**Do Gold Prices Cause Production Costs?**

**International Evidence from Country and Company Data**

**Abstract**

This paper analyses the causal relationship between gold production costs and gold prices using a set of country and company data collected at the individual mine’s level. We find strong econometric evidence for causality running from gold prices to gold production costs. The results are supported theoretically by the small amount of annual gold production relative to the total stock and the real options embedded in gold mines. The low flow to stock ratio of gold implies low market power of gold mining firms and thus an inability to significantly influence gold prices. The real options enable gold mining firms to adjust production costs conditional on the gold price; production costs thus follow gold prices[[1]](#footnote-1).

***Keywords****: gold price, gold production costs, mining, causality, real optionality, Ricardo,* *inflation channel*

1. **Introduction**

This paper provides the first empirical evidence on the causal relationships that exist between any commodity’s price and its cost of production using global data from gold miners at a country and company level with annual data ranging from 1981 to 2013. This is possible as the gold mining industry provides very detailed information on a variety of variables that are not commonly made publicly available, such as the production costs and production volume data used here. The existing literature has made use of this available data by focussing on issues such as the price exposure of gold mining firms and their hedging strategies to cope with this (e.g. see Brown, Crabb and Haushalter (2006), Tufano (1996) and Tufano (1998)). Paish (1938) provides a detailed discussion of the reasons for changes in the costs of production over the 19th and early 20th centuries and their effect on the volume of production, but does not analyse the relationship between the prices and production costs.

There are two competing theories regarding the causality between commodity prices and production costs. One theory assumes that production costs lead and determine commodity prices based on the idea that inflation increases production costs and thus the price of gold. The other theory proposes that the causality runs the other way and that gold prices lead and determine production costs. It is based on the classical law of rent described by David Ricardo in 1817 and the “real option” characteristic of mining companies as modelled by Brennan and Schwartz (1985).

This issue is also linked to a popular research question in the literature on the financial economics of gold prices. Many studies find that there is a long-run relationship between the price of gold and general inflation (e.g. Taylor (1998), Worthington and Pahlavani (2007) and Beckmann and Czudaj (2013)), and inflation is the most common factor used to explain long-run gold prices (Levin and Wright, 2006). Levin, Abhyankar and Gosh (1994) assume that changes in gold production costs are equal to general inflation over the long-run, and that the long-term gold price will rise in order to compensate miners for the increasing costs. This implies a causal relationship running from inflation to the cost of production to gold prices. Rockoff (1984) and Rockerbie (1999) also argue that the causality runs from production costs to prices.

The other possibility is that the causality runs from prices to production costs, as explained by Ricardo (1817) as part of his discussion on the Law of Rent. At any given price it can be expected that mines will supply the market up to the point where marginal costs equal marginal benefits and the industry as a whole maximises its economic profit. Ricardo notes at the beginning of Chapter 3 that mines are of various qualities. As gold prices rise marginal mines which were previously unprofitable will be brought into production. These would be deeper mines or mines yielding a lower quality of ore. This means that the average cost of production for the industry as a whole would rise after prices do and because of the rise. This would make low cost mines even more profitable and allow overall production to expand to meet demand. Similarly, if gold prices fall it would force high-cost mines to shut down and decrease supply. The opening and closure of mines conditional on the gold price is also consistent with the “real option” characteristic embedded in gold mines as analysed theoretically in Brennan and Schwartz (1985) and empirically in Krautkraemer (1989) and Moel and Tufano (2002).[[2]](#footnote-2)

There is also some industry-based discussion that points to gold prices driving production costs and not the other way around. The GFMS Gold Survey (2013 Update 1) states on page 22 that “Over the last decade rising gold prices enabled producers to adjust mine plans to incorporate lower grade material, thereby optimising assets’ lives, but this practice also served to push costs higher when expressed on a unit dollar per ounce basis.”. Barron’s (2014) also argue that production costs provide a floor below which gold prices cannot fall. Theoretically, the reaction of gold miners to gold price changes stabilizes the price of gold by increasing the supply in rising gold price regimes[[3]](#footnote-3) and decreasing the supply in decreasing gold price regimes. This seems inconsistent with the strong bull market in gold between 2004 and 2011. However, if the price rises too fast due to other influences, the stabilizing effect can be weakened temporarily.

