Green Gold - A Gold Mining Perspective

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Abstract

Gold is a long-lasting, durable and thus sustainable metal and asset. However, mining for gold often adversely affects the environment. This study proposes an alternative to mitigate these negative externalities and costs of gold mining. Instead of digging out gold for investment purposes we propose to leave it in the ground and let nature act as a natural vault and custodian legally protected by gold firms and the government. Empirically, we analyse whether portfolios of gold exploration companies with access to such "green" gold also provide exposure to the world price of gold. The results demonstrate that gold mining is not necessary to give investors access to gold.

Keywords: gold; sustainable; mining; exploration; environmental; ESG
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Gold gets dug out of the ground in Africa, or someplace. Then we melt it down, dig another hole, bury it again and pay people to stand around guarding it.

Warren Buffett

1 Introduction

The statement by star investor Warren Buffett is regularly quoted. Adams (2019) argues in a similar spirit and writes "Moreover, it is hard to make the case that mankind is achieving a great deal by digging up gold in places such as Africa and Latin America and then burying it in bank vaults in Dubai, London, New York and Zurich so that it can be used as backing for investment products." (page 13).

Whilst the argument against gold or mining gold appears compelling at least theoretically, the empirical evidence is less supportive of the argument given the popularity of gold as an investment and the number of gold mines in operation.[1]

So why is gold dug out and then buried again? One argument for mining gold is based on uncertainty and asymmetric information regarding the amount and quality (ore grade) of gold in the ground (Brennan (1990)). Only if gold is mined this uncertainty and asymmetric information can be eliminated. Another reason is, of course, jewellery, that cannot be worn if the gold is not mined. Some people may also enjoy looking at a gold bar or a coin or enjoy touching gold. The tangibility or physicality of gold is also important as a store of value and safe haven asset in regions in which many people either have no access to financial markets or in

[1] In times of Bitcoin and cryptocurrencies, gold and gold mining may appear archaic and it is often labelled a "barbarous relic" with reference to Keynes (1924). However, Keynes (1924) did not label gold a "barbarous relic" but the gold standard ("In truth, the gold standard is already a barbarous relic.", page 172).

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periods when people do not trust capital markets and non-tangible financial claims on gold.

Why is gold buried? We interpret "bury it again" as one mechanism of storing gold safely. Since gold is valuable (and has high density which makes it easy to store) it is rational to store it safely in a safe or vault. Examples of secure gold storage are the reserves held by exchange-traded funds (ETFs) and central banks. Gold ETFs are based on securely stored physical gold and provide investors with financial claims, i.e. shares, to the gold. According to the World Gold Council (2019a) the amount of gold invested through ETFs is 2,855 tonnes and valued at about US$150bn as of September 2019.[2]

Global central bank gold reserves exceeded 33,900 tonnes in 2019 (World Official Gold Holdings, 2019) valued at about US$1,700bn.[3] In other words, there is in fact a lot of gold "buried".

The World Gold Council[4] also provides information about the total above ground stocks and its composition: 190,040 tonnes of gold are estimated to be above ground with 90,718 tonnes in jewellery (47.7%), 40,035 tonnes in "private investment" (21.1%), 32,575 tonnes held by central banks (17.1%) and 26,711 tonnes held by "other" (14.1%). Below ground reserves are estimated to be 54,000 tonnes.

Given the uncertainty regarding in-ground gold resources and reserves, the "dig out - bury it again" is less of a puzzle than it may seem at first glance. With un-

[2] "In September, global gold-backed ETFs and similar products had US$4.1bn of net inflows across all regions, increasing their collective gold holdings by 78.6t to 2,855 tonnes(t), the highest levels of all time." (World Gold Council, 2019)

[3] Some governments, e.g. Australia, may view significant in-ground gold reserves as an alternative to central bank gold reserves and thus have lower central bank reserves compared with other countries of similar size. If this is indeed the case governments and central banks apply this paper's proposal.

[4] https://www.gold.org/about-gold/gold-supply/gold-mining/how-much-gold

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certainty of in-ground gold reserves and risk of above-ground gold holding losses (e.g. robbery), it may indeed be efficient to mine gold and store it in a vault.

However, the degree of efficiency or inefficiency depends on the degree of uncertainty. If we assume that the uncertainty or asymmetric information associated with underground gold is limited, i.e. if we have relatively high confidence in gold reserves estimates, and that there is significant demand for gold as an investment that is stored safely underground there is a case for an inefficient use of gold mining as both gold mining and gold storage is costly.[5] Given the adverse and often detrimental effects of mining to the environment, nature, the landscape, rivers, the habitat of animals and biodiversity (among many others) (e.g. see Adams (2019) and Norgate and Haque (2012)) there is even a bigger case for an alternative to gold mining and all the more so in regions of pristine natural environment.

To mitigate these adverse effects to the environment we propose a gold investment that is fundamentally different. It is not mined or "dug out of the ground". Instead, we propose to leave it where it is making it clean and "green". The financial exposure to the in-ground gold is provided by investments in gold exploration companies that have identified and secured gold reserves but have not yet started to mine and produce gold, and generally do not have a license to do so. Since these companies do not mine gold they can be considered "cleaner" and environmentally more friendly than mining firms. There may also be social issues that can be mitigated if the land to be mined is owned by native or indigenous people who oppose mining operations (e.g. see https://www.clc.org.au/index.php?/articles/info/mining-and-development). Any positive (social) effects of gold min-

[5] Whilst the gold storage costs charged by gold ETF providers are relatively small at less than 10bp, the costs of securing central bank gold reserves are potentially considerably greater.

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ing (e.g. see Aragon and Rud (2013)) may also be realized without mining as "in-ground securitisation" (e.g. through extended "exploration" leases sometimes referred to as retention licences) of gold can lead to increased investment and thus cash flows to the owners of the land.

Investors have a choice. They can invest in "buried" gold through ETFs or other types of financial claims in securely stored physical gold or they can invest in portfolios of exploration companies that provide a clean and "green" form of such gold. In other words, they can invest in mined "traditional" gold or in more sustainable "green" gold. A major difference is the tangibility and thus certainty of mined gold versus un-mined in-ground gold. Mined and thus tangible gold may be considered the ultimate proof of its existence and thus elimination of uncertainty and asymmetric information regarding the existence, the amount and quality of the in-ground gold. It is important to note though that it is also sometimes argued that ETFs or central bank gold reserves are not independently (or not frequently) audited and thus also exhibit some degree of uncertainty and asymmetric information.

In-ground, un-mined gold is labelled "green" gold in this paper since there are comparatively low or negligible carbon emissions associated with exploration and comparatively low or negligible adverse effects on the environment in general, and the landscape, the fauna and flora where the gold is located more specifically.

This new type of gold is not only greener but also cheaper as there are no extraction costs and no additional costs such as costs to mitigate environmental risks, costs associated with the closure of a mine or royalty payments.[6]

[6] If the use of in-ground gold as gold deposits or natural vaults became more popular governments may consider royalty payments for in-ground gold deposits decreasing the relative cost advantages of un-mined, in-ground gold over mined, above-ground gold.

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This paper is related to several strands of the literature. There is an emerging literature on the carbon footprint of gold and gold mining (e.g. see Ulrich, Trench, and Hagemann (2019a) and Ulrich, Trench, and Hagemann (2019b), World Gold Council (2018), World Gold Council (2019b)) and on the role of gold as a sustainable and low-carbon investment asset (e.g. Baur and Oll (2019)).

This study is also related to studies on the environmental impact of gold mining (e.g. see Bansah, Dumakor-Dupey, Stemn, and Galecki (2018), Gulley (2017), Keovilignavong (2019), Mancini and Sala (2018), Mudd (2007a), Urkidi and Walter (2011), Tuokuu, Gruber, Idemudia, and Kayira (2018)) and the roles of gold exploration companies and gold mining companies.[7] More broadly, the paper is also related to the debate as to the economic benefits that accrue from mining, and in particular whether the emergence of a nascent gold industry in a country adds to, or inhibits, economic growth - the resource-curse versus resource-blessings debate (Sachs and Warner (2001)).

We contribute to the existing literature with a proposal to use gold exploration companies as an alternative to investments in mined gold because gold exploration companies do not mine or extract the gold. Hence, investment in these firms mitigate (i) inefficiencies linked to digging and burying the gold and (ii) environmental costs.

We show that portfolios of listed gold exploration companies give investors exposure to the world price of gold without the direct costs of extraction and without the

[7] Adams (2019) discusses the role of exploration or alternatively junior mining companies in Chapter 11 (The Mining Cycle). The author also states that "junior mining companies are really in the information business and not in the mining business. They spend money on things such as exploration and feasibility studies in order to generate information [...]" (Chapter 11).

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additional environmental costs, e.g. environmental risk management, actual costs of pollution and mine closure provisions to name but a few. More specifically, we build portfolios of Australian gold exploration companies and analyze whether financially engineered gold (or synthetically mined gold) has similar financial features of gold bullion but additional benign environmental features not shared by gold bullion.

Our empirical analysis shows that portfolios of gold exploration companies indeed provide significant exposure to gold bullion in US dollars. We also find that gold exploration company portfolios perform similar to major gold mining ETFs and outperform physical gold depending on the number of firms in the portfolio and the frequency of (partial or full) portfolio rebalancing.

The rest of the paper is structured as follows. Section 2 describes costs of exploration and mining, and typical characteristics of exploration and gold mining companies. The section also discusses estimates of in-ground gold ounces versus above-ground gold ounces. Section 3 introduces the data based on share prices of gold exploration companies and presents the portfolio analysis. The analysis shows that gold exploration companies do indeed provide investors with exposure to the world price of gold. The portfolios (with dynamic rebalancing similar to major stock market indices) show that the gold betas of these portfolios are larger than one indicating an increased risk potentially due to the uncertainty with respect to the amount and the quality of the gold reserves of the exploration companies. The portfolios also reveal that the green gold outperforms the gold price over the sample period from 2010 - 2018. Section 4 summarizes the main results and concludes.

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2 Background Gold Mining

This section provides some background information on in-ground ("in-situ") mineral occurrences, classification of confidence in resources and reserves estimates, the value of in-situ gold versus mined gold, the costs of mining gold including direct extraction costs and additional costs (externalities) such as greenhouse gas (GHG) emissions, water pollution, deforestation etc. The section concludes with a simple model of factors that influence the decision to mine gold or leave it in-ground.

2.1 In-situ mineral occurrences

2.1.1 Classification

In-situ mineral occurrences are classified using various industry-led mineral reporting frameworks/ codes, with the Australasian and Canadian systems the most common. These reporting frameworks seek to provide broad guidance for the public communication of the level of confidence in estimates of metal contained within in-situ mineral resources. In-ground minerals, in this case gold, has been discovered, and in part, has been delineated by drilling to assign a level of confidence to the mineral resource estimate. Mineral resource reporting requires the sign-off from a technically-qualified "competent person". Reporting codes are periodically updated as to accepted good practice. The Committee for Mineral Reserves International Reporting Standards (CRIRSCO) seeks wherever possible to harmonise the mineral resources reporting codes that are used in different jurisdictions.

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Coombes (2014) presents a summary of recent developments in international reporting codes and the role of the "competent person". In Australia, all public disclosure on a company's mineral assets is subject to the Joint Ore Reserves Committee, JORC Code (2012), and the Australian Securities Exchange (ASX) Listing Rules.

The JORC Code (2012) defines a "Mineral Resource" as a "concentration or occurrence of solid material of economic interest in or on the Earth's crust in such form, grade (or quality), and quantity that there are reasonable prospects for eventual economic extraction. The location, quantity, grade (or quality), continuity and other geological characteristics of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge, including sampling. Mineral Resources are sub-divided, in order of increasing geological confidence, into Inferred, Indicated and Measured categories".(p.11) The classification is also summarized in Figure 1.

