The Investment Opportunity Set and its Proxy Variables: Theory and Evidence

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Abstract

This study evaluates the performance of proxy variables for a firm's investment opportunity set. We value investment opportunities using a real options approach, and compare the real option values with three proxy variables that have been used extensively in the empirical literature. The results show that the market-to-book assets ratio is the most informative proxy. It contains the highest relative information content with respect to a firm's investment opportunity set. Both the market-to-book equity and the earnings-price ratios do not contain information about investment opportunities that is not already contained in the market-to-book assets ratio. Importantly, we also find that the proxies significantly understate the value of investment opportunities of more financially constrained firms.

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Key words: Proxy variables, investment opportunity set, growth opportunities, real options, market-to-book ratios, mining industry, financial constraints

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1. Introduction

Investment opportunities play an important role in the theory of corporate finance. The mix of a firm's assets in place and its investment opportunities affects its capital structure,[1] the maturity and covenant structure of its debt contracts,[2] its dividend policies,[3] its compensation contracts,[4] and its accounting policies.[5] Because investment opportunities are typically unobservable to outsiders, most academic research relies on proxy variables to measure a firm's investment opportunity set. However, little is known about how well these proxies perform, which according to Baker (1993), is one of the fundamental problems in corporate finance.

In the mining industry, firms' major growth opportunities are *observable* to outsiders because SEC regulations require mining firms to disclose information about the nature, quality, and magnitude of their mineral deposits.[6] These deposits can be valued by applying Brennan and Schwartz's (1985) real option framework, for example. Hence, the disclosure rules and the existence of a well-established option pricing technique present a unique opportunity to evaluate the performance of growth opportunity proxy variables. To our knowledge, no other industry discloses similarly detailed information that would allow one to value investment opportunities directly, and hence test the performance of proxy variables.

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[1] Myers (1977); Smith and Watts (1992)

[2] Barclay and Smith (1995); Goyal (1997)

[3] Smith and Watts (1992)

[4] Smith and Watts (1992); Kole (1991); Gaver and Gaver (1993)

[5] Skinner (1993)

[6] See SEC rule 504, Sections 229.801 and 317.477.

This study evaluates three commonly used proxy variables for a firm's investment opportunity set: the market-to-book ratio of assets, the market-to-book ratio of equity, and the earnings-price ratio.[7] While the results show that all three proxies are related to the real option values of firms' investment opportunities, the market-to-book assets ratio has the highest information content of the three proxies. Neither the market-to-book equity nor the earnings-price ratio provides incremental information beyond that already contained in the market-to-book assets ratio. We also find that the market significantly understates the value of growth opportunities of firms that are more likely to be financially constrained, which suggests that some firms may not be able to exercise all of their growth options optimally because of their limited access to capital.

Existing studies that evaluate the performance of proxy variables are rare, perhaps reflecting the problem that the underlying variable is typically unobservable. Goyal, Lehn, and Racic (1998) examine how growth opportunity proxies change when there is an exogenous shock to the investment opportunity set. They argue that investment opportunities in the U.S. defense industry increased substantially during the Reagan defense buildup of the early 1980s, but declined significantly with the end of cold war and large defense budget cuts of the late 1980s. Their results show that proxies changed in the direction implied by the changes in growth opportunities. Kallapur and Trombley (1999) measure investment opportunities by the realized growth in firms' book values of equity, assets, and sales, but

[7] The literature documents positive but relatively low correlations among different growth opportunity proxies. For example, Gaver and Gaver (1993) find the correlation between the two market-to-book ratios is only 0.47, suggesting that these two variables capture distinctly different aspects of firms' growth opportunities. The relatively weak correlation could also indicate that some proxy variables do a poorer job in measuring investment opportunities than others.

report only rank correlations between these measures and various proxies for the investment opportunity set.

The remainder of this paper is organized as follows. Section 2 defines the concept of a firm's investment opportunity set and discusses examples of growth opportunities in the mining industry. Section 3 summarizes the three proxy variables, their theoretical relations among each other and with the investment opportunity set. Data sources, sample construction, and the construction of variables are documented in Section 4. The empirical results of the paper are presented in Section 5. Section 6 concludes the paper.

2. The Investment Opportunity Set

Myers (1977) divides the market value of a firm into two parts: the present value of assets already in place and the present value of future growth opportunities. According to Myers, the fundamental difference between the two is that the value of growth opportunities depends, at least in part, on future discretionary investments, while the value of assets in place does not (Myers, 1977 p.155). Examples of discretionary investments include investments in new projects, expenditures on advertising, marketing, product development and R&D, as well as maintenance expenditures on plant and equipment, and expenditures on raw materials. Given the discretionary nature of investments associated with growth opportunities, they are best regarded as options on real assets, and are commonly referred to as *real options or growth options*. The option's exercise price represents the future investment needed to acquire the asset.

Growth options can be further divided into simple and compound options. Simple options are projects that have a direct impact on the company's cash flows. Examples are routine cost reductions, maintenance, and replacement projects. Compound options are projects that provide companies with opportunities for further discretionary investments. Examples of compound options are R&D and major expansion projects, entry into a new market, and acquisitions.

2.1 Growth Opportunities in the Mining Industry

Mining operations consist of the following three stages: exploration, development, and production. The exploration stage includes prospecting, sampling, mapping, drilling and other activities associated with searching for new mineral deposits. Any discovered mineral deposits are first classified as *resources*. Further test drillings must be undertaken to geologically define the deposit more accurately and to test whether extraction is economically feasible. Once economic feasibility has been established, a resource is reclassified as a *reserve*. The project then enters the development stage that consists of building the extraction facilities and processing plants, sinking a mineshaft (for underground mines), or removing a first layer of waste rock (for open pit mines). Upon completion of the initial development of the mine the production stage begins. During this stage a firm needs to continuously develop the rest of the mine in order to make all areas of the ore body accessible for extraction. Appendix A depicts the mine development plan of the Oronorte Mine as of December 1992.

Growth opportunities exist in all three stages of operations. They consist primarily of (i) the option to develop and extract a mineral reserve (production stage), (ii) the option to develop a completely undeveloped reserve (development stage), and (iii) the option to reclassify a resource to a reserve through further exploration work (exploration stage). All of these growth opportunities are compound options. For example, by paying the development costs a firm acquires an option to extract a developed mineral reserve. This is similar to the option of setting up a local distribution network to provide households with consumer goods, etc. The option to reclassify a resource as a reserve can be compared to the option to develop a new product through investments in R&D.

These options certainly do not exhaust the set of all growth opportunities of mining firms. Firms also have the option to explore for new deposits, the option to delay the development or production stages, the option to increase the production capacity, the option to close down a mine, etc. These options, however, are difficult to value for outsiders because the necessary information is generally not available. While we do not value the entire investment opportunity set of mining firms, we believe that we value a significant part of it. Indeed, the descriptive statistics show that our estimates of the values of reserves and resources account for the major fraction of a firm's total market value.

3. The Proxy Variables

This section discusses the three most commonly used proxy variables for a firm's investment opportunity set, and shows how the proxies relate to each other. Table 1 describes the construction of these variables and the data sources.

3.1 Market-to-book assets ratio (MBA)

Perhaps the most commonly used proxy for growth opportunities is the ratio of the market value of assets to the book value of assets, or a closely related measure, Tobin's q.[8,9]

[8] Smith and Watts (1992) and Kole (1991) use the inverse, the ratio of the book value of assets to the market value of assets, and argue that a high ratio indicates few investment opportunities among a firm's assets.

[9] We do not distinguish between Tobin's q and the market-to-book assets ratio, because Perfect and Wiles (1994) show that Tobin's q and the market-to-book assets ratio are highly correlated (the correlation coefficient is about 0.96). Our results for the MBA should therefore apply to Tobin's q also.

Since firms with abundant growth opportunities derive relatively less of their value from assets in place, it is presumed that these ratios vary directly with a firm's growth opportunities. More concretely, the MBA describes the mix of assets in place and growth opportunities because the book value of assets is a proxy for assets in place, and the market value of assets is a proxy for both assets in place and growth opportunities.