Another argument that gold prices lead production costs is based on the special flow to stock ratio of gold in comparison with other commodities and the implied low market power of gold mining firms. Gold is unusual among commodities in having a vastly larger accumulated stock than its annual flow from mines. This is in contrast to other perishable commodities where the annual supply from production is roughly equal to the total supply available that year. It follows that gold miners have low market power and are likely to be price takers rather than price setters (Borenstein and Farrell, 2007 and Blose and Shieh, 1995). Any attempt to run an OPEC-style cartel to try and set prices would be swallowed up by both large historical stocks and market flows coming into the market as prices rose. From the perspective of historical gold stock levels gold miners’ supply accounts for about 1.6% of the total estimated stock of gold available as at 2010 (World Gold Council, 2010; GFMS, 2013). Recycled gold allows illiquid jewellery back into circulation to meet increased demand. Indeed as gold prices increased dramatically between 2003 and 2011 the supply of gold from this channel doubled. The total supply from miners in 2014 was 3,022 tonnes while an average day of trading on the London Market is 680 tonnes, not enough to supply that market for one week (GFMS, 2014).

Based on the above theoretical discussion we test the relationship empirically and find strong support for the causality running from gold prices to production costs both on the country and firm level. The findings also contribute to the literature on the real option characteristics of mines. The identified direction of causality provides new evidence that real options are regularly exercised, i.e. rising gold prices lead to the opening of new mines and falling prices lead to the closure of existing mines. We also find that in some cases production costs lead gold prices but not in the direction predicted by Levin, Abhyankar and Gosh (1994), i.e. with a negative sign. We explain this finding with mining companies responding slowly to price changes or failing to predict future gold price changes.

The paper is structured as follows. Section 2 outlines the econometric methodology to analyse the causal relationships between gold prices and production costs. Section 3 introduces the data and annual country and firm-level data. Section 4 presents the estimation results and discusses the main findings. Finally, section 5 summarizes the results and provides concluding remarks.

1. **Methodology**

Firstly, all data is tested for the presence of a unit root using the traditional Augmented Dickey Fuller (ADF) test. The appropriate number of lags is determined with the Akaike and Schwarz Information Criteria, AIC and SBC, respectively.

where is a constant, t is a trend, yt is the time-series variable being examined, i.e. gold prices or production costs, is a white noise term and the null hypothesis is = 0 (unit-root) against the alternative (stationarity).

In a second step, we assess whether any I(1) pairs of time-series variables are co-integrated using the methodology suggested by Johansen (1991). The framework tests for a long-run relationship between the variables which is characterised by the equation

where the Cost of Production is either cash costs or total production costs at t. If co-integration does not exist between the two variables being tested the following VAR is appropriate (Granger et al, 1988).

where represents the price of gold and represents the production costs. Engle and Granger (1987) show that rejecting implies that the production costs do Granger-cause gold prices. Rejecting implies that gold prices do Granger-cause production costs.

Granger (1988) also shows that the presence of co-integration implies Granger causality. Hence, causality tests of co-integrated variables require an error correction term () derived from the co-integrating relationship:

Rejecting *and* = 0 implies that production costs do Granger cause gold prices. Rejecting *and* = 0 implies that gold prices do Granger cause production costs.

1. **Data**

This section describes the gold mine production costs data sets and presents some preliminary descriptive evidence. Mining Costs are collected from two related sources and are provided in nominal US dollars. Longer term data is available for some larger gold producing countries in the annual GFMS Gold Surveys (1989 – 2014), with world average costs available from 1981 – 2013 and the longest country data available (for South Africa) between 1983 and 2013. Data is also available for a wider selection of countries not covered in the GFMS Gold Surveys from the Thomson Reuters GFMS Mine Economics Database over a period covering 2000-2013 at an annual level. Firm-level data is also obtained from the Thomson Reuters database between 2000 and 2013.

We use two measures of mining costs gathered by GFMS: Cash Costs and Total Production Costs. Cash Costs are defined as “Mine cash expenses (mining, ore, processing, on site general administrative costs), refining, charges, royalties and production taxes, net of by-product credits” (GFMS, 2013:52). Total Production Cost is Cash Costs plus depreciation, amortisation and reclamation of cost provisions. These are both measured as the US dollar cost of extracting one ounce of gold. The world average Cash Costs and Total Production Costs are presented in Figure 1 and strongly co-move.