- Inferred resources - can be estimated with low level of confidence. "An 'Inferred Mineral Resource' is that part of a Mineral Resource for which quantity and grade (or quality) are estimated on the basis of limited geological evidence and sampling. Geological evidence is sufficient to imply but not verify geological and grade (or quality) continuity. It is based on exploration, sampling and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes. Specifically, "an Inferred Mineral Resource has a lower level of confidence than that applying to an Indicated Mineral Resource and must not be converted to an Ore Reserve."(p.12)

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- Indicated resources - ... can be estimated with a reasonable level of confidence. “An ’Indicated Mineral Resource’ is that part of a Mineral Resource for which quantity, grade (or quality), densities, shape and physical characteristics are estimated with sufficient confidence to allow the application of Modifying Factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit.” (p.13)

- Measured resources - ... can be estimated with a high level of confidence. “A ’Measured Mineral Resource’ is that part of a Mineral Resource for which quantity, grade (or quality), densities, shape, and physical characteristics are estimated with confidence sufficient to allow the application of Modifying Factors to support detailed mine planning and final evaluation of the economic viability of the deposit.” (p.13)

“An ’Ore Reserve’ is the economically mineable part of a Measured and/ or Indicated Mineral Resource.[8] It includes diluting materials and allowances for losses, which may occur when the material is mined or extracted and is defined by studies at Pre-Feasibility or Feasibility level as appropriate that include application of Modifying Factors.” (p.16)

“ ’Modifying Factors’ are considerations used to convert Mineral Resources to Ore Reserves. These include, but are not restricted to, mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors.” (p.8)

[8]Estimates of Australia’s Resources and Reserves are reported in Britt, Senior, Summerfield, Hughes, Hitchman, Champion, Huston, Simpson, Kay, Sexton, and Schofield (2019) (Table 1). The 2017 estimates for Ore Reserves are 2903 tonnes, for Measured and Indicated Resources 6702 tonnes and for Inferred Resources 1949 tonnes.

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[Figure 1 about here.]

2.1.2 Valuation

Given the uncertainty regarding in-ground gold and future costs to be incurred in extraction, it is reasonable to assume that in-ground gold trades at a significant discount. PCF (2019) provides estimates for gold producers and gold explorers for Australian and Canadian firms. For example, the June 2019 average is estimated at A$183/oz for Australian producers and at A$38/ oz for Australian explorers and developers. The estimates for Canadian firms are C$104/ oz and C$28// oz, respectively. Hence, compared to the world gold price (about $ 1,400/ oz in June 2019) these are significant discounts. The market prices of in-ground gold are around 2.5% on average but vary significantly across firms. For example, whereas the June 2019 average was $38, firms had valuations between $1 (e.g. Citigold) and $500 (Orminex).[9]

Bell, Guj, Havlin, and Glacken (2010) also reports differences in the valuation of open pit and underground mines and large and small mines or resources. For example Mineral Resources with less than $250,000$ oz might have a higher average cost per ounce compared to resources between $250,000$ and $1,000,000$ oz which are higher than resources with more than $1,000,000$ oz. Interestingly, larger gold deposits often attract lower valuations than smaller gold deposits (Bell, Gotley, and

[9] We replicated the valuation provided by PCF (2019) for one gold exploration company, Prodigy. The 2019 Annual Report of Prodigy reports 141koz in Indicated Reources and 1010koz in Inferred Resources. If the market cap of $45m is divided by 1,151,000oz, $39/oz results. The $39/ oz is about 2.5% of the world gold price and thus heavily discounted.
It appears that industry uses the following percentage estimates. Ore Reserves 5-10% of gold price, Measured Resources 2-5% of gold price. Indicated Resources 1-2% of gold price, Inferred Resources 0.5-1% of gold price.

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Maybee (2013)). The rationale for this perhaps counterintuitive result is that bigger gold deposits attract less potential bidders who can afford to buy and develop. This value effect (discount) is most prominent when the gold is of low-grade.

2.2 Costs of Gold Mining

This section describes the cost of gold mining and distinguishes all-in sustaining extraction costs (AISC) and externalities that are often not included in the AISC such as greenhouse gas emissions, pollution and significant changes to the landscape (e.g. deforestation), the flora and fauna.

2.2.1 Extraction Costs

The average real All-in Sustaining Cost (AISC) of extracting gold in Australia was US$910/oz as of June 2018 (Ulrich et al. (2019b)). Not surprisingly, open pit (OP) is generally cheaper to mine whereas underground (UG) is more expensive. However, the environmental costs (damage) are generally lower for UG than for OP including GHG emissions. Ulrich et al. (2019b) estimate average GHG emissions intensity of 471 kg CO2 equivalents/ oz AUeq for UG mines and 777 kg CO2 equivalents/ oz AUeq for OP mines.

2.2.2 Externalities

Gold mining implies both positive and negative externalities. Positive externalities occur if gold mining leads to a reduction in poverty through job creation and better

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education if the mining company builds schools and funds teachers and teaching material (Aragon and Rud (2013)).

Negative environmental externalities include greenhouse gas emissions (GHG), changes to the landscape, pollution of rivers or lakes, deforestation etc. (e.g. see Norgate and Haque (2012)). Owens (2013) states that "gold mining can be a dirty business, both environmentally and ethically". The use of the highly poisonous chemical cyanide to extract gold is a major risk factor and can contaminate lakes, rivers and oceans if not used properly.[10] Even without contamination, gold mining generally leads to a lot of waste, e.g 20 tonnes of mining waste for 10 grams of gold. Since gold is very valuable gold mining is sometimes used to finance armed conflict.[11] Child labour in developing countries is another example of ethical concern.

Greenhouse Gas Emissions

The average GHG emissions intensity was 616 kg CO2-e/oz Au or 19,802 kg CO2-e/kg Au in the extraction of gold (Ulrich et al. (2019b)). This emissions intensity has increased by 40% since the study by Mudd (2007b), primarily driven by declining gold grades over this period. There is an inverse relationship of GHG intensity and ore grade, i.e. the higher the ore grade the lower the GHG intensity and vice versa and there are two different ways that companies calculate GHG intensity in gold mining: (1) GHG emissions/ Ore tonnes processed; or (2) GHG emissions/

[10] Artisanal mining of gold is often associated with mercury and cyanide poisoning (e.g. see Hilson (2002), Hylander and Meili (2005), Veiga, Maxson, and Hylander (2006), Spiegel and Veiga (2010) and Kim and Choi (2012).

[11] Gold is sometimes cited as a conflict mineral (e.g. see Freedman (2011) and Bleischwitz, Dittrich, and Pierdicca (2012)).

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gold (gold equivalent) ounces produced. We prefer the second way as it relates to the product of value i.e. gold and you can compare it to other commodities on a dollar per value basis. Open pit mines prefer calculation (1) as they have the lowest intensity. Underground mines generally look best under calculation (2) as they have the lowest intensity due to the inverse relationship between gold grade and GHG emissions.

Other (non-GHG) Externalities

The Minerals Council of Australia provides several examples of "responsible business practise" in relation to the environment.[12]

The Council states the aim to reduce environmental impact, "ensure healthy air, land and water in areas in which we operate" and "make a valuable contribution to biodiversity conservation or support landscape connectivity". The Council further states that it seeks to minimise land disturbance and native vegetation clearing and "usually" requires the industry "to secure biodiversity offsets to compensate or address the impact on biodiversity."

The problem of land disturbance and other negative externalities is acknowledged through the mine rehabilitation and closure regulations. "The Australian minerals industry recognises its responsibility as a temporary custodian of land to contribute to sustainable land use outcomes." The Council also acknowledges that rehabilitation methods can be improved. The "Mine Rehabilitation Update 2018" describes regulation and practise of mine rehabilitation and provides examples of successful

[12] See https://minerals.org.au/environmental-managment

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mine rehabilitation and estimates of financial surety for rehabilitation by the state government (e.g. $5.9bn for Queensland and $2.1bn for NSW).

Despite the efforts to mitigate the negative effects associated with gold mining, it is clear that there are significant costs that may even increase given the changes in environmental and climate awareness of investors and the public.

One way to reduce these significant costs is to avoid mining and instead focus on the securitization of the land.

2.3 A Simple Model of the Relationship between In-ground Gold and Mined Gold

In this section we seek to provide a simple framework to understand the relationship between "exploration" stage in-ground gold market values and "operation" stage gold market values and the factors that influence these.

Figure 2 illustrates the various stages of gold mining from exploration to resources, reserves and operation.

[Figure 2 about here.]

The graph shows that the cost of mining the gold is unknown and thus highly uncertain at the exploration stage and that both the cost and the associated uncertainty decrease over the life cycle of the mine from exploration to resources, reserves and operation. The different costs of mining and uncertainty are reflected in the market value of the in-ground gold which is heavily discounted in all stages but most extreme, below 1% (of the world market price of 1oz of gold) at the exploration

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stage, 0.5% - 8% at the resources stage (scoping study), 8% - 15% at the reserves stage (feasibility study) and 15% - 30% at the operation stage.

The value of gold at the extreme ends of the life cycle spectrum can also be written as

$$V_{\text{Gold, exploration stage}} = P_G - U \tag{1}$$

where V is the market value of gold per oz, P_G is the bullion price of gold and U denotes uncertainty and

$$V_{\text{Gold, operation stage}} = P_G - U^* - C - EC \tag{2}$$

where U^* denotes uncertainty at the operation stage, C denotes mining costs and EC environmental costs.

It can be assumed that $U >> U^*$, i.e. U is significantly larger than U^* because exploration, scoping and feasibility studies reduce uncertainty.

The above equations can also be expressed in terms of expected costs $E(C)$ which are significantly higher and more uncertain at the exploration stage than at the operation stage ($E(C^*)$), i.e. $E(C) > E(C^*)$.

$$V_{\text{Gold, exploration stage}} = P_G - E(C) \tag{3}$$

and

$$V_{\text{Gold, operation stage}} = P_G - E(C^*) \tag{4}$$

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For example, given the discounts attached to gold ounces in the ground at the exploration stage and a bullion price of gold at $1,300$\$ per oz, the expected costs could be $E(C) = 1,200$\$ per oz whereas the expected costs at the operation stage could be $E(C^*) = 800$\$ per oz as it excludes significant costs incurred at all stages prior to the operation stage. The expectation operator E is used to reflect the uncertainty regarding the cost estimates. Low market values of in-ground gold at the exploration stage or the operation stage can either be obtained by assuming certain levels of expected costs or alternatively by more realistically assuming that the gold is mined over several periods and future cash flows are discounted at the appropriate discount rate.

Importantly, whatever the expected costs and uncertainty with respect to the in-ground gold are, what matters for investors is the link and thus the exposure to gold. If the in-ground gold is highly correlated with gold bullion, investors can obtain exposure to the price of gold through investments in gold exploration firms and "green" gold. If in-ground gold market values at the exploration and operation stage are indeed given by equations 3 and 4, the correlation would be one and imply perfect exposure to the price of gold.[13]

3 Empirical Analysis

This section presents an analysis of the financial performance of "green gold" through investments in gold exploration companies relative to the world price of gold. More specifically, we build portfolios (i) based on gold betas and market

[13] More formally, this important relationship can be written as $\rho(V_{\text{Gold, operation stage}}, P_G) = 1$ where ρ denotes the correlation coefficient.

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betas of gold exploration companies that have similar betas as gold bullion in US dollars, i.e. a gold beta of one and a market beta of zero and (ii) based on the best-performing gold exploration companies over the past 3, 6, 9 or 12 months. For illustrative purposes, we only consider equally-weighted portfolios and fix the number of stocks in the portfolios to $N = 10$. The asset selection criteria proposed here are based on risk (betas) and returns. However, alternative asset selection criteria could also be considered such as the amount and quality of gold resources and the level of confidence in resource estimates, e.g. only measured resources are used to select firms. After the portfolio building, we analyze how such portfolios perform relative to gold bullion and the stock market. For the portfolios based on the best-performing gold exploration companies we consider a partial re-balancing of the portfolio by deleting the worst-performing stock and including the best-performing stock over the past x months into the portfolio. A full rebalancing where every x months the best n stocks are included in the portfolio is also analyzed. The partial re-balancing is similar to the practise of major stock indices that regularly change the index composition by deletions and additions. The full re-balancing would incur higher costs than the partial re-balancing and is mainly used as a benchmark for comparison.