The MBA or Tobin's q has also been used in the empirical literature to measure other variables, such as corporate performance.[10] The argument is that Tobin's q is the ratio of the present value of expected cash flows to the replacement value of assets in place. Firms that generate higher expected cash flows per unit of existing assets perform better than firms that generate lower expected cash flows. Therefore, cross-sectional differences in Tobin's q reflect cross-sectional differences in current and expected performance. Lindenberg and Ross (1981) and Morck, Shleifer and Vishny (1988) use Tobin's q to measure the contribution of intangible assets to firm value, based on the assumption that the market value of the firm includes intangible assets but the replacement value does not.

These examples show that Tobin's q and the MBA are used to measure many different variables, which undermines one's confidence that Tobin's q and the market-to-book assets ratio are 'good' proxies for a firm's investment opportunity set.

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[10] For example, Morck, Shleifer and Vishny (1988) and McConnell and Servaes (1990) examine the relation between a firm's ownership structure and Tobin's q. Wernerfelt and Montgomery (1988), Lang and Stulz (1994), and Berger and Ofek (1995) examine how diversification affects Tobin's q. Lang, Stulz, and Walkling (1989) use Tobin's q to examine cross-sectional variation in bidder and target returns at announcement. Yermack (1996) examines how board size affects q. Recently Allayanis and Weston (1999) examine how a firm's hedging policy affects its q ratio.

3.2 *Market-to-book equity ratio (MBE)*

A second commonly used proxy for growth opportunities is the ratio of the market value of equity to the book value of equity.[11] According to Collins and Kothari (1989), the MBE measures the extent to which a firm's return on its assets-in-place and expected future investments exceeds its required return on equity. Like the MBA, the MBE may also proxy for other variables, such as corporate performance. A second problem is that the MBE is affected by leverage. Assuming the market value of debt equals its book value, the MBA is related to the MBE by the following equation:

$$MBE = MBA\left(1 + \frac{D}{E}\right) - \frac{D}{E}, \tag{1}$$

where D = book value of debt, and E = book value of equity. The leverage problem arises because leverage itself is a function of growth opportunities, as argued in the debt contracting literature. If low-growth firms choose more debt in their capital structure, then their market-to-book equity ratios would be higher than what would be implied by growth opportunities alone. Therefore, the MBE is not a simple linear transformation of the MBA as the above equation suggests.

A third problem with the use of the MBE is that firms with negative equity values are omitted from the analysis since negative market-to-book equity ratios are not meaningful in measuring growth opportunities.

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[11] See Chung and Charoenwong (1991), Collins and Kothari (1989), Graham and Rogers (1999), and Lewellen, Loderer and Martin (1987).

3.3 *Earnings-price ratio (E/P-ratio)*

A third commonly used proxy of growth opportunities is the earnings-price ratio or its inverse, the price-earnings ratio.[12] Chung and Charoenwong (1991) argue that a higher earnings-price ratio indicates that a larger proportion of equity value is attributable to assets in place relative to growth opportunities. This inference assumes that current earnings proxy for future cash flows received from assets in place, and that the market value of equity comprises the present value of all future cash flows, i.e., cash flows from assets in place and future investment opportunities.

The earnings-price ratio and the market-to-book equity ratio are related by the following identity:

$$MBE \equiv \frac{P}{E} \times ROE, \qquad (2)$$

where P/E is the inverse of the earnings-price ratio, and ROE is the current book return on equity. The above identity shows that the relationship between the MBE and the E/P ratio is clouded by the book return on equity. The ROE itself is a function of leverage which in turn is a function of growth opportunities.

Penman (1996) finds that for only 66 percent of firms a high market-to-book equity ratio is associated with a low earnings-price ratio. Thus, a high P/E ratio may not always indicate that a firm has good growth opportunities because current earnings can temporarily deviate from their long-run expected values. By contrast, the MBE projects future growth in book

[12] See Kester (1984), Chung and Charoenwong (1991), and Smith and Watts (1992). An advantage of the earnings-price ratio over the price-earnings ratio is that it remains a meaningful proxy even if earnings are zero, which is not the case for the price-earnings ratio.

value of equity (or the ability to enhance book value through future earnings) and is not affected by transitory earnings.

The P/E ratio has several other interpretations in the literature. Penman notes that the P/E ratio has been interpreted as an earnings growth indicator,[13] a risk measure,[14] and an earnings capitalization rate.[15] Finally, a major problem with the earnings-price ratio is that it is not a meaningful measure of growth opportunities if firms report zero or negative earnings.

In summary, the MBE is endogenous to a firm's leverage decision, which reduces its usefulness as a proxy for growth opportunities. Similarly, the transitory component of earnings reduces the information content of the earnings-price ratio as a proxy for growth opportunities. Thus, from a theoretical perspective, the MBA appears to be the most suitable proxy.

4. Sample and variable description

The empirical tests focus on the North American metal mining industry. We construct our sample by first identifying all firms listed on Compustat (Canadian, U.S. industrial, full coverage, and research tapes) for the year 1996 with a two-digit Standard Industrial Classification code of 10. We then exclude pure exploration companies, identified by zero sales for the entire period 1989-96, because publicly available information is not sufficient to value the growth opportunities of exploration companies. An additional benefit is that the distribution of growth opportunities in our sample is closer to the economy wide average, and hence more representative. We also exclude firms that produce specialty metals, such as

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[13] See Cragg and Malkiel (1982) and Litzenberger and Rao (1971).

[14] See Ball (1978).

molybdenum, cobalt, uranium, etc., for which sufficient financial data is not available. Finally, we exclude firm-years with missing corporate financial statements.

The final sample consists of 90 mining companies operating 405 different mines, covering 8 years from 1989 to 1996 for a total of 449 firm-years. Appendix B lists the companies included in our final sample. These companies engage in the production of precious metals, such as gold and silver, and base metals, such as copper, lead, nickel, and zinc. Gold producing mines account for about 73 percent of the sample. Copper and zinc mines account for 15 percent each. Appendix C provides descriptive statistics on annual production, production costs, reserves, resources, mine-life and other option pricing parameters for all mines in our sample stratified by the primary metal of a mine.

4.1. Valuation of Mineral Reserves

Brennan and Schwartz (1985) showed that the value of a copper mine can be regarded as an option, and argued that established option-pricing techniques could be applied to value mining projects.[16] We use Brennan and Schwartz's basic methodology to value a firm's proven and probable reserves. The valuations depend on the six well-known option price parameters for commodity options: the metal spot price, the volatility of the metal, the net convenience yield (convenience yield less storage costs), the risk-free rate, the strike price of the option, and the option maturity. Spot and forward prices are obtained from COMEX and the London Metal Exchange (LME) to estimate a metal's net convenience yield. The metal price volatility is based on historical spot prices using a 3-month window. The yield on US

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[15] See Graham, Dodd and Cottle (1962), Boatsman and Baskin (1981), and Alford (1992).

[16] Papers that have adopted the real option framework for valuing natural resources include Siegel, Smith and Paddock (1987), Trigeorgis (1990), Kemna (1993), and Smith and McCardle (1997).

Treasury securities is used as the risk-free rate. The option strike price (unit extraction costs and development costs), and the option maturity (expected remaining mine life) are estimated based on information contained in firms' annual reports and 10-K statements. Appendix D describes these estimation procedures in detail.

Most mining takes place sequentially. While this is obvious for open-pit mining, it is also common in underground mining. For example, Appendix A depicts the projected production and development schedule at the Oronorte Mine (Greenstone Resources) as of 1992. Furthermore, mine extraction rates appear to be relatively stable over time unless the production capacity is increased or a mine experiences unexpected operational problems. To account for the sequential nature of mining, we value reserves as a portfolio of European call options with maturities ranging from one year to the expected mine life. We assume a constant production rate under which a mine maintains its current annual production level until the exhaustion of the deposit.

For example, if a deposit contains 1,000,000 ounces of gold, of which 100,000 ounces are extracted annually, we assume the following portfolio of options to value this deposit.

Option No.	Quantity (ounces)	Maturity	Option Value
1	100,000	1 Year	\$5.6 million
2	100,000	2 Years	\$6.2 million
3	100,000	3 Years	\$6.8 million
⋮	⋮	⋮	⋮
10	100,000	10 Years	\$9.4 million
Total	1,000,000		\$77.8 million

The option values assume a current gold spot price of US\$300/oz, unit extraction and development costs of US\$250/oz, a net convenience yield of 2%, a risk-free interest rate of 5%, and a gold price volatility of 8% p.a.