\*\*\* Insert Figure 1 about here \*\*\*

24 countries and 32 companies are covered by this analysis, all countries and companies for which time-series data is available between at least 2000 and 2013. These are presented in the Tables in Section 4. GFMS gather data at a mine level and aggregate the data based on mine location for country level statistics and mine ownership for companies. The annual data is on a calendar and not fiscal year basis. The two sets of data (country and company) are then based on the same underlying dataset with the country and company data representing a total production of 48 and 32 million troy ounces in 2013, respectively. The analysis that follows will focus more on the country level data as it is more complete. The 2013 world average Cash Costs and Total Production Costs are presented in Table 1.

\*\*\* Insert Table 1 about here \*\*\*

Annual average gold prices in US dollar are gathered from the Gold Fields Minerals Service (GFMS) Annual Gold Survey’s (1989-2014)**,** these are based on the London PM Fixings gold prices. These have been shown to be jointly as important as the New York based COMEX gold futures prices (see Lucey, Larkin and O’Connor, 2014).

Figures 2a and 2b present the dynamic relationship of the US dollar gold price and the average world cash costs in levels and in percentage changes, respectively. The graphs provide a preliminary indication that gold prices and cash costs are not co-integrated (Figure 2a) and that gold prices move first (Figure 2b).

\*\*\* Insert Figure 2a about here \*\*\*

\*\*\* Insert Figure 2b about here \*\*\*

1. **Estimation Results**

**Country-level data**

This section presents the estimation results of the unit-root tests, the co-integration tests and the Granger causality tests for country level data. We begin by testing all variables for a unit root. Table 2 presents the test statistics of the Augmented-Dickey Fuller (ADF) tests with the null hypothesis that the time-series is non-stationary. The test statistics shows that all variables are non-stationary and exhibit a unit-root in levels (the null is not rejected) and are stationary if measured in first differences.

\*\*\* Insert Table 2 about here \*\*\*

Table 3 presents the results of the Johansen co-integration tests and shows that the gold price and either cash costs or total production costs are rarely co-integrated. This finding is consistent with Figure 2a that illustrates that the gold price and aggregate world production costs are not co-integrated, most likely due to the strong price increase of gold between 2004 and 2011. Given this relationship it is not surprising that co-integration is only found for countries with a shorter (later) sample period as this implicitly accounts for a structural break.

\*\*\* Insert Table 3 about here \*\*\*

\*\*\* Insert Figure 3 about here \*\*\*

The Granger causality test results are presented in Table 4A for the countries with longer time-series available and Table 4B for the shorter time-series results.

\*\*Insert Table 4A about here\*\*\*

The longest available time-series is world production costs. The series starts in 1981 and covers the largest sample of gold production as all mines surveyed are included in this aggregated figure. The world average is weighted on the basis of the level of production. The results show that the price of gold causes the cost of production and not vice versa. For every $1 increase in the gold price, average world cash costs are shown to increase by just over $0.36 over the following two years. For average world production costs the increase is $0.44 which makes sense as Total Production Costs are always higher than Cash Costs. In fact when we look at the annual data for the countries with the longer time-series data all have a very similar finding with significant F-statistics and positive coefficients. The coefficient estimates also support the finding of no long-run relationship between costs and prices as the costs rise or fall significantly less than the price of gold. The decoupling of the costs and the prices in the period between 2004 and 2011 (see Figure 2a) indicates that prices rose much faster than costs.

For Australia and the group of countries labelled “Other”[[4]](#footnote-4) we also see that production costs are driving gold prices, but only at the 10% level of significance. In addition, the relationship is negative. This implies that if cash costs rise in a given year gold prices fall in the following. While this could be interpreted as a causal relationship it seems unlikely that miners would aim to increase their costs before a price fall intentionally. Instead we view this result as indicative of an inability to predict prices with some miners opening new expensive mines before subsequent price falls or closing mines before subsequent price increases. However this is not the case in the US, Canada or South Africa, three of the largest gold mining countries over the period examined. As the world figure for each production cost is weighted to reflect the size of production within each country it seems that this statistic is the best reflector of the industry at large.