3.1 Data and Methodology

We identify 75 listed Australian gold exploration companies (that do not mine any gold) as of May 2019 and obtain time-series data of share prices over 113 months based on a sample of end-of-month prices from January 2010 until May 2019. We use monthly prices to account for relative illiquidity and thus risk of the compa-

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nies. We expect daily or weekly frequencies to yield biased beta estimates. For example, irregular trading on a daily level may lead to lower market and gold betas misleadingly indicating lower risk than is actually incurred due to the lack of liquidity.

The names of all gold exploration companies in the sample are presented in Table 1.

[Table 1 about here.]

The descriptive statistics of the share price returns shown in Tables 2 and 3 illustrate that about a third of the gold exploration firms exhibit negative mean returns and are very risky (compared to gold bullion) based on the standard deviation, the minimum and the maximum returns. This information is also presented graphically as boxplots in Figure 3.

Figure 4 illustrates a clear positive risk-return relationship of the returns and risk estimates of all companies.

[Table 2 about here.]

[Table 3 about here.]

[Figure 3 about here.]

[Figure 4 about here.]

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3.2 Portfolios based on gold and market betas

Since the aim is to form "green" gold portfolios that provide exposure to the world market price of gold and follow the price of gold as closely as possible, we first analyze how gold bullion returns are related to market risk. The estimates of a regression of gold bullion in US dollars on Australian market risk proxied by ASX200 stock index returns are presented in Table 4 and show a statistically insignificant market beta of 0.045. We use this zero market beta estimate and the implicit gold beta of one as benchmarks for the subsequent analysis of gold exploration firms, i.e. we will form portfolios based on firms that exhibit the smallest deviations from a gold beta of one and a market beta of zero across all firms.

[Table 4 about here.]

Tables 13 and 14 and Figures 5 and 6 present the estimation results for all firms sorted according to their gold beta and market beta. Based on these estimates we select firms that exhibit gold betas and market betas closest to the gold (= 1) and the market (= 0) benchmarks. Figure 7 presents the gold beta and market beta estimates graphically and Table 5 displays an example of selected companies using the filter that the maximum absolute deviation from the benchmarks must not exceed 0.5.

[Figure 5 about here.]

[Figure 6 about here.]

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[Figure 7 about here.]

[Table 5 about here.]

Table 6 presents the estimation results for a portfolio of firms based on a high exposure (beta) to the price of gold and a low exposure (beta) to the market in-sample and out-of-sample, i.e. the portfolio of firms is created based on in-sample relationships (exposures) and also used for an out-of-sample prediction. Whereas the in-sample formation performs well based on the selected firms (as expected), the out-of-sample results are very different reflected in a lower gold beta and a higher market beta. However, the excess return is 2.3% per month and thus compensating for the non-zero market beta.

[Table 6 about here.]

Table 7 shows estimation results for different beta filters or selection criteria (gold beta larger than 0.75 and market beta smaller than 0.25) but yields similar results qualitatively, i.e. whereas the in-sample results yield betas consistent with the selection criteria, the out-of-sample results are less favourable with an insignificant gold beta and a highly significant market beta.

[Table 7 about here.]

The results indicate that beta-based portfolio selection criteria do not perform well out-of-sample if there is no dynamic rebalancing. In the next section we consider such dynamic rebalancing.

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3.3 Dynamic Gold Portfolios (Indices)

As an alternative to the above selection of gold exploration companies based on their gold and market betas, we select $N = 10$ firms[14] based on their past performance and either fully rebalance the entire portfolio every 3, 6, 9 or 12 months or only partially rebalance the portfolio by deleting the worst performing stock from the portfolio and including the best performing stock from the entire sample of companies based on the previous 3, 6, 9 or 12 months. If the stock is already included in the portfolio we select the second-best performing stock and so on to avoid over-weighting of any stock in the portfolio.

Table 8 presents the estimation results for the full rebalancing and Table 9 displays the results for the partial rebalancing.

[Table 8 about here.]

The estimation results for the full rebalancing yield relatively small gold betas in general and only one statistically significant gold beta for the 9-month rebalancing frequency. The market beta is negative for all rebalancing periods and only statistically significantly different from zero for the 12-month rebalancing frequency. The excess returns captured by the constant are all large (between 12% and 7.5%) and highly significant. Despite the relatively weak co-movement with the price of gold in general, the portfolio yields a risk-adjusted average monthly return of 7.5% for the 12-month rebalancing period and close to 12% for the 3-month rebalancing period. It is important to note that these relatively high returns do not reflect the

[14]The number of firms is fixed for illustrative purposes but can be easily changed. The portfolio analysis is based on code written in R.

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costs of rebalancing which can be assumed to be relatively high implying much lower effective returns.

[Table 9 about here.]

[Table 10 about here.]

The partial rebalancing portfolios yield considerably larger gold betas and market betas for all rebalancing frequencies and smaller excess returns. The 3-month and 6-month rebalancing periods are arguably superior to the alternatives as they yield high gold betas, statistically insignificant market betas and relatively high and statistically significant excess returns.

The time-varying performances of the portfolios relative to the price of gold are shown graphically for a selection of size and rebalancing specifications in Figure 8.

[Figure 8 about here.]

The findings imply that portfolios comprised of gold exploration companies can provide significant exposure to gold bullion, low market risk and considerable excess returns. The high gold beta estimates (all well above one) represent the higher risk of "green" gold relative to gold bullion. The evolution of the portfolio compositions is presented in Table 11 for 5 firms and 12-month rebalancing as an example.

[Table 11 about here.]

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To provide a perspective and benchmark for these results, we also estimate gold betas, market betas and risk-adjusted returns for four major gold mining exchange-trade funds (ETFs).[15] Table 12 displays the estimation results and reveals that the ETF-based estimates are qualitatively similar to the green gold portfolio estimates, i.e. the ETFs exhibit relatively high gold and market betas. The only difference is the excess return or constant estimate which is negative or insignificant for the ETF sample but positive for the gold exploration sample.

[Table 12 about here.]

4 Summary and Concluding Remarks

This paper proposes an alternative to gold investment. Instead of investing in mined gold that includes "digging it out" and "burying it" we avoid both stages by proposing an investment in un-mined, in-ground gold through shares in gold exploration companies. These firms only explore the land and secure underground gold resources or reserves without mining it and without causing any major harm to the environment such as CO2 emissions, water contamination, land disruption etc. Whilst there is and remains significant uncertainty with respect to the actual

[15]The four ETFs are (i) VanEck Vectors Junior Gold Miners ETF (GDXJ) "which is intended to track the overall performance of small-capitalization companies that are involved primarily in the mining for gold and/or silver", (ii) Solactive Pure Gold Miners Index which "tracks the performance of the largest and most liquid gold mining companies globally", (iii) NYSE Arca Gold Miners Index (GDM) which is "a rules-based index designed to measure the performance of highly capitalized companies in the Gold Mining industry" and (iv) The MSCI ACWI Select Gold Miners Investable Market Index (IMI) which "aims to focus on companies in the gold mining industry that are highly sensitive to underlying prices of gold. The index includes companies primarily engaged in gold mining or that derive a majority of their revenues from gold mining".

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amount and quality of the in-ground gold we show that this form of "green" gold is highly correlated with gold bullion.

This study is motivated by the significant costs associated with gold mining, in particular the environmental costs including CO2 emissions, changes to the landscape, potential pollution of water and other adverse effects to the environment. Since gold is an investment asset and often stored underground the benefits of digging it out and then "burying" it again in a vault are limited. In fact, a significant amount of gold is stored in vaults including ETF gold holdings and central bank gold reserves.

If investors use exploration companies as a way to invest in green gold, it is evidence that financial markets and innovative ideas can help to create carbon-neutral and environmentally-friendly forms of investment even without any government intervention such as a carbon tax or carbon pollution rights. The proposed idea may be an example for how existing financial markets and products can be used to transition to a low-carbon and environmentally more friendly mining industry.

However, there are a number of open questions. For example, it is not clear how "green" gold would eventually trade against gold bullion. Given the uncertainty regarding the amount and quality of in-ground gold and the intrinsic illiquidity of in-ground gold, it is likely that green gold would continue to trade at a major discount relative to "classical" gold. More importantly, it is not clear how this would change the mining industry and the relative prices of mined gold and unmined in-ground gold.

Finally, this study also highlights that there is no stranded asset risk for gold. Unlike other commodities such as oil, coal, or iron ore, gold is also useful in-ground

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and need not be mined to have value. Hence, it does not exhibit the usual risk of becoming not minable and thus stranded.

Given this feature and the special properties of gold, e.g. that it does not degenerate over time, gold may be the ultimate store of value and safe haven for investors against financial but also against extreme climate change risks such as heat, storms and flooding.

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[Table 13 about here.]

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[Table 14 about here.]

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[Table 15 about here.]

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Figure 1: JORC 2012 Classification Resources and Reserves
Source: JORC Code (2012)

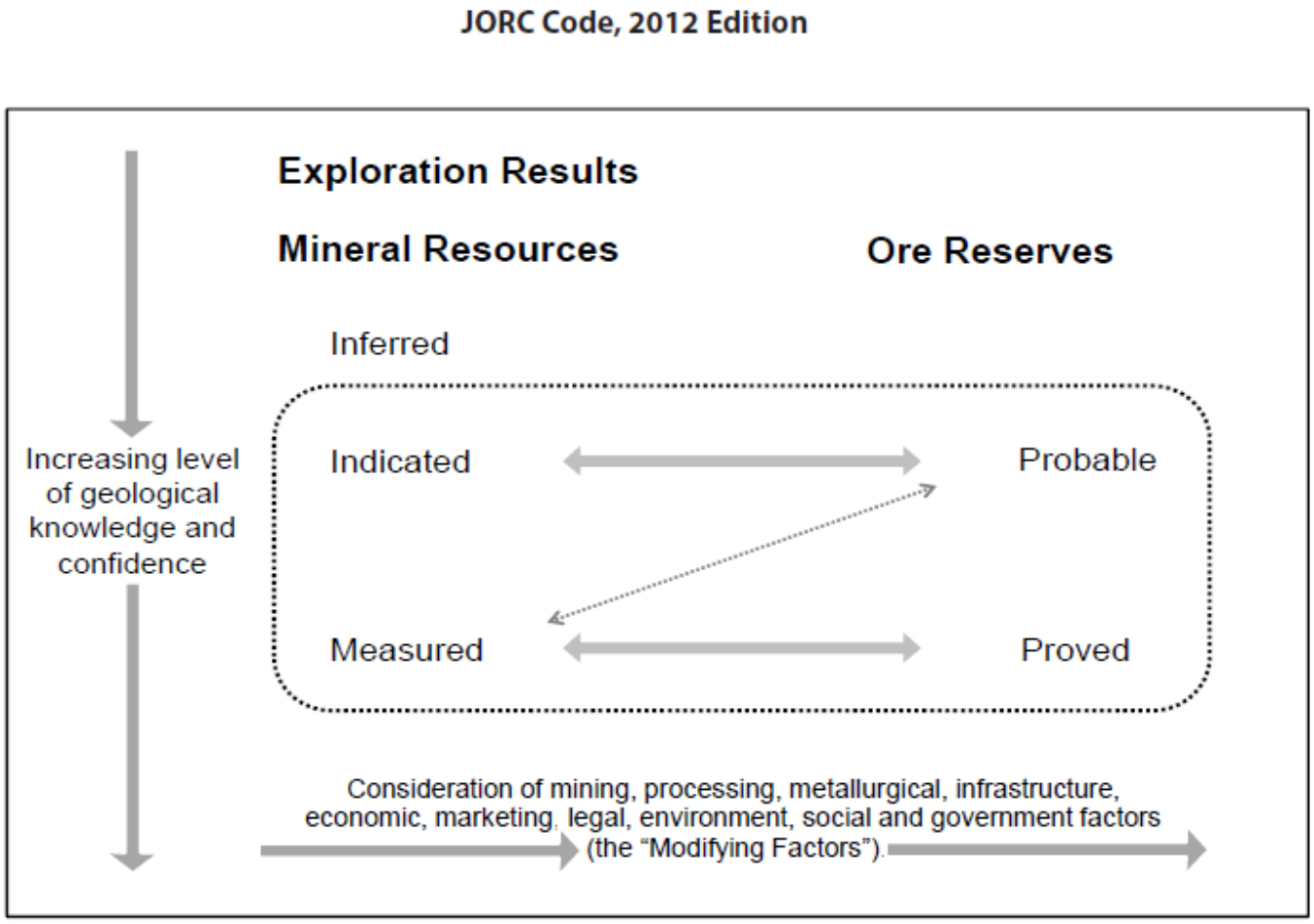

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Figure 2: Life cycle of Gold Mining - From Exploration to Operation