Each option is valued using the Black and Scholes (1973) option-pricing model.[17] Reserve estimates are usually reported as 'contained' metal, which is more that what can be economically recovered. We therefore multiply the reported reserve figures by the expected recovery rate to obtain the amount of recoverable metal of a mine. Recovery rates range from 23-100% and average at about 85% in the sample. If several companies own a deposit we split the value of the deposit among the owners according to their fractional ownerships. Only 'permitted' reserves, reserves for which a mining permit has already been obtained are considered for valuation.

Proven and probable reserves are associated either with mines in the production or development stage. The major difference between these two stages is that the major extraction and processing facilities are already in place at producing mines while they are still under construction at development projects. We value the reserves associated with mines in both stages similarly, except that we deduct the initial development costs from the value of reserves associated with development projects. We aggregate the reserve values at producing and development properties due to the small number of development project in the sample. If a company operates several mines, we aggregate mine-level values to estimate the real option value of all of the firm's proven and probable reserves.

[17] Alternatively, one could value a mineral reserve as an American call option. This procedure would assume that the entire reserve could be extracted at any time until the end of the expected mine life. This is technologically infeasible, and would thus overstate the true value of the reserves. However, to test the robustness of our results with respect to the valuation technique, we perform all tests using both valuation techniques. The correlation between American and European reserve values is about 0.85. American option values tend to be 10-30 percent larger than their European counterparts. None of our results depend materially on any specific valuation technique, however.

4.2 *Valuation of Mineral Resources*

Mineral deposits for which the economic feasibility of extraction has not yet been established are classified as resources. Further exploration work is necessary to classify them as a reserve. The valuation of resources is more difficult, however, because of a lack of information. For example, little is known about the number of test drillings necessary to define the deposit as a reserve, the length of the process, and the fraction of resources that eventually will be reclassified as a reserve. Furthermore, the future processing technology and production capacity and hence the expected mine life may not be known. Even management may not have this information at this point. The only publicly available information is the size of the resource, the average metal concentration in the ground (metal grade), and whether extraction would require an open-pit or underground mine. This information does not allow us to use real option valuation techniques to value resources. Instead we use the Hotelling valuation principle to estimate the value of resources. According to this method, the value of a metal resource is determined by the current metal price less the expected extraction costs less the expected development costs, multiplied by the resource size.[18] This technique is similar to the Black and Scholes model but ignores the time value of money.

4.3 *Control variables*

We include several control variables in our analysis because as we argued in Section 3 the growth opportunity proxies are also affected by profitability, diversification, and

[18] The expected extraction cost for gold resources is based on the regression model reported in Appendix C (assuming the industry median extraction rate of 14 percent). For non-gold resources we rely on the industry average cash cost for a particular metal. The mine development costs are assumed to equal the average development costs, which we estimate from 42 development projects during the 1989-1996 period. Summary statistics on development costs are also provided in Appendix C.

leverage. Following Graham and Rogers (1999), we measure profitability by the return on assets (ROA), defined by the ratio of earnings before interest and taxes (EBIT) over the book value of assets. We construct two measures of diversification: the Herfindahl index based on production values of different metals, and the Herfindahl index based on firms' assets in different industry segments. Leverage is defined as long-term debt over long-term debt plus market value of equity.

We also include the ratio of total exploration expenditures (expensed and capitalized) to assets in the analysis because exploration activities may affect firm value and hence the growth opportunity proxies. Since this variable does not necessarily reflect the value added by exploration activities but merely proxies for them we use it as a control variable only. Finally, we control for size, although the existing literature is ambiguous on the relation between size and growth opportunities. The argument for including size in q regressions rests on supposedly greater efficiency of larger firms (see Peltzman (1977)). Gaver and Gaver (1993) find that size and growth opportunities are positively related. However, Baker (1993) criticizes these results and regards the positive correlation as a sign that the traditional measures of growth opportunities are questionable. Size is measured as the log of the book value of assets. Table 1 summarizes the construction of variables used in the study.

5. Results

5.1 Univariate results

Table 2 reports descriptive statistics on the book and market values of assets, the two real option measures (value of reserves and resources), the three growth opportunity proxies, and the control variables. The data show that the mining industry consists of a few large firms and many small producers. The average book value of assets is about $500 million, while the median is only about $100 million. The distribution of the market value of assets is similarly skewed.

The distribution of the total value of reserves is similar to that of the book and market values of assets: the mean and median are $616 million and $82 million respectively. More than half the firms in our sample do not own or do not report resources. The average value of resources is $19 million while the median is 0. Thus, reserves contribute significantly more to the value of growth opportunities than resources. Note that the difference between the market and book values of assets, which is a proxy for the market's estimation of the value of growth opportunities, is smaller than the real option values. This difference suggests either that we overestimate the value of growth opportunities or that the market undervalues them. For example, if agency problems or capital market imperfections prevent a firm from optimally exercising its growth options, then we would expect the real option values, which assume optimal exercise, to exceed market valuations. In fact, we show in the last section of the paper that the market value of growth opportunities of financially constrained firms is significantly lower than that of unconstrained firms.

Two points emerge from the descriptive statistics of the growth opportunity proxy variables. First, although we focus on a single industry, there is substantial variation in the three proxies for growth opportunities. For example, the 10^{th} percentile of the market-to-book assets ratio in our sample has a value of 0.91 while the 90^{th} percentile has a value of 3.44. Second, the sample distribution of the growth opportunity proxies in the mining industry is similar to that of a broader industry segment. For example, we estimate the 10^{th}, 50^{th}, and 90^{th}

percentiles for all non-financial and non-utility firms from the Compustat universe to be 0.88, 1.48, and 4.12 respectively. Hence, in terms of growth opportunities our sample of mining firms is comparable to a random sample drawn from the non-financial, non-utility sector.

Table 2 also provides descriptive statistics for the control variables used in the multivariate analysis. Mining firms differ from non-mining firms along two dimensions. First, mining firms are highly focused. The Herfindahl index based on industry segment assets has a mean value of 0.96 and a median of 1. We exclude this Herfindahl index from the multivariate analysis since there is too little variation in this variable. In contrast, the distribution of the Herfindahl index based on metal sales is broader - ranging from 0.46 to 1. Second, mining firms have less debt in their capital structure than firms in non-mining industries. The median leverage ratio is only 12%.

Table 3 reports correlation coefficients between the growth opportunity proxies, the real option measures, and firm size. The negative correlation between size and the MBA is consistent with the widespread view that high growth firms are typically small firms. This notion, however, is not supported by either the MBE or the E/P ratio. Both show the 'wrong' relation to firm size.

All three proxies are significantly correlated with each other. The correlation coefficient between the MBA and the MBE is 0.7. Consistent with the E/P ratio being an inverse measure of growth opportunities, the two market-to-book ratios are negatively correlated with the E/P ratio.

While the real option values of reserves are correlated with all three growth opportunity proxies, the correlation is strongest with the MBA (0.283). Resources appear to be uncorrelated to any of the proxy variables.[19] We also report the correlation coefficients between the proxy variables and exploration expenditures, which we use as a control variable. However, no statistically significant correlations could be detected. Finally, the correlations among the real option measures are statistically insignificant, suggesting that regression specifications do not suffer from a multicollinearity problem.

5.2 *Multivariate Results*

To determine how a particular proxy variable is related to the growth opportunity measures we regress each proxy separately on the two real option measures and several control variables. For each proxy variable, we estimate three regressions: a baseline regression that only includes the real option measures and two further specifications that include additional control variables. We also estimate all regression specifications by including year dummies and on a year-by-year basis. The results are qualitatively similar to those we report below.