\*\*\* Insert Table 4B about here \*\*\*

For the shorter time period results are presented in Table 4B. We can see that for many countries such as Chile, the same pattern holds with cash costs or total production costs significantly caused by gold prices. However, in many cases no causality is found, possibly due to the shorter dataset. On a number of occasions, such as for Argentina, total production costs are shown to lead gold prices but as above with a negative sign, i.e. a $1 increase in Argentina’s total production costs is causing or preceding a $0.88 fall in the gold price. This again points to a lack of forecasting ability on the part of Argentinian miners. A number of other countries (Ghana, Guinea, Kyrgyzstan) also show a negative relationship running from costs to the price of gold or vice versa for New Zealand. Since all variables are in US dollars exchange rate effects could also affect and weaken the evidence for causality. For example, if the US dollar falls significantly, the price of gold in US dollar increases and the average costs of mining tend to fall as US dollar denominated cost components decrease in local currency.

We have also analysed quarterly data for the period 2005 (Q1) until 2013 (Q4). For some countries the same pattern of causality with gold prices causing production costs is found. However, most countries show no relationship. This may be due to the shorter time span under investigation or the more noisy nature of the quarterly data. Selvanathan and Selvanathan (1999) examine the relationship between production volume and prices in Western Australia and show that changes happen over years so that quarterly data may not be appropriate to capture changes in costs. In some instances, such as Niger and Papua New Guinea, we see causality present from production costs to gold prices but with a negative sign as in some cases for annual data.

**Firm-level data**

For the company data we present time-series results for the top 10 producers in our sample as well as 5 of the smaller producers, with their 2013 production levels shown in Figure 4.

\*\*\* Insert Figure 4 about here \*\*\*

Table 5 presents the time-series results of the unit root tests. In a subsequent step, we test for co-integration if the production cost is non-stationary and I(1) as presented in Table 6. Finally, we estimate the statistics for Granger causality displayed in Table 7.

\*\*\* Insert Table 5 about here \*\*\*

\*\*\* Insert Table 6 about here \*\*\*

Table 7 shows a number of companies where gold prices do indeed drive costs such as Anglo Gold Ashanti and Newcrest. Again, in some cases costs cause prices with a negative sign, e.g. Barrick Gold’s cash costs cause changes in the gold price with a $1 rise in cash costs followed by a $2.38 fall in the gold price. This points to a lack of predictive ability among some gold producers especially in rising gold price regimes.

\*\*\* Insert Table 7 about here \*\*\*

1. **Summary and Concluding Remarks**

This paper is motivated by the importance and scarcity of studies on the relationship between gold prices and gold production costs, as well as any other mined commodities. We use a new data set on gold mine production costs and describe two competing theories regarding the causal relationship between prices and production costs. One theory is based on the role of general inflation on production costs ultimately affecting gold prices whilst the other is based on classical laws of rent and the “real option” character of gold mine operations. Our empirical analysis for a comprehensive set of country and firm-level data provides strong evidence for causality running from gold prices to production costs and not the other way around. Higher gold prices lead to the opening of previously unprofitable mines increasing the average production costs whilst lower gold prices lead to the closure of previously profitable mines decreasing the average production costs.

The study contributes to the growing literature on gold in general and gold mining firms in particular and to a better understanding of the link between production costs and gold prices. The data set also enables an implicit analysis of real optionality both on the aggregate country level and the firm-level avoiding a common focus on changes in the gold exposures of listed gold mining firms.

Industry analyses sometimes argue that production costs provided a floor below which gold prices cannot fall such as reported in Barron’s in July 2014. While this study does not test this issue directly we do show that costs do not provide a long term price floor as decreasing gold prices lead to lower production costs over time.

With more data available over the coming years future research could test for asymmetries in Granger causality both in mean and in volatility. In addition some of the countries not examined in this study will have sufficient data to include them such as China, the largest gold producer in 2013.

**References**

Barrons (2014) <http://blogs.barrons.com/focusonfunds/2014/07/24/goldman-on-gold-target-1050-an-ounce-but-1200-is-the-real-floor/>

Batten, J.A., C. Ciner, and B.M. Lucey (2014), On the Economic Determinants of the Gold-Inflation Relation, Resources Policy, 41, 101-108.

Beckmann, J. and R. Czudaj (2013), Gold as an Inflation Hedge in a Time-Varying Coefficient Framework, The North American Journal of Economics and Finance, 24, 208-222.