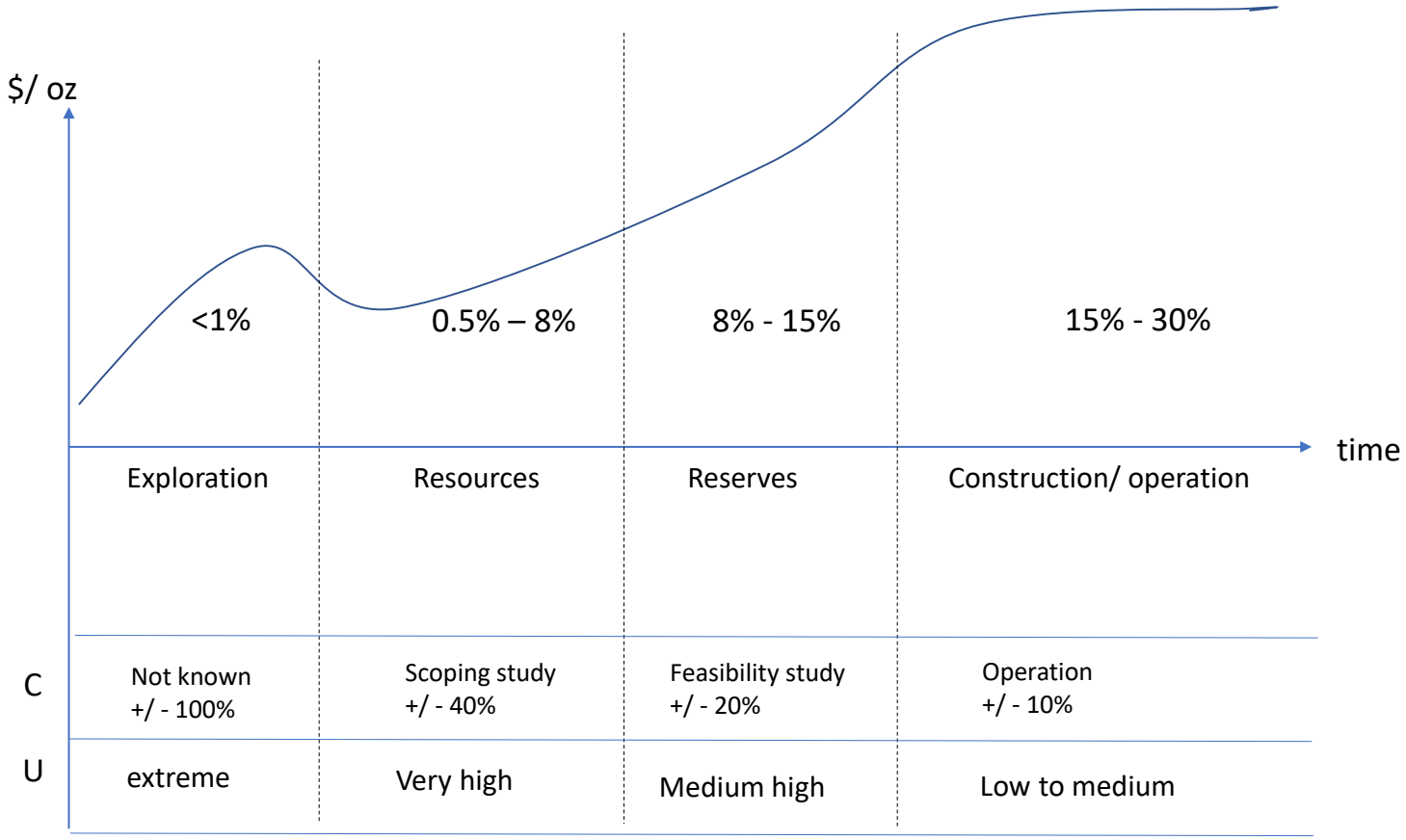

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Figure 3: Return Distribution Boxplots

This Figure presents the return distributions of Gold Mining Company Shares, Gold bullion and the ASX200 Index. The boxplots show that gold mining shares are more dispersed and thus more risky than gold bullion which is more risky than the stock index.

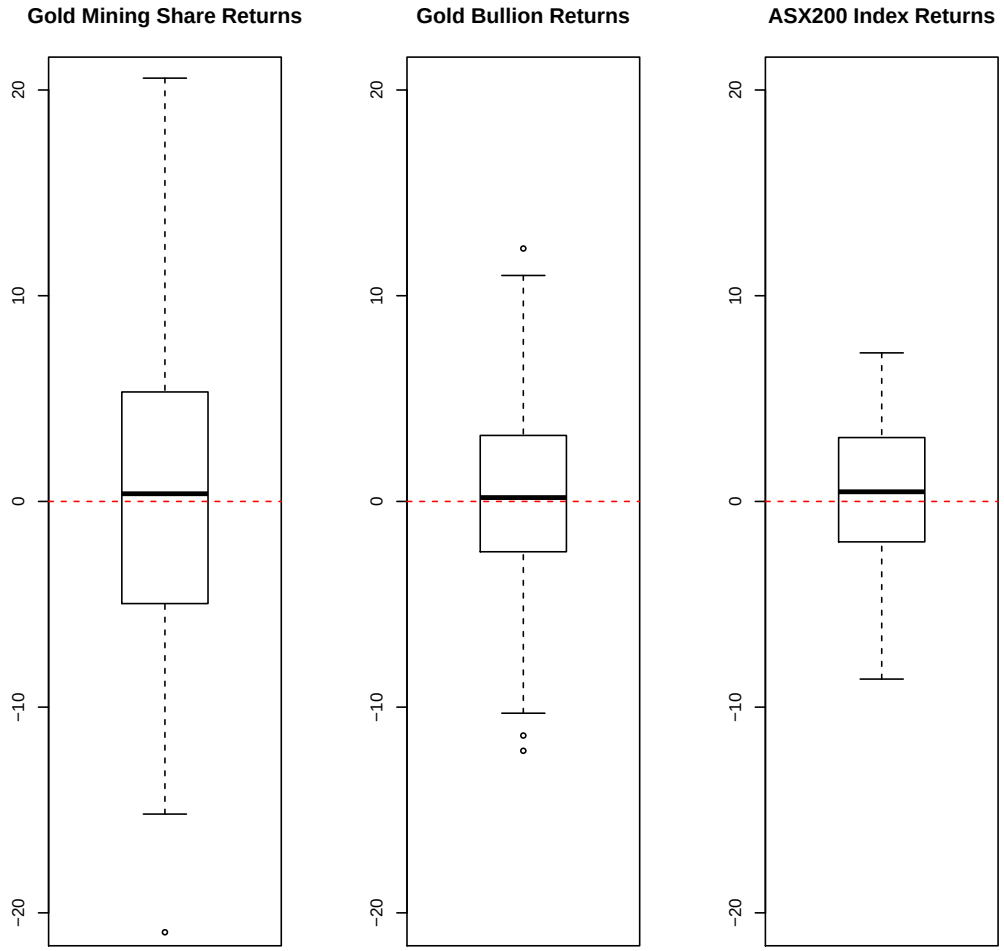

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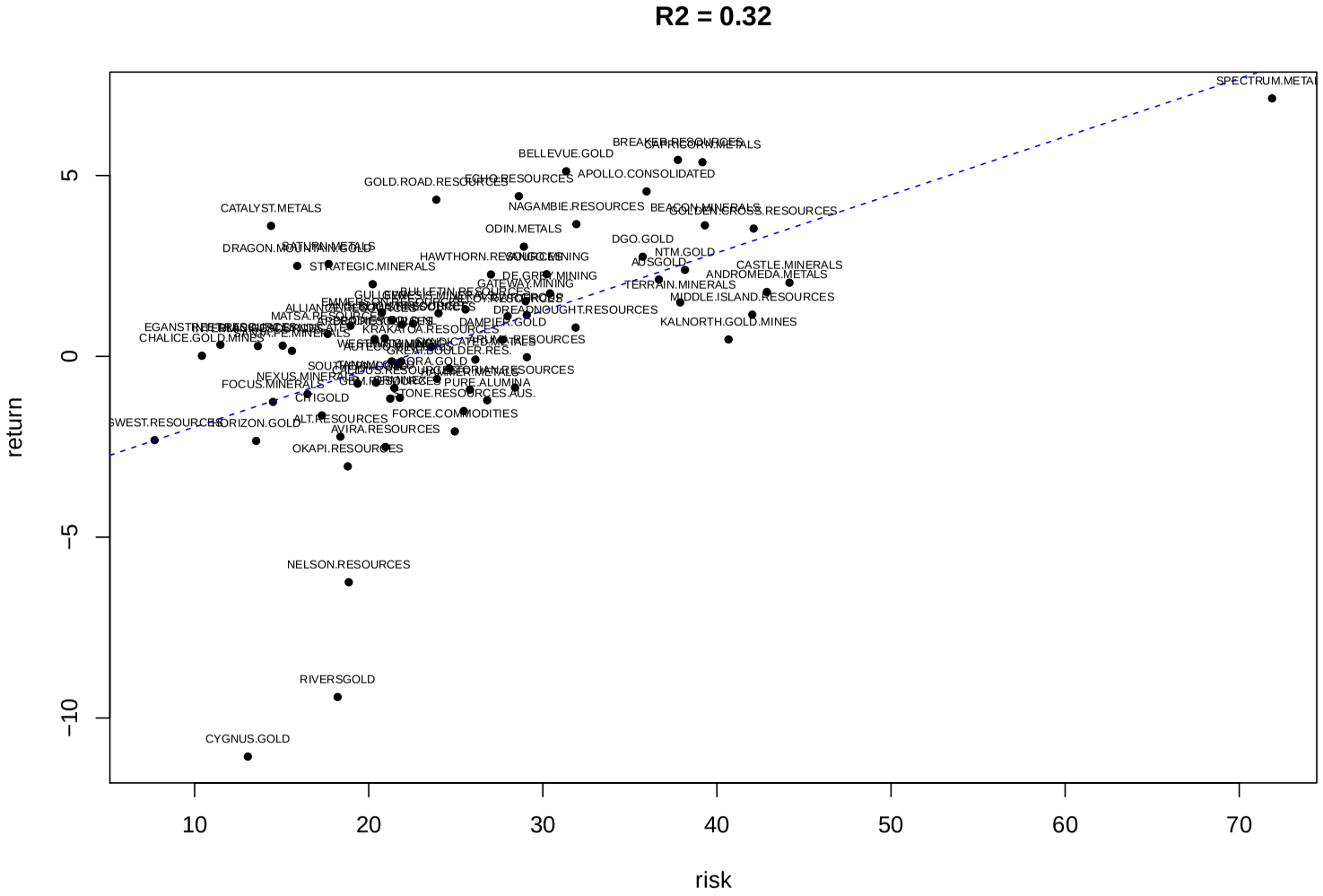
Figure 4: Risk-return relationship of all Gold exploration firms