The results, presented in Table 4, show that the MBA is significantly positively related to both the value of reserves and resources. This relation is robust even after we control for exploration expenditures, firm size, profitability, diversification, and leverage. In contrast, the market-to-book equity ratio is only weakly related to the value reserves, and the positive relation disappears once the regression is controlled for by leverage. It is also disconcerting that the coefficient on the exploration expenditure variable in Regressions 5 & 6 has the

[19] To examine the robustness of these results, we divide our sample into high and low growth opportunity firms based on the median values of developed reserves, undeveloped reserves and resources. We then test whether growth opportunity proxies differ across high and low growth opportunity firms. The results from these tests are consistent with the tests of correlation coefficients and are therefore not reported.

wrong sign. The earnings-price ratio is, as expected, negatively related to the value of reserves and resources, but the significance with respect to resources disappears as control variables are added to the baseline specification.

The overall comparison of the results leads us to conclude that the MBE is the worst proxy of growth opportunities in our sample. With respect to reserves both the MBA and the E/P ratio perform equally well, but with respect to resources the MBA dominates the E/P ratio as a proxy for growth opportunities. [20] Note, however, that the growth opportunity proxies are also affected by several control variables, such as size, diversification and leverage which diminishes their general usefulness as proxy variables. In order to obtain an unambiguous performance ranking for the three proxy variables the following section determines the relative and incremental information contents of each proxy with respect to reserves.

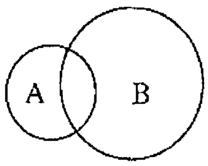
5.3 The Relative and Incremental Information Content

This section examines which proxy variable contains most information about a firm's growth opportunities, and whether any one proxy contains information that the other proxies do not. More specifically, we determine the relative and incremental information contents of each proxy with respect to the value of reserves. Relative comparisons are useful in determining which measure has the greatest information content of all measures. They are applicable when making mutually exclusive choices among alternatives. Incremental

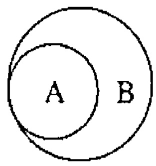
[20] To examine whether the differences in the results between the market-to-book ratios and the earning-price ratio are driven by different sample sizes, we re-estimate the MBA and the MBE regressions for the sub-sample of firms with positive earnings. We find qualitatively no differences in the results and therefore do not report them separately.

comparisons are useful in determining if one measure provides information beyond that provided by another. They apply when one measure is given and the inclusion of another measure is considered. For example, the relation between two proxy variables A and B with respect to their information contents can be as follows.

Case I



Case II



In both cases, B has greater *relative* information content than A. In Case I, A has *incremental* information content beyond B, whereas in Case II it does not. In the latter case it is sufficient to use only one proxy, i.e. the variable with the highest relative information content, whereas in Case I both proxies should be used. Case I also illustrates that extracting a common factor from A and B would reduce the total information content and hence is not useful in this situation.

To establish which proxy has the highest relative information content, we employ the method developed by Biddle, Seow and Siegel (1995). This test involves running the following reverse regressions of the investment opportunity measure on the three proxy variables.

$$\begin{aligned} \text{Value of reserves} &= \alpha_1 + \beta_1 \text{MBA} + \varepsilon \\ \text{Value of reserves} &= \alpha_2 + \beta_2 \text{MBE} + \varepsilon \\ \text{Value of reserves} &= \alpha_3 + \beta_3 \text{E/P-ratio} + \varepsilon \end{aligned} \qquad (3)$$

The proxy variable that yields the highest R^2 contains the highest information content relative to the other proxies. A Wald test is used to identify whether differences in the R^2s from these regressions are statistically significant. The incremental information content of each proxy is determined by estimating a regression that contains all proxy variables as explanatory variables, and performing a standard F-test on the null hypothesis that the slope coefficients equals zero.

Table 5 summarizes the results. Regressions 1-3 indicate that although all proxy variables are informative with respect to the value of reserves the MBA has the highest information content *relative* to the other two proxy variables. The results from the subsample of firms with positive earnings (Panel A) show that the MBA can explain 35 percent of the variation in the value of reserves, whereas the MBE and the E/P ratio can explain only 8 percent and 3 percent of the variation respectively. The Wald tests show that the R^2 of Regression 1 (0.35) is significantly different from the R^2s of Regressions 2 and 3, while the R^2s of Regressions 2 and 3 do not differ statistically from each other. Panel B repeats the analysis for the full sample that includes firms with positive and negative earnings. Since a negative E/P ratio is not a meaningful measure of growth opportunities it is excluded from the analysis. In the full sample, the MBA explains 8% of the variation in the value of reserves while the MBE explains only 2%. This difference is statistically significant at the 5.8% level.

Finally, Regressions 4 and 7 show that only the MBA is incremental, i.e. neither the MBE nor the E/P ratio contains information beyond the information contained in the MBA. The significant coefficient on the MBE has the wrong sign and should therefore not be interpreted as an indication of incremental information content.

In summary, the results show that the MBA has the highest relative information content with respect to firms' growth opportunities. Furthermore, neither the MBE nor the E/P ratio has incremental information content beyond that provided by the MBA. We therefore conclude that the market-to-book ratio of assets is the best among the three proxies for growth opportunities that we examined in this study.

5.4 Financing constraints and the value of growth opportunities

The previous analysis assumed that the value of investment opportunities is independent of who owns them. In particular, we assumed that all firms are able to exercise their growth options optimally. However, a firm that is financially constrained may find it relatively more costly to exercise its growth options than a firm that is not. In such case some options may not be exercised at all or at the optimal time. If it is costly to transfer the ownership of the option then such financial constraints can persist. Since information asymmetries are commonplace in the mining industry the cost of transfer of ownership of mines could be substantial.

In this section, we examine whether the proxy variables are less correlated with growth opportunities of financially constrained firms than of unconstrained firms. To test this hypothesis we re-estimate the baseline regressions reported in Table 4, but this time allow for different slope coefficients on the real option measures for constrained and unconstrained firms.

There is no commonly accepted way to divide a sample into financially constrained and unconstrained firms. Several different variables have been used in the past to proxy for financial constraints. Fazzari, Hubbard, and Petersen (1988) argue that dividend-paying firms are less likely to face financial constraints than firms that do not pay dividends. Calomiris, Himmelberg and Wachtel (1995), Kashyap, Lamont and Stein (1994), and Whited (1992) use the absence of a bond rating to identify financially constrained firms. They argue that firms with no bond ratings have more information asymmetries and therefore find external financing more costly. Gertler and Gilchrist (1994) and Himmelberg and Petersen (1994) argue that small firms are more likely to face financial constraints because they are typically younger, less well known, and therefore more subject to capital market imperfections. Instead of arbitrarily selecting any one of these approaches we report the results for the following five definitions of financially constrained and unconstrained firms. A firm is financially constrained (i) if it does not have a bond rating, (ii) if the book value of its assets is less than \$107 million (the sample median) or (iii) less than \$31 million (the 25^{th} percentile), (iv) if it pays no dividends, and (v) if it has no bond rating, does not pay dividends, and if its book value of assets is less than that of the median firm in the sample. For each of these cases we construct a financial constraints dummy variable that takes a value of 1 if a firm is financially constrained and 0 otherwise.

Table 6 summarizes the results, which are consistent across all definitions of financial constraints.[21] The regression coefficients on both the value of reserves and its interaction with the financial constraints dummy have the opposite sign and are statistically significant. Allowing for different slope coefficients for financially constrained and unconstrained firms substantially increases the R^2 and hence the fit in three of the five regressions. We therefore conclude that the proxies significantly understate the value of growth opportunities for firms that are financially constrained.

[21] Since the previous results showed that the MBA is the best proxy we focus the discussion on this variable.

An alternative explanation of the results is that financially constrained firms perhaps overstate the size of their reserves. However, misreporting by firms is significantly constrained by SEC regulations that provide a rigid framework for the reporting of mineral reserves. Moreover, the discounts are large relative to any possible misreporting by firms. Thus, the possible overstating of reserves cannot explain the entire discount.

The results show that the investment opportunity proxies are affected by both investment opportunities and by financial constraints. These relations will bias results of studies in which growth opportunity proxies are used as a measure of investment opportunities only. Since the use of growth opportunity proxies is widespread in the empirical literature future research should examine the extent and economic significance of this bias.

