust to outliers since the smoothing is 'local' as the bandwidth can be made small to ensure nearby data-points are given greater weights relative to outliers (Cleveland 1979; Lokshin 2006; Yatchew 1997).

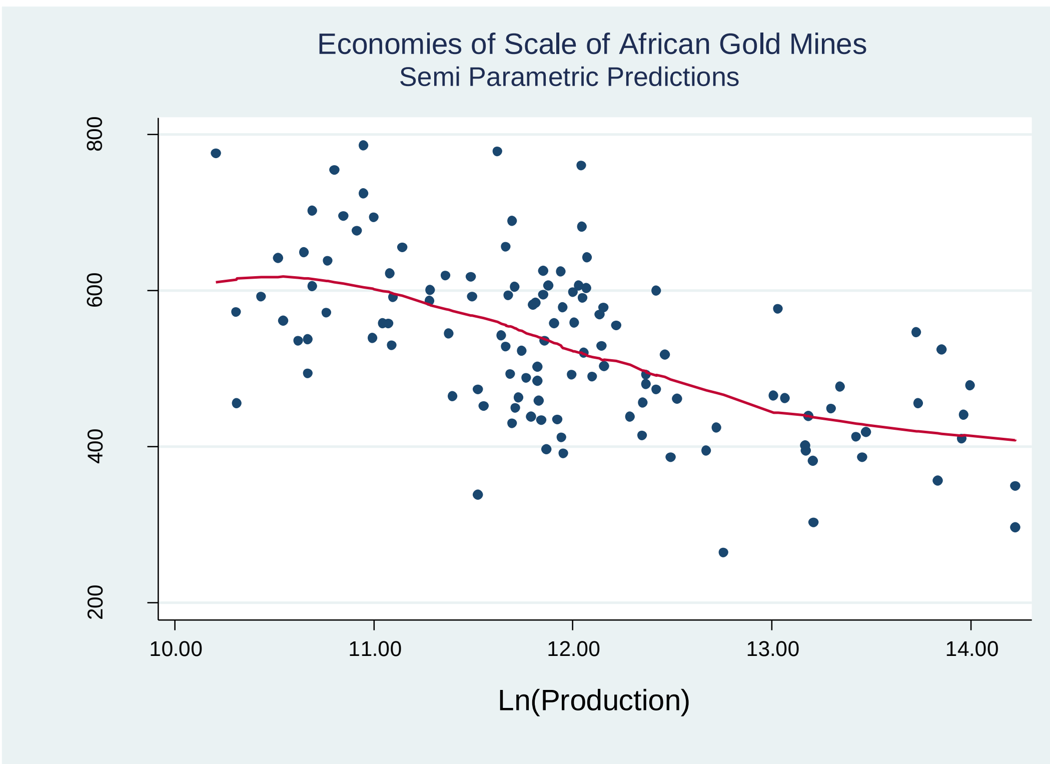
Our main test for the presence of economies of scale is whether gradient of the function, $f(\cdot)$ is downward sloping (negative gradient). The range of production where $f(\cdot)$ is downward sloping

[5] Gold supply in a period usually comes from mine production, sale from recycled gold (either from the jewelry market and governments). Therefore, even though mine gold production is dominated by relatively few firms, the total number of sellers is quite large, which tends to limit market power by individual mining companies.

would suggest economies of scale. In other words, unit cost of production is falling with increasing scale or mine output. And conversely, the range of production where $f(\cdot)$ is rising would suggest diseconomies of scale.

The main result, specifically the estimation of the function $f(LnQ_{ijt})$ is presented in figure 2. The result clearly shows the presence of economies of scale over the range of production in our sample. The average cost for firms at the 95$^{\text{th}}$ percentile of production is 44.65% lower than those at the 25th percentile. A test on the gradient of $f(LnQ_{ijt})$ with a null hypothesis that it has a slope of zero produces a p-value of 0.001. In other words, $f'(LnQ_{ijt}) < 0$. This suggests that recent technological advances reflected in, among other things, increased automation and machinery with greater capacity and larger mines are likely driven by declining unit production cost[6].

Figure 2: The estimation of the function $f(LnQ_{ijt})$ in equation (1).



[6] As a robustness check, we estimated a fully parametric version of equation (2) where LnQ_{ijt} enters in quadratic form. The result (figure A1 in the appendix) also confirms that unit cost falls as output increases.

The parametric results from the estimation of equation (1) are presented in Table A2 in the appendix. As expected, the grades of mines are negatively associated with cost. In other words, the higher the grade, the lower the unit cost of production. Open pit mines are also significantly associated with lower unit cost of production. Specifically, open pit mines have average lower cost by about USD 182 per ounce.

4. Policy issues

The trend of increasingly larger mines has implications for policy in resource rich countries. Specifically, the presence of economies of scale has consequences for environmental mitigation and inclusiveness of the mining industry.

Larger mines, which are more likely to be open-pit, are bound to have a significant adverse effect on the local ecosystem. On the other hand, large mines tend to be operated by major mining firms, which are becoming increasingly cognizant of environmental effects due to pressures from regulatory agencies and non-governmental organizations. Nevertheless, countries should not be passive about this development and need to ensure that mining codes and mineral laws are kept updated with these new trends. Specifically, standards for reclamation of mines would need to be more stringent given the potential impact on the ecosystem as the average mine size continues to increase.

To the extent that inclusiveness is expected through employment generation, the mining industry is not inclusive relative to sectors such as agriculture and manufacturing (Gajigo et al. 2012a). This is mainly due to fact that it is capital-intensive, and only limited processing occurs in African countries. Economies of scale would tend to reinforce this effect since larger mines would be more capital-intensive, and would require greater automation. So low direct job creation from the industry is likely to continue. Hence, focus should be on the distribution of resource rents to help broaden the benefits of the industry since labor share of costs for mining firms would likely decline further. The extent of rent-sharing between mining companies and countries is determined by the fiscal regimes in the mining codes that specify royalty payments and dividend sharing (Gajigo et al. 2012b). Governments would not only have to ensure that rent sharing occurs, but these benefits are shared by local communities.