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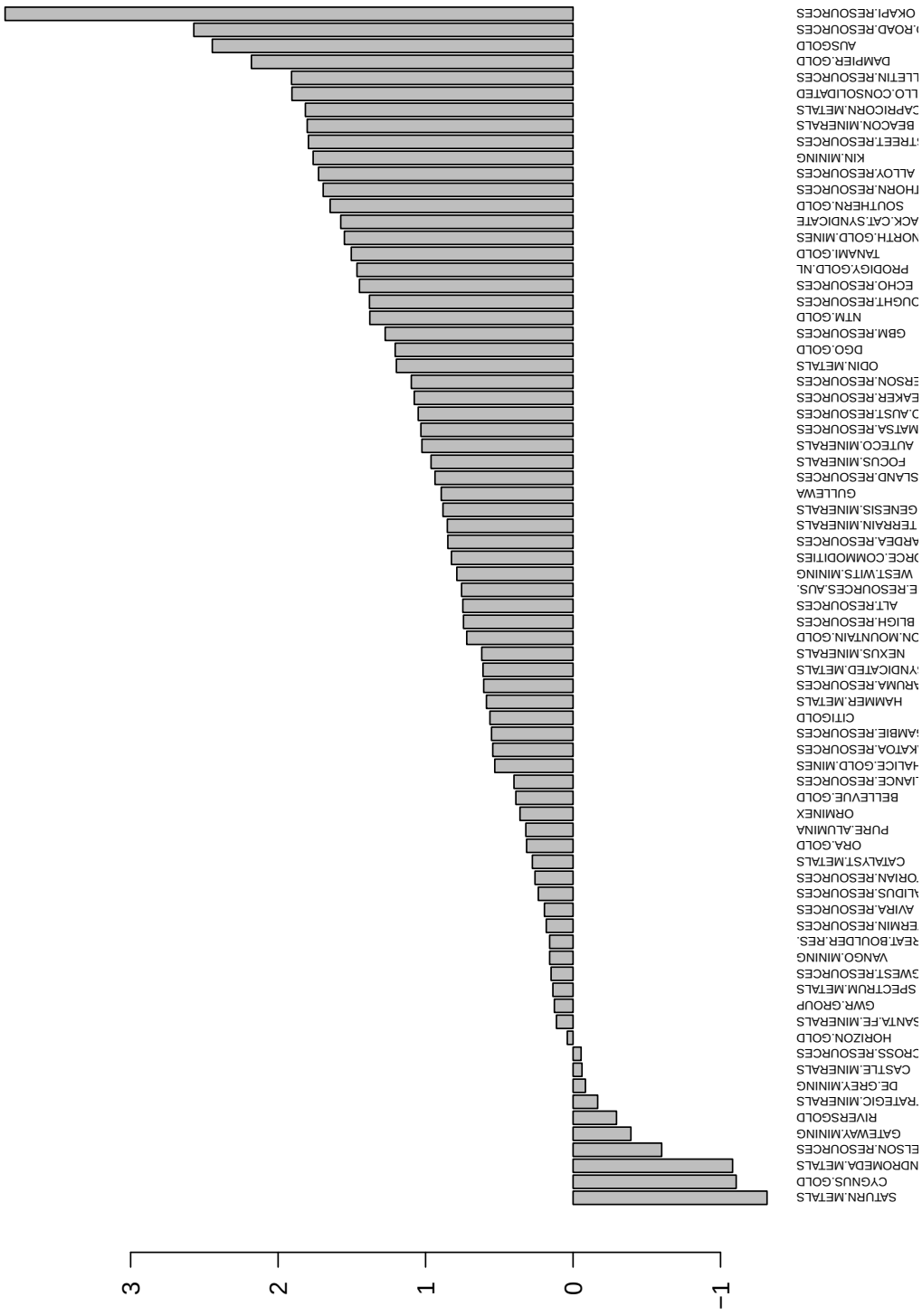

Figure 5: Barplot Gold Betas (sorted)

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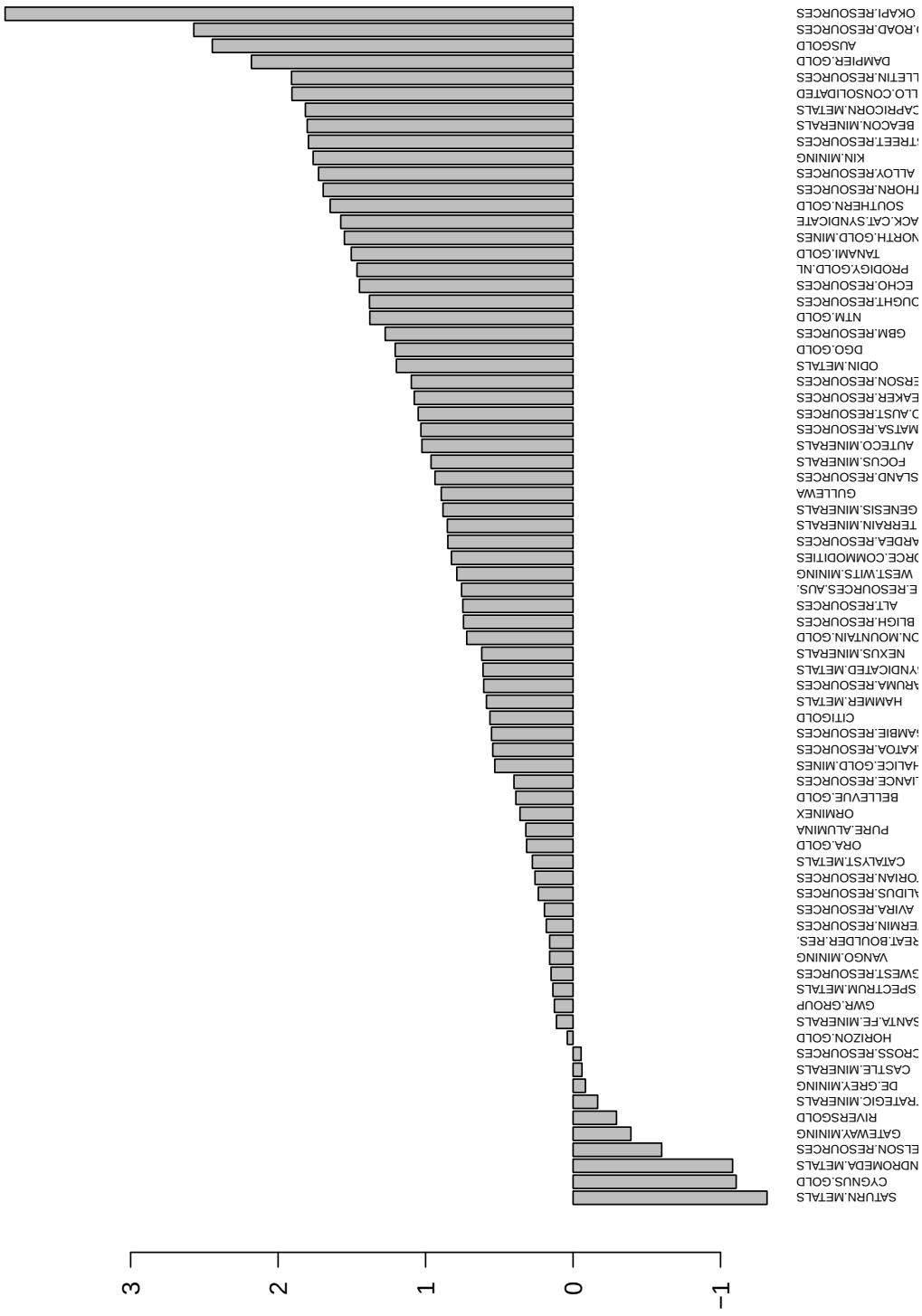

Figure 6: Barplot Market Betas (sorted)

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Figure 7: Scatter plot: market beta versus gold beta

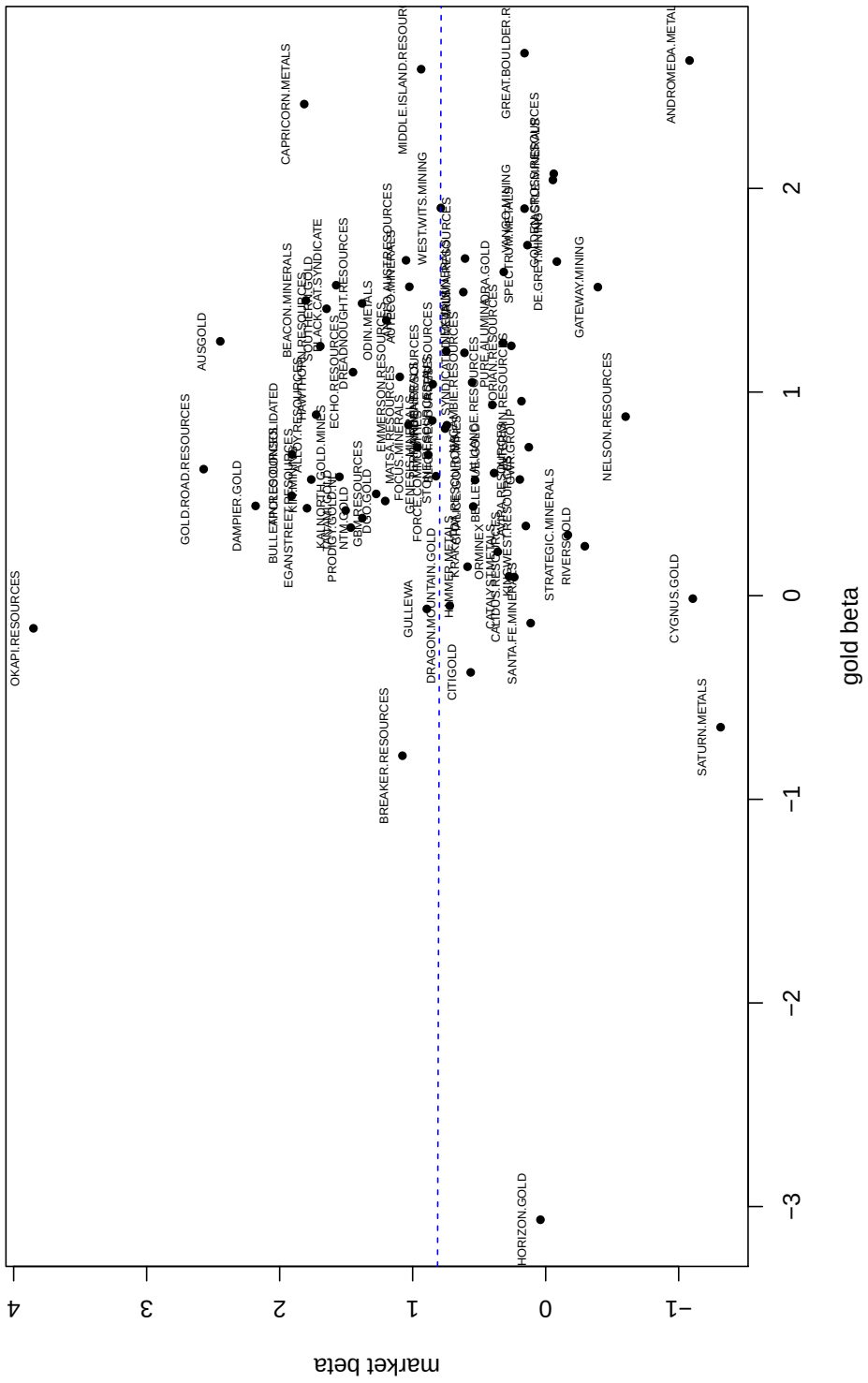

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Figure 8:
Portfolio Performance for differernce size (N) and rebalancing specifications