Conclusions

Despite the important role that growth opportunities play in the corporate finance literature, there is no consensus on how to measure the value of a firm's investment opportunity set. The problem is that firms' growth opportunities are generally unobservable to outsiders. Researchers are therefore forced to rely on proxy variables, but little is known about the performance of these proxies. The metal mining industry, in which growth opportunities are relatively well defined and transparent, represents an exception. In this paper, we estimate the value of growth opportunities of metal mining firms using a real options approach, and compare these measures with the three most commonly used growth opportunity proxy variables.

The results show that the MBA is the most suitable variable to proxy for a firm's investment opportunities. It is positively correlated with all growth opportunities that we consider, and bears the highest information content of all proxies. These correlations are robust after controlling for exploration expenditures, firm size, diversification, profitability, and leverage only for the market-to-book assets ratio and the earnings-price ratio. In contrast, the market-to-book equity ratio appears as a rather poor measure of growth opportunities. Its relation to growth opportunities is weak and not robust. Finally, the earnings-price ratio is related to growth opportunities. However, it does not contain information that is not already reflected in the market-to-book assets ratio.

Our results further show that the market-to-book assets ratio significantly understates the value of the investment opportunity set of financially constrained firms. This finding suggests that some firms may not be able to exercise all their growth options optimally because of their limited access to capital.

While we use the mining industry for our experimental setup, we believe that our findings are relevant to studies that focus on non-mining sectors. First, in terms of growth opportunities our sample of mining firms is similar to a random sample drawn from the non-financial and non-utility sector. Second, corporate financial decisions are affected by the *value* of growth opportunities not by their *type* or structure. Growth options in non-mining industries may be of different nature, even more complex, than growth options in the mining industry, and hence may require different valuation techniques. But, once the options are properly valued, the empirical relations between real option values and proxies should be similar in mining and non-mining industries.

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Table 1: Variables definitions and data sources

Variable	Construction	Data-sources
Panel A: Growth opportunity proxies		
Market-to-book assets ratio	Market value of assets divided by book value of assets. Market value of assets equals market value of equity plus book value of preferred stock and debt.	*Compustat*
Market-to-book equity ratio	Market value of equity divided by book value of equity. Negative values are treated as missing.	*Compustat*
Earnings-price ratio	Earnings before interest and taxes (EBIT) per share divided by share price at fiscal year end. Negative values are treated as missing.	*Compustat*
Panel B: Growth opportunity measures		
Value of mineral reserves	Real option value of all proven & probable reserves. Data: Spot prices, forward rates, risk-free rate, metal reserves, production and development costs, recovery rates, metal grades, mining technology, annual metal production, production months, and mine lives.	*Datastream*, annual reports and forms 10-K.
Value of mineral resources	Hotelling value of any mineral deposit that is not classified as either proven or probable reserves. Data: Spot price of extracted metal, information on metal resources, grades and mine-type.	*Datastream*, annual reports and forms 10-K.
Panel C: Control variables		
Profitability	Book return on assets (ROA)	*Compustat*
Herfindahl index based on metal production	Defined by $\sum_{i=1}^{N}\left(\frac{s_i}{s}\right)^2$, where s_i is the revenue contribution of each metal (estimated as metal production × spot price), and s is the total metal sales for the year. N is the total number of metals produced by the firm.	Spot prices of metals are from *Datastream*. Annual metal production figures are from annual reports. Total firm sales are from *Compustat*.

Panel C cont.: Control variables		
Variable	Construction	Data-sources
Herfindahl index based on asset industry segments	Defined by $\sum_{i=1}^{N}\left(\frac{q_i}{q}\right)^2$, where q_i is the book value of each asset segment and q is the total book value of assets. N is the total number of industry segments.	Segment data from *Compustat*
Leverage	Leverage is calculated by (long term debt)/(long term debt + book value of equity).	*Compustat*
Firm-size	Natural logarithm of book value of assets	*Compustat*
Exploration expenditures	Capitalized and expensed exploration expenditures divided by book value of assets	Annual reports and forms 10-K

Table 2: Descriptive statistics

This table presents descriptive statistics on growth opportunity proxies, real option values and other firm characteristics for a sample of 90 mining firms, 1989-96. The market-to-book assets ratio is defined as the ratio of market value of assets to book value of assets, where the market value of assets is the sum of the market value of equity and book values of debt and preferred stock. The market-to-book equity is defined as the ratio of market value of equity and book value of equity. The earnings-price ratio is defined as the ratio of earnings per share to stock price at fiscal year end. The value of developed and undeveloped reserves is estimated assuming a fixed production/development schedule using the B&S option-pricing model. The value of resources is estimated as resource size × (spot price - estimated extraction cost - estimated development costs). Diversification is measured by Herfindahl indices calculated as $\sum_{i=1}^{N}\left(\frac{s_i}{s}\right)^2$, where s_i is metal-sales (or segment assets), s is total sales (or book value of assets), and N is the total number of metals (or industry segments). Leverage is calculated by book value of long-term debt over the sum of the book values of long-term debt and equity. Nominal figures are converted into real figures using a GDP deflator (Source: Budget of the United States Government website, http://w3.access.gpo.gov/usbudget/fy2001/sheets/hist10z1.xls).

	10%ile	Median	Mean	90%ile	N
Book value of assets (in million of 1996 dollars)	10	107	496	1,464	449
Market value of assets (in millions of 1996 dollars)	15	145	871	2,635	449
Value of reserves (in millions of 1996 dollars)	0	82	616	1,996	449
Value of resources (in millions of 1996 dollars)	0	0	19	18	449
Market-to-book assets ratio	0.91	1.57	1.96	3.44	449
Market-to-book equity ratio	0.82	1.88	2.64	5.12	417
Earnings-price ratio	.0.01	0.03	0.04	0.09	204
Profitability (ROA)	-0.34	-0.02	-0.12	0.08	447
Herfindahl index - based on metal production	0.46	0.95	0.84	1.00	388
Herfindahl index - based on industry segment assets	0.85	1	0.96	1	424
Leverage	0.00	0.12	0.18	0.47	449
Exploration expenditures / book value of assets	0.00	0.02	0.06	0.15	449

Table 3: Spearman rank correlations between size, growth opportunity proxies and real option measures.

Please refer to Table 1 for the description and construction of variables. MBA, MBE, and E/P ratio stand for the market-to-book assets ratio, the market-to-book equity ratio, and the earnings-price ratio respectively. Log(book value of assets) is the natural logarithm of the real book value of assets in 1996 dollars. Correlation coefficients that are significantly different from zero are shown in bold face. p-values are recorded in parentheses.

	Growth opportunity proxies			*Real option measures*		*Control variable*
	MBA	MBE	E/P ratio	Value of reserves/assets	Value of resources/assets	Exploration expenditures/assets
Size:						
Log (book value of assets)	**-0.081** (0.085)	**0.112** (0.023)	**-0.216** (0.002)	**0.168** (0.000)	-0.013 (0.786)	-0.013 (0.791)
Growth opportunity proxies:						
MBA		**0.700** (0.000)	**-0.203** (0.004)	**0.283** (0.000)	0.075 (0.111)	-0.018 (0.703)
MBE			**-0.182** (0.009)	**0.142** (0.004)	-0.002 (0.965)	-0.058 (0.235)
E/P ratio				**-0.186** (0.008)	-0.096 (0.174)	-0.074 (0.294)
Real option measures:						
Value of reserves/assets					-0.012 (0.806)	-0.040 (0.402)
Value of resources/assets						-0.063 (0.186)

Table 4: The relation between growth opportunities and its proxy variables

This table presents ordinary least squares regressions of growth opportunity proxies on the two real option measures, exploration expenditures, and control variables. Please refer to Table 1 for the description and construction of variables. Figures in parenthesis denote t-statistics based on White-adjusted standard errors.