5. Conclusion

Whether higher capacity reduces unit cost of production in mining is an empirical question. Greater automation reduces labor requirement and larger capacity equipment can accomplish larger workload in a given time period. On the other hand, greater technological complexity may increase the frequency of equipment breakdown, slowing work and increasing cost. So it is not obvious at first glance whether economies of scale may exist in mining. This paper investigates the presence of economies of scale in the gold mining industry. The data, which is at the mine level, comes from mines in countries that account for 83% of Africa's gold production. We find that economies of scale is present as the unit cost of production decreases significantly with the level of annual production of mines while controlling for relevant variables.

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Appendix

Table A1: The list of mines used in the analysis.

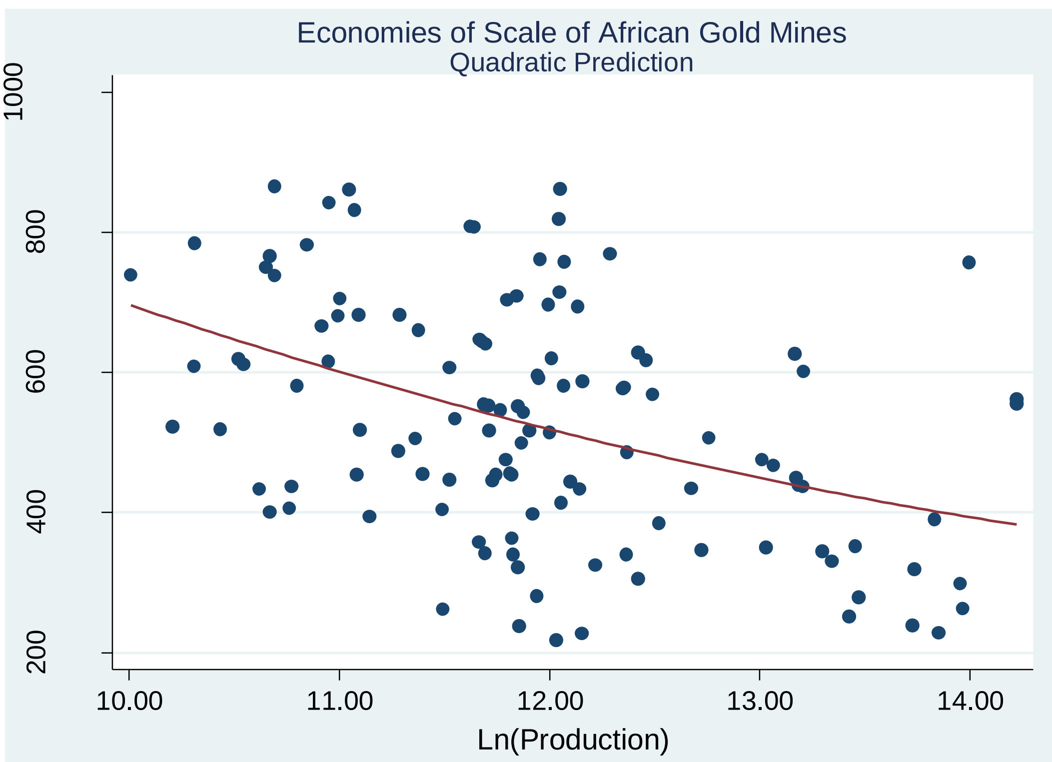
Mine	Country
Mupane	Botswana
Essakane	Burkina Faso
Mana	Burkina Faso
Ahafo	Ghana
Bogoso/Prestea	Ghana
Chirano	Ghana
Damang	Ghana
Tarkwa	Ghana
Wassa	Ghana
Kiniero	Guinea
Sadiola	Mali
Yatela	Mali
Samira Hill	Niger
Bambanani	South Africa
Beatrix	South Africa
Doornkop	South Africa
Driefontein	South Africa
Evander	South Africa
Joel	South Africa
Kalgold	South Africa
KDC	South Africa
Kloof	South Africa
Kusasalethu	South Africa
Masimong	South Africa
Phakisa	South Africa
South Deep	South Africa
Target	South Africa
Tshepong	South Africa
Vaal River	South Africa
Virginia	South Africa

Table A2: The parametric results from the semi-parametric estimation of equation (1). The omitted year dummy is 2005, and the omitted country dummy is Botswana.

	Coefficients	**Standard Error**
Grade	-30.08**	10.24
Open Pit Dummy	-182.75***	39.92
_Iyear_2006	48.60	37.76
_Iyear_2007	122.85**	40.97
_Iyear_2008	222.08***	39.47
_Iyear_2009	213.21***	40.22
_Iyear_2010	359.23***	39.04
_Icountry_2	-245.68***	77.04
_Icountry_3	-57.00	55.60
_Icountry_4	-42.70	82.04
_Icountry_5	-147.71**	56.58
_Icountry_6	-136.63**	59.74
_Icountry_7	-80.97	57.41
Observations	119	
Adjusted R^2	0.74	

***significant at 1%; **significant 5%; *significant at 10%.

Figure A1: Evidence of returns to scale using parametric (quadratic) specification.



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African Development Bank
Angle de l'avenue du Ghana et des rues Pierre
de Coubertin et Hédi Nouira
BP 323 –1002 Tunis Belvédère (Tunisia)
Tel.: +216 71 333 511 – Fax: +216 71 351 933
E-mail: afdb@afdb.org – Internet: www.afdb.org