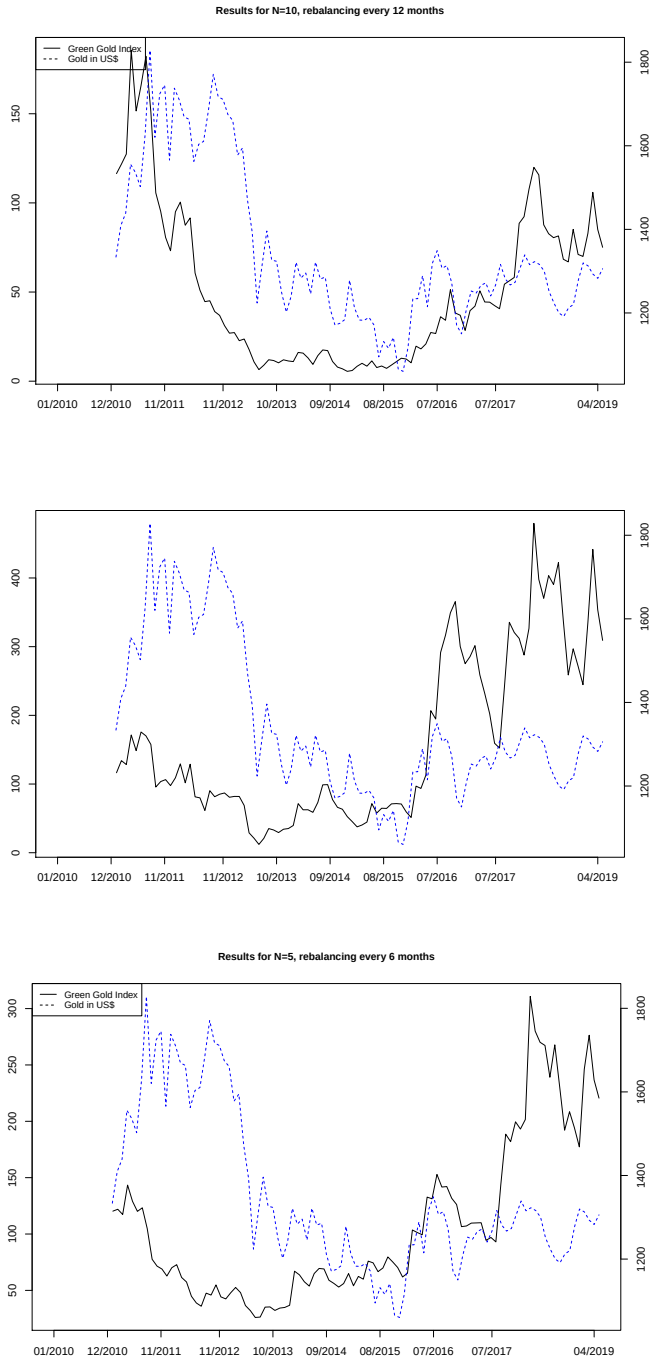

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Table 1: Names of all gold exploration companies in the sample

	1	2	3	4
ALLIANCE.RESOURCES	CATALYST.METALS	GULLEWA	PRODIGY.GOLD.NL	
ALLOY.RESOURCES	CHALICE.GOLD.MINES	GWR.GROUP	PURE.ALUMINA	
ALT.RESOURCES	CITIGOLD	HAMMER.METALS	RIVERSGOLD	
ANDROMEDA.METALS	CYGNUS.GOLD	HAWTHORN.RESOURCES	SANTA.FE.MINERALS	
ANGLO.AUST.RESOURCES	DAMPIER.GOLD	HORIZON.GOLD	SATURN.METALS	
APOLLO.CONSOLIDATED	DE.GREY.MINING	INTERMIN.RESOURCES	SOUTHERN.GOLD	
ARDEA.RESOURCES	DGO.GOLD	KALNORTH.GOLD.MINES	SPECTRUM.METALS	
ARUMA.RESOURCES	DRAGON.MOUNTAIN.GOLD	KIN.MINING	STONE.RESOURCES.AUS.	
AUSGOLD	DREADNOUGHT.RESOURCES	KINGWEST.RESOURCES	STRATEGIC.MINERALS	
AUTECO.MINERALS	ECHO.RESOURCES	KRAKATOA.RESOURCES	SYNDICATED.METALS	
AVIRA.RESOURCES	EGANSTREET.RESOURCES	MATSA.RESOURCES	TANAMI.GOLD	
BEACON.MINERALS	EMMERSON.RESOURCES	MIDDLE.ISLAND.RESOURCES	TERRAIN.MINERALS	
BELLEVUE.GOLD	FOCUS.MINERALS	NAGAMBIE.RESOURCES	TORIAN.RESOURCES	
BLACK.CAT.SYNDICATE	FORCE.COMMODITIES	NELSON.RESOURCES	VANGO.MINING	
BLIGH.RESOURCES	GATEWAY.MINING	NEXUS.MINERALS	WEST.WITS.MINING	
BREAKER.RESOURCES	GBM.RESOURCES	NTM.GOLD		
BULLETIN.RESOURCES	GENESIS.MINERALS	ODIN.METALS		
CALIDUS.RESOURCES	GOLD.ROAD.RESOURCES	OKAPI.RESOURCES		
CAPRICORN.METALS	GOLDEN.CROSS.RESOURCES	ORA.GOLD		
CASTLE.MINERALS	GREAT.BOULDER.RES.	ORMINEX		

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Table 2: Descriptive Statistics - Panel A

	mean	median	sd	min	max
ALLIANCE.RESOURCES	0.85	-1.17	18.96	-42.69	72.18
ALLOY.RESOURCES	1.11	0.00	27.98	-50.85	103.45
ALT.RESOURCES	-2.22	-4.76	18.37	-42.86	31.82
ANDROMEDA.METALS	1.78	-6.00	42.87	-62.49	400.72
ANGLO.AUST.RESOURCES	0.88	0.00	21.91	-40.54	72.00
APOLLO.CONSOLIDATED	4.56	0.00	35.96	-50.00	185.81
ARDEA.RESOURCES	0.48	-3.45	20.34	-27.38	56.03
ARUMA.RESOURCES	-0.02	0.00	29.08	-40.96	175.00
AUSGOLD	2.12	-3.41	36.67	-45.13	274.03
AUTECO.MINERALS	-0.22	-2.38	21.68	-40.00	86.49
AVIRA.RESOURCES	-2.50	0.00	20.97	-91.57	100.00
BEACON.MINERALS	3.62	0.00	39.31	-46.00	356.25
BELLEVUE.GOLD	5.12	0.00	31.34	-44.00	142.86
BLACK.CAT.SYNDICATE	0.30	-2.57	15.06	-16.22	31.58
BLIGH.RESOURCES	0.90	0.00	22.56	-47.76	108.52
BREAKER.RESOURCES	5.43	0.00	37.76	-59.94	219.05
BULLETIN.RESOURCES	1.30	-2.50	25.56	-52.73	119.05
CALIDUS.RESOURCES	-0.87	0.00	21.47	-92.33	100.00
CAPRICORN.METALS	5.37	-3.81	39.17	-54.16	215.75
CASTLE.MINERALS	2.04	-2.74	44.17	-55.56	308.33
CATALYST.METALS	3.61	0.00	14.39	-30.43	60.00
CHALICE.GOLD.MINES	0.02	0.00	10.42	-22.59	39.16
CITIGOLD	-1.63	-4.00	17.31	-26.87	100.00
CYGNUS.GOLD	-11.07	-10.10	13.06	-35.29	9.68
DAMPIER.GOLD	0.46	-3.45	27.69	-47.37	140.00
DE.GREY.MINING	1.74	0.00	30.41	-50.00	134.38
DGO.GOLD	2.76	0.00	35.74	-66.68	240.40
DRAGON.MOUNTAIN.GOLD	2.50	0.00	15.89	-27.78	58.33
DREADNOUGHT.RESOURCES	0.80	0.00	31.88	-50.00	127.26
ECHO.RESOURCES	4.43	0.00	28.62	-47.67	173.61
EGANSTREET.RESOURCES	0.32	0.00	11.48	-17.86	28.00
EMMERSON.RESOURCES	1.01	-1.31	21.36	-35.84	133.37
FOCUS.MINERALS	-1.26	-2.57	14.50	-33.33	57.78
FORCE.COMMODITIES	-2.07	-5.56	24.94	-56.27	107.69
GATEWAY.MINING	1.53	0.00	29.01	-40.00	177.55
GBM.RESOURCES	-1.17	-3.22	21.23	-38.40	91.44
GENESIS.MINERALS	1.19	0.00	24.01	-40.05	92.88
CMX.GOLD	0.27	0.19	4.61	-12.12	12.30
ASX200	0.36	0.47	3.36	-8.64	7.22

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Table 3: Descriptive Statistics - Panel B

	mean	median	sd	min	max
GOLD.ROAD.RESOURCES	4.33	-1.37	23.88	-34.17	108.73
GOLDEN.CROSS.RESOURCES	3.53	0.00	42.11	-61.11	233.33
GREAT.BOULDER.RES.	-0.33	-6.08	24.63	-37.69	61.29
GULLEWA	1.21	0.00	20.75	-44.00	95.40
GWR.GROUP	1.15	-3.18	29.08	-42.62	223.08
HAMMER.METALS	-0.92	-0.90	25.81	-60.00	141.66
HAWTHORN.RESOURCES	2.26	0.00	27.02	-44.44	95.00
HORIZON.GOLD	-2.34	-3.23	13.53	-30.23	42.86
INTERMIN.RESOURCES	0.29	0.00	13.63	-30.00	40.91
KALNORTH.GOLD.MINES	0.47	-2.49	40.66	-64.29	277.78
KIN.MINING	-0.14	-3.85	21.87	-34.64	94.65
KINGWEST.RESOURCES	-2.32	0.00	7.70	-12.50	7.14
KRAKATOA.RESOURCES	0.26	0.00	23.58	-70.50	82.45
MATSA.RESOURCES	0.62	-2.95	17.64	-34.10	56.56
MIDDLE.ISLAND.RESOURCES	1.15	-5.35	42.03	-56.93	304.44
NAGAMBIE.RESOURCES	3.66	-3.85	31.93	-42.42	140.00
NELSON.RESOURCES	-6.24	-7.69	18.85	-41.86	35.71
NEXUS.MINERALS	-1.04	-3.64	16.48	-29.35	70.73
NTM.GOLD	2.39	-3.33	38.16	-62.22	280.00
ODIN.METALS	3.03	0.00	28.91	-69.21	174.50
OKAPI.RESOURCES	-3.04	-4.94	18.80	-31.03	58.06
ORA.GOLD	-0.62	-5.68	23.92	-43.72	103.11
ORMINEX	-1.15	0.00	21.79	-96.50	129.89
PRODIGY.GOLD.NL	0.50	-3.60	20.93	-57.89	100.00
PURE.ALUMINA	-1.21	-4.81	26.81	-50.00	100.00
RIVERSGOLD	-9.42	-10.00	18.21	-46.43	45.45
SANTA.FE.MINERALS	0.15	0.00	15.59	-54.39	45.45
SATURN.METALS	2.56	1.50	17.69	-20.00	31.58
SOUTHERN.GOLD	-0.75	-2.00	19.36	-43.75	77.78
SPECTRUM.METALS	7.13	-1.19	71.88	-50.57	675.00
STONE.RESOURCES.AUS.	-1.51	0.00	25.46	-50.00	100.00
STRATEGIC.MINERALS	2.00	0.00	20.23	-42.87	131.99
SYNDICATED.METALS	-0.09	0.00	26.12	-60.87	150.00
TANAMI.GOLD	-0.73	-2.50	20.41	-60.48	73.33
TERRAIN.MINERALS	1.49	0.00	37.89	-45.00	300.00
TORIAN.RESOURCES	-0.86	0.00	28.40	-80.00	100.00
VANGO.MINING	2.27	-3.26	30.22	-50.00	110.53
WEST.WITS.MINING	-0.14	-4.41	21.32	-46.99	88.64
CMX.GOLD	0.27	0.19	4.61	-12.12	12.30
ASX200	0.36	0.47	3.36	-8.64	7.22

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Table 4: Gold and market betas of gold bullion in US dollars

	Dependent variable:
	Gold
ASX	0.045
	(0.131)
Constant	0.256
	(0.440)
Observations	112
R^2	0.001
Adjusted R^2	−0.008
Residual Std. Error	4.626 (df = 110)
F Statistic	0.117 (df = 1; 110)
Note:	*p<0.1; **p<0.05; ***p<0.01

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Table 5: Selection of firms with specific betas

Criteria: maximum absolute deviation of 0.5 from gold (=1) and market (=0) benchmarks