	Market-to-book assets ratio			Market-to-book equity ratio			Earnings-price ratio		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Intercept	1.68*** (20.69)	2.07*** (10.31)	0.99*** (3.34)	2.54*** (11.85)	2.86*** (4.10)	3.11** (2.49)	0.05*** (9.18)	0.09*** (5.07)	0.06* (1.95)
Value of reserves/assets	0.24*** (3.60)	0.26*** (3.70)	0.23*** (2.95)	0.20* (1.77)	0.21* (1.79)	0.17 (1.25)	-0.01*** (-2.91)	-0.01*** (-2.70)	-0.01*** (-3.24)
Value of resources/assets	0.46** (2.41)	0.46** (2.51)	0.57** (2.48)	-0.40 (-0.75)	-0.47 (-0.82)	-0.92 (-1.63)	-0.04** (-2.48)	-0.03** (-2.21)	0.00 (0.11)
Exploration expenditures/assets		-0.03 (-0.08)	-0.20 (-0.53)		-1.89** (-2.37)	-3.35*** (-2.71)		-0.05** (-2.24)	-0.03 (-1.38)
Log (book value of assets)		-0.09** (-2.47)	0.04 (1.14)		-0.04 (-0.33)	0.13 (0.70)		-0.01** (-2.38)	-0.01** (-2.07)
Profitability (ROA)			-0.26** (-2.12)			-1.08 (-1.06)			0.42*** (4.98)
Herfindahl index - based on metal production			0.60*** (2.63)			-0.42 (-0.68)			-0.01 (-0.23)
Leverage			-0.69* (-1.73)			-4.41*** (-5.25)			0.12** (2.50)
N	449	449	387	420	420	360	204	204	195
Adjusted R^2	0.09	0.10	0.18	0.01	0.01	0.07	0.04	0.09	0.46

***Significant at the 1% level. **Significant at the 5% level. *Significant at the 10% level.

Table 5: Relative and incremental information contents

This analysis determines the relative and incremental information contents of each of the three proxies with respect to the value of reserves. The table presents ordinary least squares estimates of the following general regression model.

$$\text{Value of reserves} = \alpha + \sum_{i=1}^{3} \beta_i \text{Proxy}_i + \varepsilon .$$

We distinguish between firms with positive and negative earnings in Panel A and B because the E/P ratio is a valid proxy only if earnings are positive. t-statistics are given in parentheses.

Tests of relative information contents are based on Regressions 1-3 and 5-6. Biddle, Seow and Siegel (1995) developed a test that identifies significant differences between the R^2s from a pair of regressions. P-values are listed in the last column. For example, the p-value of 0.058 between Regressions 5 and 6 implies that the MBA contains more information with respect to reserves than the MBE at the 5.8% level.

No.	*Intercept*	*MBA*	*MBE*	*E/P ratio*	*N*	R^2	*P-values*	
Panel A: Sample includes firms with positive earnings only								
1.	-0.03 (-0.18)	0.72*** (10.36)			201	0.35	0.0000 MBA>MBE	
2.	0.99*** (7.34)		0.14*** (4.32)		201	0.08		0.0001 MBA>E/P Ratio
3.	1.65*** (12.56)			-5.78*** (-2.78)	201	0.03	0.5137 MBE=E/P Ratio	
4.	0.08 (0.41)	0.86*** (9.28)	-0.10*** (-2.65)	-2.47 (-1.44)	201	0.38		
Panel B: Sample includes firms with positive and negative earnings (full sample)								
5.	0.44*** (3.43)	0.37*** (6.29)			416	0.08	0.058 MBA>MBE	
6.	0.93*** (9.34)		0.08*** (3.91)		416	0.02		
7.	0.42*** (3.24)	0.48*** (5.87)	-0.07* (-1.94)		416	0.09		

***Denotes significant at the 1% level. *Denotes significant at the 10% level.

Table 6: Financial constraints and the value of growth opportunities

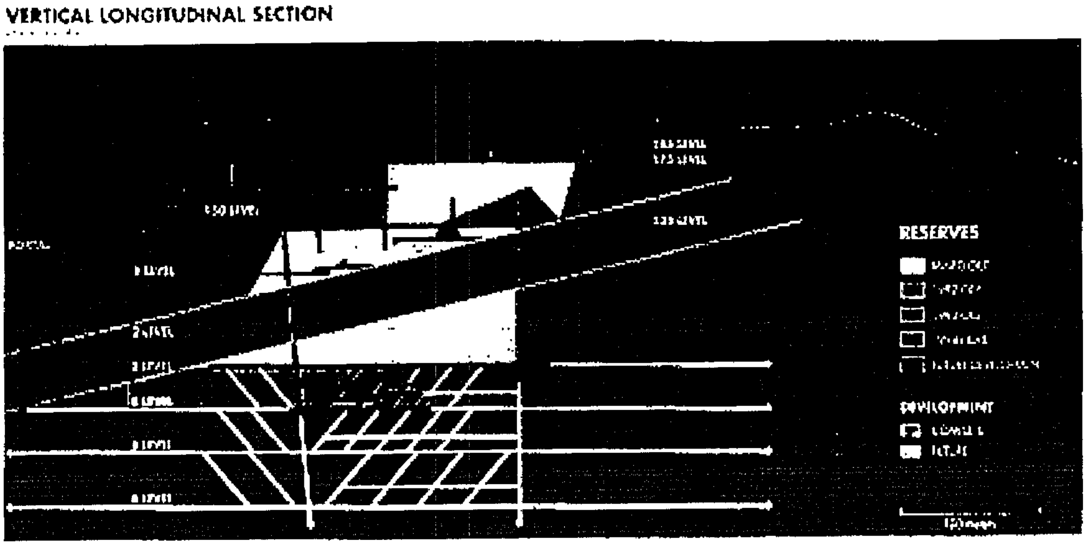
This table presents the results of re-estimating Regression 2 from Table 4, but this time allowing for different slope coefficients on the value of reserves and resources for financially constrained and unconstrained firms. We report the results for five different definitions of financially constrained and unconstrained firms. A firm is financially constrained (i) if it does not have a bond rating, (ii) if the book value of its assets is less than $107 million (the sample median or (iii) $31 million (the 25th percentile), (iv) if it pays no dividends, and (v) if it has no bond rating, does not pay dividends, and if its book value of assets is less than that of the median firm in the sample. For each of these cases we construct a financial constraints dummy that takes a value of 1 if a firm is financially constrained and 0 otherwise. In all cases the MBA is the dependent variable. Please refer to Table 1 for the description and construction of variables. t-statistics based on White-adjusted standard errors are reported in parentheses.

Division into financially constrained and unconstrained firms by	Existence of debt rating	Median book value of assets (size)	Payment of dividends	Rating, dividends & size	Lower quartile of book value of assets
Number of firms classified as financially constrained	380 firms	224 firms	270 firms	207 firms	112 firms
Intercept	2.18***	2.30***	2.37***	1.98***	1.15***
	(7.11)	(5.79)	(7.88)	(5.67)	(4.48)
Financial constraint dummy	-0.02	0.23	0.15	0.37*	0.95***
	(-0.09)	(1.10)	(1.00)	(1.94)	(4.38)
Value of reserves/assets	0.45***	0.61***	0.59***	0.55***	0.37***
	(5.56)	(7.64)	(6.97)	(6.66)	(4.81)
Value of reserves/asset × Financial constraint dummy	-0.20*	-0.58***	-0.56***	-0.52***	-0.28**
	(-1.85)	(-5.92)	(-5.48)	(-5.04)	(-2.19)
Value of resources/assets	1.15	0.88**	1.20***	0.29	0.27
	(1.37)	(2.08)	(2.61)	(0.63)	(0.84)
Value of resources/assets × Financial constraint dummy	-0.73	-0.60	-0.81*	0.11	0.25
	(-0.85)	(-1.23)	(1.65)	(0.22)	(0.76)
Exploration expenditures/assets	0.04	0.34	0.12	0.23	0.42
	(0.09)	(0.71)	(0.27)	(0.47)	(0.93)
Log(book value of assets)	-0.11***	-0.19***	-0.19***	-0.13**	0.03
	(-2.67)	(-3.03)	(-4.14)	(-2.37)	(0.84)
N	449	449	446	449	449
Adjusted R^2	0.11	0.23	0.24	0.11	0.16

***Significant at the 1% level. **Significant at the 5% level. *Significant at the 10% level.

Appendix A

Production and Development Schedule at the Oronorte Mine as of December 1992



This figure, taken from the 1992 annual report of Greenstone Resources Ltd., shows the projected mining sequence for the years 1992, 1993, 1994 and beyond at the Oronorte Mine in Colombia. The initial development of this mine began in 1989. The figure demonstrates that the initial development of a mine does not make the entire ore body accessible for extraction. Instead, a firm must continuously develop further/deeper partitions of the ore body to extract the entire mineral reserve. The figure also shows that even in underground mining there exists a mining plan that specifies a particular extraction sequence.