Blose, L. E., and J. CP Shieh (1995), The impact of gold price on the value of gold mining stock, Review of Financial Economics 4 (2), 125-139.

Blose, L.E. (2010), Gold Prices, Cost of Carry, and Expected Inflation, Journal of Economics and Business, 62(1), 35-47.

Borenstein, S. and J. Farrell (2007), Do investors forecast fat firms? Evidence from the gold‐mining industry, The RAND Journal of Economics 38 (3): 626-647.

Brown, G. W., Crabb, P.R. and D. Haushalter, 2006, Are Firms Successful at Selective Hedging? Journal of Business 79, 2925–2949.

[Brennan, J.](http://en.wikipedia.org/wiki/Michael_Brennan_%28finance%29) and E. [Schwartz](http://en.wikipedia.org/wiki/Eduardo_Schwartz) (1985), Evaluating Natural Resource Investments, [Journal of Business](http://en.wikipedia.org/wiki/The_Journal_of_Business) 58 (2), 35–157

Economist, The. (2014). Munk’s Tale. The Economist 19th April 2014.

Engle, R.F. and C.W.J. Granger (1987), Co-integration and Error Correction: Representation, Estimation and Testing, Econometrica 55 (2), 251-276.

Granger, C.W.J. (1988), Causality, cointegration, and control. Journal of Economic Dynamics and Control, 12(2-3), 551-559.

GFMS (2013), Gold Survey 2013, update 2

GFMS (2013). Gold Fields Minerals Gold Survey 2012.

GFMS (2014). Gold Fields Minerals Gold Survey 2013.

Krautkraemer, J.A. (1989), Price expectations, ore quality selection, and the supply of a non-renewable resource, Journal of Environmental Economics and Management 16 (3), 253-267.

Levin, E., Abhyankar, A. and D. Gosh (1994), Does the gold market reveal real interest rates? The Manchester School 62 (1), 93-103.

Levin, E.J. & Wright, R.E., 2006. SHORT-RUN AND LONG-RUN DETERMINANTS OF THE PRICE OF GOLD Determinants of the Price of Gold. World Gold Council. Research Study No. 32.

Lucey, B., Larkin, C. and O’Connor, F. (2014), Gold markets around the world - who spills over what, to whom, when? Applied Economics Letters, 21(13), pp.887–892.

Moel, A. and P. Tufano (2002), When are real options exercised? An empirical study of mine closings, The Review of Financial Studies 15, 35-64.

Paish, F.W. (1938), Causes of changes in gold supply, Economica, 379-409.

Ricardo, D. (1817), On the Principles of Political Economy and Taxation (1 ed.), London: John Murray

Rockerbie, D.W., 1999. Gold prices and gold production evidence for South Africa. Resources Policy, 25(2), pp.69–76.

Rockoff, H. (1984), Some evidence on the real price of gold, its costs of production, and commodity prices - A Retrospective on the Classical Gold Standard, 1821-1931, University of Chicago Press, 613-650.

Taylor, N.J., 1998. Precious metals and inflation. Applied Financial Economics, 8(2), pp.201–210.

Tufano, P. (1996), Who Manages Risk? An Empirical Examination of Risk Management Practices in the Gold Mining Industry, Journal of Finance 51, 1097-1137.

Tufano, P. (1998), The determinants of stock price exposure: Financial engineering and the gold mining industry, The Journal of Finance 53, 1015-1052.

World Gold Council (2010), Gold Demand Trends, [www.gold.org](http://www.gold.org)

Worthington, A.C. & Pahlavani, M., 2007. Gold investment as an inflationary hedge: Cointegration evidence with allowance for endogenous structural breaks. Applied Financial Economics Letters, 3(4), pp.259–262.

1. We would like to thank William Tankard for his feedback on an early draft of this paper. [↑](#footnote-ref-1)
2. For example, Krautkraemer (1989) finds that as prices rise miners tend to mine lower quality ore. [↑](#footnote-ref-2)
3. Paul Krugman states „Placing a ceiling on the value of gold is mining technology, and the prospect that if its price gets out of whack for long on the upside a great deal more of it will be produced.“ (New York Times, December 28, 2013). [↑](#footnote-ref-3)
4. *“Other” represents all other countries covered by Thomson Reuters GFMS but not listed in Panel A of Table 4.* [↑](#footnote-ref-4)