	α	β_G	β_M	R^2
CITIGOLD	-1.6504	0.5638	-0.3768	0.0272
	(0.02)	(2.97)	(1.76)	
DGO.GOLD	2.261	1.2063	0.4649	0.0265
	(0.71)	(2.28)	(1.34)	
DRAGON.MOUNTAIN.GOLD	2.3213	0.7211	-0.0494	0.0437
	(1.45)	(1.07)	(-0.62)	
GBM.RESOURCES	-1.6938	1.2741	0.4998	0.0841
	(1.12)	(2.34)	(2.27)	
GULLEWA	0.9907	0.894	-0.065	0.0394
	(1.38)	(2.53)	(1.4)	
HAMMER.METALS	-1.1342	0.5875	0.1423	0.0115
	(0.03)	(2.52)	(0.56)	
KRAKATOA.RESOURCES	0.1862	0.5446	0.4379	0.0122
	(-0.15)	(2.53)	(0.69)	
NTM.GOLD	1.8803	1.3784	0.3809	0.0292
	(1.6)	(0.6)	(0.68)	
PRODIGY.GOLD.NL	-0.0183	1.4653	0.3341	0.1081
	(0.41)	(-0.13)	(1.92)	

Note: t-statistics in parentheses

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Table 6: Regression results

Portfolios based on absolute deviations from 1 and 0 benchmarks not greater than 0.5, respectively

	Dependent variable: Portfolio Returns	
	in-sample	out-of-sample
	(1)	(2)
Gold	1.048^{***}	0.734^{*}
	(0.225)	(0.418)
ASX	0.219	1.641^{***}
	(0.350)	(0.465)
Constant	-0.966	2.337
	(1.199)	(1.519)
Observations	56	57
R^2	0.312	0.205
Adjusted R^2	0.286	0.176
Residual Std. Error	8.922 (df = 53)	11.415 (df = 54)
F Statistic	12.005^{***} (df = 2; 53)	6.980^{***} (df = 2; 54)
Note:		*p<0.1; **p<0.05; ***p<0.01

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Table 7: Regression results
Portfolios based on firms with gold beta > 0.75 and market beta < 0.25

	Dependent variable: Portfolio Returns	
	in-sample	out-of-sample
	(1)	(2)
Gold	1.206^{***}	0.506
	(0.367)	(0.547)
ASX	-0.109	1.552^{**}
	(0.570)	(0.609)
Constant	-1.601	3.329
	(1.953)	(1.990)
Observations	56	57
R^2	0.172	0.111
Adjusted R^2	0.140	0.079
Residual Std. Error	14.533 (df = 53)	14.958 (df = 54)
F Statistic	5.492^{***} (df = 2; 53)	3.386^{**} (df = 2; 54)
Note:		*p<0.1; **p<0.05; ***p<0.01

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Table 8: Estimation Results - Green Gold Portfolio
Full rebalancing every x months. Number of firms in portfolio index $N = 10$

	Portfolio Returns			
	rebalancing every ... months			
	3	6	9	12
	(1)	(2)	(3)	(4)
Gold	0.133	0.036	0.203	0.189
	(0.120)	(0.120)	(0.126)	(0.141)
ASX	−0.094	−0.113	−0.093	−0.321
	(0.169)	(0.170)	(0.179)	(0.199)
Constant	11.325***	9.701***	8.653***	7.447***
	(0.560)	(0.563)	(0.591)	(0.659)
Observations	101	101	101	101
R^2	0.015	0.005	0.027	0.040
Adjusted R^2	−0.005	−0.015	0.007	0.021
Residual Std. Error (df = 98)	5.595	5.625	5.902	6.588
F Statistic (df = 2; 98)	0.735	0.252	1.374	2.064
Note:				*p<0.1; **p<0.05; ***p<0.01

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Table 9: Estimation Results - Green Gold Portfolio
Partial rebalancing every x months. Number of firms in portfolio index $N = 10$

	Portfolio Returns			
	rebalancing every ... months			
	3	6	9	12
	(1)	(2)	(3)	(4)
Gold	2.168***	2.607***	1.602***	2.034***
	(0.519)	(0.488)	(0.483)	(0.448)
ASX	1.486**	1.796**	1.888***	1.442**
	(0.734)	(0.691)	(0.683)	(0.634)
Constant	3.763	2.425	1.432	1.864
	(2.427)	(2.284)	(2.259)	(2.097)
Observations	101	101	101	101
R^2	0.189	0.276	0.169	0.218
Adjusted R^2	0.172	0.261	0.152	0.202
Residual Std. Error (df = 98)	24.250	22.825	22.579	20.955
F Statistic (df = 2; 98)	11.410***	18.657***	9.980***	13.642***

Note: *p<0.1; **p<0.05; ***p<0.01

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Table 10: Estimation Results - Green Gold Portfolio
Partial rebalancing every x months. Number of firms in portfolio index $N = 5$

	Portfolio Returns			
	rebalancing every ... months			
	3	6	9	12
	(1)	(2)	(3)	(4)
Gold	1.157***	1.364***	0.555	0.587*
	(0.397)	(0.360)	(0.346)	(0.337)
ASX	0.558	0.653	1.348***	0.830*
	(0.561)	(0.510)	(0.490)	(0.477)
Constant	3.864**	1.921	1.163	0.115
	(1.856)	(1.686)	(1.621)	(1.578)
Observations	101	101	101	101
R^2	0.092	0.146	0.099	0.062
Adjusted R^2	0.073	0.128	0.081	0.043
Residual Std. Error (df = 98)	18.546	16.847	16.198	15.767
F Statistic (df = 2; 98)	4.966***	8.354***	5.385***	3.246**
Note:				*p<0.1; **p<0.05; ***p<0.01

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Table 11: Portfolio Composition (equally-weighted) through time for 5 firms and 12-month rebalancing frequency

Composition Date	1	2	3	4	5
T-60	EMMERSON.RESOURCES	BELLEVUE.GOLD	GOLD.ROAD.RESOURCES	GATEWAY.MINING	ANDROMEDA.METALS
T-48	EMMERSON.RESOURCES	BELLEVUE.GOLD	GOLD.ROAD.RESOURCES	GATEWAY.MINING	TERRAIN.MINERALS
T-36	EMMERSON.RESOURCES	BELLEVUE.GOLD	GOLD.ROAD.RESOURCES	BREAKER.RESOURCES	TERRAIN.MINERALS
T-24	EMMERSON.RESOURCES	BELLEVUE.GOLD	BEACON.MINERALS	BREAKER.RESOURCES	TERRAIN.MINERALS
T-12	BLACK.CAT.SYNDICATE	BELLEVUE.GOLD	BEACON.MINERALS	BREAKER.RESOURCES	TERRAIN.MINERALS
T	GOLDEN.CROSS.RESOURCES	BELLEVUE.GOLD	BEACON.MINERALS	BREAKER.RESOURCES	TERRAIN.MINERALS

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Table 12: Gold Mining ETFs for comparison

	Dependent variable:			
	ETF Gold Miners			
	Market Vectors Jr	Solactive Pure	NYSE Arca	MSCI ACWI Select
	(1)	(2)	(3)	(4)
Gold	1.890***	1.094***	1.751***	2.114***
	(0.107)	(0.150)	(0.088)	(0.140)
ASX200	0.812***	0.291	0.358***	−0.081
	(0.146)	(0.211)	(0.120)	(0.180)
Constant	−1.047*	−0.409	−0.964**	0.323
	(0.560)	(0.705)	(0.460)	(0.592)
Observations	165	102	165	89
R^2	0.681	0.364	0.715	0.725
Adjusted R^2	0.677	0.351	0.712	0.719
Residual Std. Error	7.101 (df = 162)	7.078 (df = 99)	5.833 (df = 162)	5.512 (df = 86)
F Statistic	172.583*** (df = 2; 162)	28.351*** (df = 2; 99)	203.523*** (df = 2; 162)	113.491*** (df = 2; 86)
Note:				*p<0.1; **p<0.05; ***p<0.01

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Table 13: Estimation Results - gold beta sorted

	α	β_G	β_M	R^2
SATURN.METALS	2.98	-1.32	-0.65	0.03
CYGNUS.GOLD	-11.21	-1.11	-0.01	0.03
ANDROMEDA.METALS	1.14	-1.08	2.63	0.05
NELSON.RESOURCES	-6.54	-0.60	0.88	0.03
GATEWAY.MINING	1.09	-0.39	1.52	0.03
RIVERSGOLD	-9.48	-0.29	0.24	0.00
STRATEGIC.MINERALS	1.93	-0.17	0.30	0.00
DE.GREY.MINING	1.18	-0.08	1.64	0.03
CASTLE.MINERALS	1.31	-0.06	2.07	0.02
GOLDEN.CROSS.RESOURCES	2.82	-0.05	2.04	0.03
HORIZON.GOLD	-0.98	0.04	-3.06	0.33
SANTA.FE.MINERALS	0.24	0.11	-0.13	0.00
GWR.GROUP	0.85	0.13	0.73	0.01
SPECTRUM.METALS	6.48	0.14	1.72	0.01
KINGWEST.RESOURCES	-2.52	0.15	0.34	0.02
VANGO.MINING	1.55	0.16	1.90	0.05
GREAT.BOULDER.RES.	-1.92	0.16	2.66	0.08
INTERMIN.RESOURCES	-0.10	0.18	0.96	0.06
AVIRA.RESOURCES	-2.76	0.19	0.57	0.01
CALIDUS.RESOURCES	-0.97	0.24	0.09	0.00
TORIAN.RESOURCES	-1.37	0.26	1.23	0.02
CATALYST.METALS	3.50	0.28	0.10	0.01
ORA.GOLD	-1.28	0.32	1.59	0.05
PURE.ALUMINA	-1.75	0.32	1.24	0.03
ORMINEX	-1.32	0.36	0.22	0.01
BELLEVUE.GOLD	4.80	0.39	0.60	0.01
ALLIANCE.RESOURCES	0.40	0.40	0.94	0.04
CHALICE.GOLD.MINES	-0.33	0.53	0.57	0.09
KRAKATOA.RESOURCES	0.19	0.54	0.44	0.01
NAGAMBIE.RESOURCES	3.13	0.55	1.05	0.02
CITIGOLD	-1.65	0.56	-0.38	0.03
HAMMER.METALS	-1.13	0.59	0.14	0.01
ARUMA.RESOURCES	-0.79	0.61	1.66	0.05
SYNDICATED.METALS	-0.68	0.61	1.19	0.04
NEXUS.MINERALS	-1.74	0.62	1.49	0.13
DRAGON.MOUNTAIN.GOLD	2.32	0.72	-0.05	0.04
BLIGH.RESOURCES	0.52	0.74	0.84	0.03
ALT.RESOURCES	-3.25	0.75	1.20	0.04
STONE.RESOURCES.AUS.	-2.01	0.76	0.82	0.03
WEST.WITS.MINING	-1.03	0.79	1.90	0.12
FORCE.COMMODITIES	-2.30	0.82	0.59	0.03
ARDEA.RESOURCES	-0.14	0.85	1.04	0.02
TERRAIN.MINERALS	0.95	0.85	0.86	0.02
GENESIS.MINERALS	0.70	0.88	0.69	0.04
GULLEWA	0.99	0.89	-0.06	0.04
MIDDLE.ISLAND.RESOURCES	0.22	0.94	2.59	0.06
FOCUS.MINERALS	-1.78	0.96	0.73	0.13
AUTECO.MINERALS	-1.04	1.02	1.52	0.11
MATSA.RESOURCES	0.04	1.03	0.84	0.10
ANGLO.AUST.RESOURCES	0.00	1.05	1.65	0.12
BREAKER.RESOURCES	6.04	1.08	-0.79	0.02
EMMERSON.RESOURCES	0.33	1.10	1.07	0.09
ODIN.METALS	2.30	1.20	1.35	0.07
DGO.GOLD	2.26	1.21	0.46	0.03
GBM.RESOURCES	-1.69	1.27	0.50	0.08
NTM.GOLD	1.88	1.38	0.38	0.03
DREADNOUGHT.RESOURCES	-0.09	1.38	1.44	0.06
ECHO.RESOURCES	3.64	1.45	1.10	0.07
PRODIGY.GOLD.NL	-0.02	1.47	0.33	0.11
TANAMI.GOLD	-1.29	1.50	0.42	0.12
KALNORTH.GOLD.MINES	-0.16	1.55	0.58	0.03
BLACK.CAT.SYNDICATE	-0.11	1.58	1.52	0.12
SOUTHERN.GOLD	-1.71	1.65	1.41	0.22
HAWTHORN.RESOURCES	1.37	1.69	1.22	0.11
ALLOY.RESOURCES	0.32	1.73	0.89	0.09
KIN.MINING	-0.40	1.76	0.57	0.09
EGANSTREET.RESOURCES	0.05	1.79	0.43	0.18
BEACON.MINERALS	2.61	1.80	1.45	0.06
CAPRICORN.METALS	4.01	1.82	2.41	0.09
APOLLO.CONSOLIDATED	3.79	1.91	0.69	0.06
BULLETIN.RESOURCES	1.08	1.91	0.49	0.13
DAMPIER.GOLD	-0.05	2.18	0.44	0.14
AUSGOLD	1.01	2.45	1.25	0.11
GOLD.ROAD.RESOURCES	3.41	2.57	0.62	0.26
OKAPI.RESOURCES	-3.38	3.85	-0.16	0.19