Appendix B
Metal Mining Firms in the Sample

1. Agnico-Eagle Mines Ltd.
2. Alaska Gold Co.
3. Alta Gold Co.
4. Amax Gold Inc.
5. American Eagle Resources Inc.
6. American Resource Corp. Inc.
7. Atlas Corp.
8. Audrey Resources Inc.
9. Aur Resources Inc.
10. Barrick Gold Corp.
11. Battle Mountain Gold
12. Belmoral Mines Ltd.
13. Bema Gold Corp.
14. Bethlehem Resources Corp.
15. Breakwater Resources Ltd.
16. Caledonia Mining Corp.
17. Cambior Inc.
18. Campbell Resources Inc.
19. Caprock Corp.
20. Casmyn Corp.
21. Clayton Sliver Mines Inc.
22. Coca Mines Inc.
23. Coeur D'alene Mines Corp.
24. Cominco Ltd.
25. Consolidated Golden Quail Resources Ltd.
26. Cornucopia Resources Ltd.
27. Crested Corp.
28. Curragh Inc.
29. Cusac Gold Mines Ltd.
30. Cyprus Amax Minerals Co.
31. Dakota Mining Corp.
32. Dayton Mining Corp.
33. Dickenson Mines Ltd.
34. Echo Bay Mines Ltd.
35. Equinox Resources Ltd.
36. Freeport-McMoran Copper & Gold Inc.
37. Galactic Resources Ltd.
38. GEXA Gold Corp.
39. Giant Yellowknife Mines Ltd.
40. Goldcorp Inc.
41. Golden Cycle Gold Corp.
42. Golden Knight Resources Inc.
43. Golden Star Resources Ltd.
44. Great Basin Gold Ltd.
45. Greenstone Resources Ltd.
46. Hanover Gold Co.
47. Hecla Mining Co.
48. Homestake Mining Co.
49. Inmet Mining Corp.
50. International Corona
51. Kinross Gold Corp.
52. KWG Resources Inc.
53. La Teko Resources Ltd.
54. Lac Minerals Ltd.
55. MK Gold Co.
56. Meridian Gold Inc. (FMC Gold Co.)
57. Miramar Mining Corp.
58. Newmont Gold Co.
59. Newmont Mining Corp.
60. North American Metals Corp.
61. North Lily Mining Co.
62. Northgate Exploration Ltd.
63. Northwest Gold Corp.
64. Pan American Silver Corp.
65. Pegasus Gold Inc.
66. Piedmont Mining Co., Inc.
67. Placer Dome Inc.
68. Prime Resources Group Inc.
69. Rea Gold Corp.
70. Rayrock Yellowknife Resources Inc.
71. Real Del Monte Mining (Consol. Nevada)
72. Royal Oak Mines Inc.
73. Santa Fe Pacific Gold Corp.
74. Silverado Gold Mines Ltd.
75. Siskon Gold Corp.
76. Sonora Gold Corp.
77. Southern Peru Copper Corp.
78. Sunshine Mining & Refining Co.
79. TVX Gold Inc.
80. Teck Corp.
81. Terra Mines Ltd.
82. USMX Inc.
83. U.S. Precious Metal Inc.
84. Vanderbilt Gold Corp.
85. Viceroy Resources Corp.
86. Vista Gold Corp. (Granges)
87. Westmin Resources Ltd.
88. Wharf Resources Ltd.
89. William Resources Inc.
90. Yuba Westgold Inc.

Appendix C

Descriptive Statistics for North American Mines Producing Selected Metals, 1989-1996.

Metal price volatility is the standard deviation of the metal price, and calculated from historical daily spot prices over a 90-day window. The net convenience yield (q) is estimated using the following pricing function: forward price = spot price × $e^{(r-q)T}$ where r is the risk free rate and T is the maturity of the contract. Metal price is the spot price of extracted metal as of the fiscal year end. Cash costs are the total cash costs incurred in extracting a unit of metal. Total production costs equal cash costs + non-cash costs including depreciation, amortization, and depletion. Development costs is the difference between total production costs and cash costs. Metal reserves are a firm's estimated proven and probable reserves. Metal resources are mineral deposits that are not classified as either proven or probable reserves. Annual production is the amount of metal produced per year. Mine life is the expected number of years required to deplete the proven and probable reserves given the current extraction rate. When mine life is not given in the annual reports, we estimate it as the ratio of reserves over annual production.

	Mean	Median	10%	90%	Standard Deviation
Panel A: Copper (242 mine-years)					
Metal Price Volatility	0.24	0.24	0.15	0.37	0.07
Net Convenience Yield	0.19	0.24	0.08	0.32	0.10
Metal Price (US$/t)	2437.50	2302.79	1815.08	3044.86	373.50
Cash Cost (US$/t)	1191.70	1084.99	370.44	2315.25	631.49
Total Production Cost (US$/t)	1679.77	1697.85	877.59	2513.70	592.45
Development costs (US$/t)	321.70	224.91	110.25	639.45	204.81
Metal Reserve (000t)	1100.55	244.12	0.00	2451.60	2423.83
Metal Resource (000t)	477.19	160.00	0.00	1192.88	843.44
Annual Production (000t)	26.38	0.00	0.00	83.20	64.17
Expected Mine Life (years)	17.08	14.55	7.30	29.57	12.76
Panel B: Gold (1768 mine-years)					
Metal Price Volatility	0.09	0.08	0.05	0.16	0.04
Net Convenience Yield	0.01	0.01	-0.01	0.04	0.02
Metal Price (US$/oz)	375.93	382.75	333.05	401.00	20.72
Cash Cost (US$/oz)	253.89	240.00	164.00	356.00	83.36
Total Production Cost (US$/oz)	335.43	321.00	230.00	444.00	112.59
Development costs (US$/oz)	84.75	74.00	32.00	146.00	76.00
Metal Reserve (000oz)	1050.22	322.00	0.00	2504.00	2438.79
Metal Resource (000oz)	648.47	202.05	0.00	1443.00	1554.88
Annual Production (000oz)	65.64	17.30	0.00	158.59	167.11
Expected Mine Life (years)	8.67	7.61	2.00	15.45	7.73
Panel C: Lead (7 mine-years)					
Metal Price Volatility	0.26	0.25	0.17	0.34	0.05
Net Convenience Yield	-0.01	0.01	-0.05	0.01	0.04
Metal Price (US$/t)	565.04	542.59	451.93	718.37	100.46

	Mean	Median	10%	90%	Standard Deviation
Cash Cost (US$/t)	-	-	-	-	-
Total Production Cost (US$/t)	-	-	-	-	-
Metal Reserve (000t)	98.06	114.44	0.00	130.18	49.00
Metal Resource (000t)	14.60	14.60	0.00	29.20	20.65
Annual Production (000t)	25.85	28.71	10.05	33.82	9.03
Expected Mine Life (years)	4.12	3.98	3.65	4.84	0.46
Panel D: Silver (100 mine-years)					
Metal Price Volatility	0.18	0.18	0.13	0.22	0.04
Net Convenience Yield	0.05	0.04	0.00	0.14	0.04
Metal Price (US$/oz)	4.63	4.80	3.67	5.22	0.57
Cash Cost (US$/oz)	4.41	4.50	2.81	5.81	1.10
Total Production Cost(US$/oz)	5.10	5.13	3.81	6.77	1.13
Development costs (US$/oz)	1.21	1.23	0.25	2.05	0.65
Metal Reserve (000oz)	29383.81	13748.50	0.00	98999.99	36855.74
Metal Resource (000oz)	27662.63	8724.40	0.00	61667.60	41496.60
Annual Production (000oz)	1781.95	822.90	0.00	5707.70	2591.34
Expected Mine Life (years)	13.61	9.00	3.23	20.84	17.83
Panel E: Zinc (137 mine-years)					
Metal Price Volatility	0.22	0.21	0.13	0.39	0.07
Net Convenience Yield	0.06	-0.02	-0.04	0.26	0.12
Metal Price (US$/t)	1131.99	1134.50	1001.25	1336.50	113.03
Cash Cost (US$/t)	757.72	900.58	408.95	1041.67	322.06
Total Production Cost (US$/t)	857.15	997.58	489.42	1176.15	331.93
Development costs (US$/t)	99.43	97.00	80.47	134.48	21.25
Total Metal Reserve (000t)	1060.71	277.84	20.29	1881.00	2478.24
Total Metal Resource (000t)	949.72	80.75	0.00	1451.51	2726.66
Annual Production (000t)	36.50	13.35	0.00	106.96	63.20
Expected Mine Life (years)	12.35	9.61	4.00	20.38	10.86
Panel F: Nickel (4 mine-years)					
Metal Price Volatility	0.23	0.24	0.11	0.33	0.10
Net Convenience Yield	0.01	0.01	-0.01	0.06	0.03
Metal Price (US$/t)	6898.75	6757.50	5917.50	8162.50	991.37
Cash Cost (US$/t)	-	-	-	-	-
Total Production Cost (US$/t)	-	-	-	-	-
Total Metal Reserve (000t)	0.00	0.00	0.00	0.00	0.00
Total Metal Resource (000t)	52.02	7.15	6.78	187.00	89.99
Annual Production (000t)	0.00	0.00	0.00	0.00	0.00
Expected Mine Life (years)	-	-	-	-	-

Appendix D

Estimation of Initial Development Costs, Expected Mine Lives, and Unit Cash Costs

This appendix presents summary statistics on initial development costs and describes our estimation procedure for the expected mine life and the unit extraction costs. All estimations are based on information contained in firms' annual reports and 10-K statements.

D.1 Initial development costs

The initial development costs consist of investments in mining infrastructure (mineshafts, processing plants, roads) and mobile mining equipment. We collect the actual development costs of 42 mining projects that commenced production during 1989-1996. The following table summarizes the average initial development costs per unit of initial reserve.

Metal and mine-type	Number of Projects	Average Initial Development Cost
Gold - Open Pit	20	$45.66/ounce
Gold - Underground	5	$57.07/ounce
Gold - Open Pit & Underground	5	$98.66/ounce
Silver	3	$0.86/ounce
Copper	6	$373.45/tonne
Zinc	3	$102.66/tonne

These estimates are consistent with Dobra (1997) who reports average initial development costs for eight open pit gold mines of $49.52 per ounce of reserve and development costs for underground gold mines of $76.94 per ounce of reserve during 1989-90. For 24 development projects during 1991-96 he estimated average initial development costs of $50.57 per ounce of gold reserve.

D.2 Expected mine life

The expected mine life is defined as the number of years it takes a firm to extract its mineral reserves. Some companies report expected mine lives in their annual reports and 10K-statements. When this information is not available, we calculate the remaining mine life by dividing the total reserves by the current annual production implicitly assuming that production remains constant throughout the life of the mine. This procedure is consistent with reported expected mine lives. If operations were temporarily shut down and hence annual production is unexpectedly low, we divide reserves by an adjusted production figure, which reflects how much the mine would have produced during the year had it not experienced the shutdown, i.e. adjusted production = actual production / number of months of operation × 12.

If production is zero, i.e. because a mine is currently under development, we estimate the expected mine life by regressing reported mine lives on the mining technology and the reserve size. The reserve size is measured as the weight of the metal bearing rock (ore) in tones. The following table reports the estimates from mine-life regressions across all metals. Figures in parenthesis denote t-statistics.

OLS regression estimates for mine life (in years) of metal producing mines

Intercept	Open Pit Mine (dummy variable)	Underground Mine (dummy variable)	Log of ore reserves	N	Adj. R^2
-23.98*** (-19.21)	-1.45*** (-3.10)	1.86*** (-3.71)	2.18*** (28.86)	1327	0.39

***Significant at the 1% level.

Descriptive statistics (figures in years)

	Mean	Median	Std	10%	90%	N
Reported mine life	11.95	9.00	13.35	2.67	30.09	2735
Predicted mine life for reserves	9.77	9.83	4.03	4.44	16.67	2568
Predicted mine life for resources	9.19	9.22	4.10	3.89	16.21	1796

The results show that underground mines tend to have longer mine lives than open-pit mines. The expected mine life increases with the size of the ore reserve. The median predicted mine life for reserve deposits is 9.83 years, which is close to the reported median mine life of 9 years.

D.3 Unit extraction costs

SEC regulations require mining companies to disclose information about their unit extraction costs for each operating mine. There are three cost classifications: cash operating costs, total cash costs, and total production costs per unit of metal produced. Cash operating costs consist of direct mining expenses, stripping, smelting and refining expenses, and by-product credits. Total cash costs consist of cash operating costs plus royalties and production taxes. Total production costs include all cash costs plus depreciation, depletion, amortization, and projected mine closure costs. In 1996, cash operating costs accounted for about 80 percent of the total production costs. Royalties and mining taxes accounted for 3 percent, and non-cash items accounted for about 17 percent of the total costs.

We rely on reported cash costs as our primary estimate of the unit extraction costs. When mine-specific cost information is not available, which typically happens if a mine is currently under development, we use the company's estimated future cash costs, reported in annual reports, as the best estimate of the future extraction costs. When a company does not report such cost estimates, we use a regression model to estimate cash costs based on four parameters: the mining technology – open pit versus underground mining (captured by two dummy variables), the concentration of the metal in the ground (reserve grade), the size of the ore body, and the extraction rate (defined by the ratio of annual production over reserves).

The following table summarizes the regression results and provides descriptive statistics on reported and estimated costs and other regression parameters. Figures in parentheses denote t-statistics.

OLS regression estimates for cash costs (in US$/oz) of gold producing mines

Intercept	OP dummy	UG dummy	Log of metal reserves	Log of reserve grade	Extrn. rate	(Extrn. rate)^2	Prodn. Months	N	Adj-R^2
630.5 (12.1)***	2.1 (0.2)	5.0 (0.4)	-24.9 (-7.6)***	-9.9 (-2.0)**	-157.3 (-2.7)***	91.2 (1.8)*	-84.1 (-4.5)***	535	0.16

***Significant at the 1% level. **Significant at the 5% level. *Significant at the 10% level.

Descriptive statistics for gold producing mines

	Mean	Median	Std	10%	90%	N
Open-pit dummy	0.46	0.00	0.50	0.00	1.00	3849
Underground dummy	0.33	0.00	0.47	0.00	1.00	3849
Gold reserves (million oz)	6.23	0.28	81.45	0.00	5.80	2889
Reserve grade (oz/t)	0.77	0.07	4.79	0.01	0.94	2391
Extraction rate	0.20	0.12	0.24	0.03	0.48	1704
Production months	11.52	12	1.8	12	12	3849
Cash cost (US$/oz)	256	242	85	162	357	641
Predicted cash costs for reserves (US$/oz)	256.59	252.71	34.62	217.95	300.25	888
Predicted cash costs for resources (US$/oz)^	266.89	265.53	40.42	216.82	311.42	475

^The cash cost estimation for resources assumes the extraction rate to equal the industry median of 14%.

Because the sample sizes for metals other than gold are too small, cash costs are estimated only for gold reserves. For non-gold deposits, we rely on industry average cash costs reported in

Appendix C. The above table shows that about half the mines are open pit, a third are underground, and the rest are a combination of open-pit and underground mines, or the mining technology was not reported. Gold mines on average contain one million ounces of gold reserves, with grades ranging from 0.03 to 0.35 ounces per tonne of ore. The median extraction rate is 14 percent of reserves per year. Over the 1989-1996 period, cash costs averaged $253 per ounce of gold.

The regression results show that cash costs at gold producing mines are negatively related to the reserve size and the reserve grade. In addition, cash costs are non-linearly related to the extraction rate. Surprisingly, the mining technology is not a significant determinant of cash costs. We use the estimated regression coefficients to estimate cash costs for reserves and resources whenever they are missing. If, for a particular mining property, the actual extraction rate is zero because the property is currently not producing, we infer the expected extraction rate from the inverse of the expected mine life. The average predicted cash costs for gold reserves and resources are $262 and $276 respectively, which are close to the reported cash costs of $253.