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Table 14: Estimation Results - market beta sorted

	α	β_G	β_M	R^2
HORIZON.GOLD	-0.98	0.04	-3.06	0.33
BREAKER.RESOURCES	6.04	1.08	-0.79	0.02
SATURN.METALS	2.98	-1.32	-0.65	0.03
CITIGOLD	-1.65	0.56	-0.38	0.03
OKAPI.RESOURCES	-3.38	3.85	-0.16	0.19
SANTA.FE.MINERALS	0.24	0.11	-0.13	0.00
GULLEWA	0.99	0.89	-0.06	0.04
DRAGON.MOUNTAIN.GOLD	2.32	0.72	-0.05	0.04
CYGNUS.GOLD	-11.21	-1.11	-0.01	0.03
CALIDUS.RESOURCES	-0.97	0.24	0.09	0.00
CATALYST.METALS	3.50	0.28	0.10	0.01
HAMMER.METALS	-1.13	0.59	0.14	0.01
ORMINEX	-1.32	0.36	0.22	0.01
RIVERSGOLD	-9.48	-0.29	0.24	0.00
STRATEGIC.MINERALS	1.93	-0.17	0.30	0.00
PRODIGY.GOLD.NL	-0.02	1.47	0.33	0.11
KINGWEST.RESOURCES	-2.52	0.15	0.34	0.02
NTM.GOLD	1.88	1.38	0.38	0.03
TANAMI.GOLD	-1.29	1.50	0.42	0.12
EGANSTREET.RESOURCES	0.05	1.79	0.43	0.18
KRAKATOA.RESOURCES	0.19	0.54	0.44	0.01
DAMPIER.GOLD	-0.05	2.18	0.44	0.14
DGO.GOLD	2.26	1.21	0.46	0.03
BULLETIN.RESOURCES	1.08	1.91	0.49	0.13
GBM.RESOURCES	-1.69	1.27	0.50	0.08
CHALICE.GOLD.MINES	-0.33	0.53	0.57	0.09
KIN.MINING	-0.40	1.76	0.57	0.09
AVIRA.RESOURCES	-2.76	0.19	0.57	0.01
KALNORTH.GOLD.MINES	-0.16	1.55	0.58	0.03
FORCE.COMMODITIES	-2.30	0.82	0.59	0.03
BELLEVUE.GOLD	4.80	0.39	0.60	0.01
GOLD.ROAD.RESOURCES	3.41	2.57	0.62	0.26
GENESIS.MINERALS	0.70	0.88	0.69	0.04
APOLLO.CONSOLIDATED	3.79	1.91	0.69	0.06
FOCUS.MINERALS	-1.78	0.96	0.73	0.13
GWR.GROUP	0.85	0.13	0.73	0.01
STONE.RESOURCES.AUS.	-2.01	0.76	0.82	0.03
BLIGH.RESOURCES	0.52	0.74	0.84	0.03
MATSA.RESOURCES	0.04	1.03	0.84	0.10
TERRAIN.MINERALS	0.95	0.85	0.86	0.02
NELSON.RESOURCES	-6.54	-0.60	0.88	0.03
ALLOY.RESOURCES	0.32	1.73	0.89	0.09
ALLIANCE.RESOURCES	0.40	0.40	0.94	0.04
INTERMIN.RESOURCES	-0.10	0.18	0.96	0.06
ARDEA.RESOURCES	-0.14	0.85	1.04	0.02
NAGAMBIE.RESOURCES	3.13	0.55	1.05	0.02
EMMERSON.RESOURCES	0.33	1.10	1.07	0.09
ECHO.RESOURCES	3.64	1.45	1.10	0.07
SYNDICATED.METALS	-0.68	0.61	1.19	0.04
ALT.RESOURCES	-3.25	0.75	1.20	0.04
HAWTHORN.RESOURCES	1.37	1.69	1.22	0.11
TORIAN.RESOURCES	-1.37	0.26	1.23	0.02
PURE.ALUMINA	-1.75	0.32	1.24	0.03
AUSGOLD	1.01	2.45	1.25	0.11
ODIN.METALS	2.30	1.20	1.35	0.07
SOUTHERN.GOLD	-1.71	1.65	1.41	0.22
DREADNOUGHT.RESOURCES	-0.09	1.38	1.44	0.06
BEACON.MINERALS	2.61	1.80	1.45	0.06
NEXUS.MINERALS	-1.74	0.62	1.49	0.13
GATEWAY.MINING	1.09	-0.39	1.52	0.03
AUTECO.MINERALS	-1.04	1.02	1.52	0.11
BLACK.CAT.SYNDICATE	-0.11	1.58	1.52	0.12
ORA.GOLD	-1.28	0.32	1.59	0.05
DE.GREY.MINING	1.18	-0.08	1.64	0.03
ANGLO.AUST.RESOURCES	0.00	1.05	1.65	0.12
ARUMA.RESOURCES	-0.79	0.61	1.66	0.05
SPECTRUM.METALS	6.48	0.14	1.72	0.01
VANGO.MINING	1.55	0.16	1.90	0.05
WEST.WITS.MINING	-1.03	0.79	1.90	0.12
GOLDEN.CROSS.RESOURCES	2.82	-0.05	2.04	0.03
CASTLE.MINERALS	1.31	-0.06	2.07	0.02
CAPRICORN.METALS	4.01	1.82	2.41	0.09
MIDDLE.ISLAND.RESOURCES	0.22	0.94	2.59	0.06
ANDROMEDA.METALS	1.14	-1.08	2.63	0.05
GREAT.BOULDER.RES.	-1.92	0.16	2.66	0.08

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Table 15: Estimation Results - alpha sorted

	α	β_G	β_M	R^2
CYGNUS.GOLD	-11.21	-1.11	-0.01	0.03
RIVERSGOLD	-9.48	-0.29	0.24	0.00
NELSON.RESOURCES	-6.54	-0.60	0.88	0.03
OKAPI.RESOURCES	-3.38	3.85	-0.16	0.19
ALT.RESOURCES	-3.25	0.75	1.20	0.04
AVIRA.RESOURCES	-2.76	0.19	0.57	0.01
KINGWEST.RESOURCES	-2.52	0.15	0.34	0.02
FORCE.COMMODITIES	-2.30	0.82	0.59	0.03
STONE.RESOURCES.AUS.	-2.01	0.76	0.82	0.03
GREAT.BOULDER.RES.	-1.92	0.16	2.66	0.08
FOCUS.MINERALS	-1.78	0.96	0.73	0.13
PURE.ALUMINA	-1.75	0.32	1.24	0.03
NEXUS.MINERALS	-1.74	0.62	1.49	0.13
SOUTHERN.GOLD	-1.71	1.65	1.41	0.22
GBM.RESOURCES	-1.69	1.27	0.50	0.08
CITIGOLD	-1.65	0.56	-0.38	0.03
TORIAN.RESOURCES	-1.37	0.26	1.23	0.02
ORMINEX	-1.32	0.36	0.22	0.01
TANAMI.GOLD	-1.29	1.50	0.42	0.12
ORA.GOLD	-1.28	0.32	1.59	0.05
HAMMER.METALS	-1.13	0.59	0.14	0.01
AUTECO.MINERALS	-1.04	1.02	1.52	0.11
WEST.WITS.MINING	-1.03	0.79	1.90	0.12
HORIZON.GOLD	-0.98	0.04	-3.06	0.33
CALIDUS.RESOURCES	-0.97	0.24	0.09	0.00
ARUMA.RESOURCES	-0.79	0.61	1.66	0.05
SYNDICATED.METALS	-0.68	0.61	1.19	0.04
KIN.MINING	-0.40	1.76	0.57	0.09
CHALICE.GOLD.MINES	-0.33	0.53	0.57	0.09
KALNORTH.GOLD.MINES	-0.16	1.55	0.58	0.03
ARDEA.RESOURCES	-0.14	0.85	1.04	0.02
BLACK.CAT.SYNDICATE	-0.11	1.58	1.52	0.12
INTERMIN.RESOURCES	-0.10	0.18	0.96	0.06
DREADNOUGHT.RESOURCES	-0.09	1.38	1.44	0.06
DAMPIER.GOLD	-0.05	2.18	0.44	0.14
PRODIGY.GOLD.NL	-0.02	1.47	0.33	0.11
ANGLO.AUST.RESOURCES	0.00	1.05	1.65	0.12
MATSA.RESOURCES	0.04	1.03	0.84	0.10
EGANSTREET.RESOURCES	0.05	1.79	0.43	0.18
KRAKATOA.RESOURCES	0.19	0.54	0.44	0.01
MIDDLE.ISLAND.RESOURCES	0.22	0.94	2.59	0.06
SANTA.FE.MINERALS	0.24	0.11	-0.13	0.00
ALLOY.RESOURCES	0.32	1.73	0.89	0.09
EMMERSON.RESOURCES	0.33	1.10	1.07	0.09
ALLIANCE.RESOURCES	0.40	0.40	0.94	0.04
BLIGH.RESOURCES	0.52	0.74	0.84	0.03
GENESIS.MINERALS	0.70	0.88	0.69	0.04
GWR.GROUP	0.85	0.13	0.73	0.01
TERRAIN.MINERALS	0.95	0.85	0.86	0.02
GULLEWA	0.99	0.89	-0.06	0.04
AUSGOLD	1.01	2.45	1.25	0.11
BULLETIN.RESOURCES	1.08	1.91	0.49	0.13
GATEWAY.MINING	1.09	-0.39	1.52	0.03
ANDROMEDA.METALS	1.14	-1.08	2.63	0.05
DE.GREY.MINING	1.18	-0.08	1.64	0.03
CASTLE.MINERALS	1.31	-0.06	2.07	0.02
HAWTHORN.RESOURCES	1.37	1.69	1.22	0.11
VANGO.MINING	1.55	0.16	1.90	0.05
NTM.GOLD	1.88	1.38	0.38	0.03
STRATEGIC.MINERALS	1.93	-0.17	0.30	0.00
DGO.GOLD	2.26	1.21	0.46	0.03
ODIN.METALS	2.30	1.20	1.35	0.07
DRAGON.MOUNTAIN.GOLD	2.32	0.72	-0.05	0.04
BEACON.MINERALS	2.61	1.80	1.45	0.06
GOLDEN.CROSS.RESOURCES	2.82	-0.05	2.04	0.03
SATURN.METALS	2.98	-1.32	-0.65	0.03
NAGAMBIE.RESOURCES	3.13	0.55	1.05	0.02
GOLD.ROAD.RESOURCES	3.41	2.57	0.62	0.26
CATALYST.METALS	3.50	0.28	0.10	0.01
ECHO.RESOURCES	3.64	1.45	1.10	0.07
APOLLO.CONSOLIDATED	3.79	1.91	0.69	0.06
CAPRICORN.METALS	4.01	1.82	2.41	0.09
BELLEVUE.GOLD	4.80	0.39	0.60	0.01
BREAKER.RESOURCES	6.04	1.08	-0.79	0.02
SPECTRUM.METALS	6.48	0.14	1.72	0.01

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