THE JOURNAL OF FINANCE • VOL LIII, NO. 3 • JUNE 1998

The Determinants of Stock Price Exposure: Financial Engineering and the Gold Mining Industry

PETER TUFANO*

ABSTRACT

This paper studies the exposure of North American gold mining firms to changes in the price of gold. The average mining stock moves 2 percent for each 1 percent change in gold prices, but exposures vary considerably over time and across firms. As predicted by valuation models, gold firm exposures are significantly negatively related to the firm's hedging and diversification activities and to gold prices and gold return volatility, and are positively related to firm leverage. Simple discounted cash flow models produce useful exposure predictions but they systematically overestimate exposures, possibly due to their failure to reflect managerial flexibility.

CORPORATE MANAGERS AND INVESTORS care about the exposures firms have to interest rates, exchange rates, and commodity prices. By engaging in risk management, corporate managers believe they affect the exposures of their firms, and investors seem to pay attention to these exposures. For example, investors in gold mining stocks track how gold mining stocks perform relative to investments in bullion, and how managerial decisions—in particular, hedging decisions—affect the type of "gold play" they will get from their mining stock investments (see Brimelow (1996)). To respond to investors' concern that a firm's hedging decisions may affect exposures, the American Stock Exchange recently issued options on a new index of gold mining firms that refrain from hedging gold price exposure to "provide equity derivative investors with a 'purer' play on gold than was available" (see Hu (1996)).

This paper studies North American gold mining firms and their exposures to fluctuations in gold prices. Almost surely, the value of gold mines changes with the price of gold. In this paper, I measure the size of these exposures, analytically establish their determinants, and empirically test how observed

*Harvard Business School. I would like to thank John Campbell, Sanjiv Das, Ken Froot, John Parsons, André Perold, Mitch Petersen, Jack Porter, Paul Seguin, René Stulz, an anonymous referee, and seminar attendees at the University of Michigan, New York University, the University of Maryland, the University of Chicago, the Harvard Business School, the NBER Lunch Series, the Mineral Economics and Management Society, the Gold and Silver Institute, the Financial Management Association meetings and Charles River Associates for their comments on this work. I gratefully acknowledge the cooperation of Ted Reeve, who allowed me to use his surveys of gold mining firms' risk management activities, and research support by Jonathan Headley, B.J. Whalen, and Bhanu Narasimhan. Alberto Moel provided invaluable assistance with this project. Funding was provided by the Harvard Business School Division of Research as part of the Global Financial Systems project.

exposures correspond to analytically predicted exposures. I show how exposures are determined jointly by market characteristics such as the price of gold, relatively "exogenous" firm characteristics such as the firm's cost structure, and the financial policies of the firm such as its leverage choices and risk management policy.

The North American gold mining industry serves as an ideal laboratory for studying the determinants of exposures. Publicly traded gold mining firms produce a commodity output whose price is highly volatile. As described in a companion paper (Tufano (1996)), firms have adopted a wide range of approaches to managing their exposure to gold price risk, and these risk management strategies are well-documented. Finally, a key advantage of studying gold price exposures of gold mining firms is that the relatively "simple" structure of these firms enables one to develop explicit valuation models that predict exposures. Thus, it is possible to test how corporate risk management activities affect realized firm exposures.

This work follows in the tradition of earlier research that measures stock price exposures of firms to various macroeconomic forces, including foreign exchange, interest rates, inflation, and commodity prices.[1] Using a methodology similar to these prior studies, I find that observed gold exposures of mines vary over time and across firms. The nonstationarity of exposures requires measuring them using high-frequency (daily) data, which in turn requires correcting for nonsimultaneous prices.

From valuation models, I establish the factors that should affect exposures. As predicted, gold mining firm exposures are inversely related to the level of gold prices, the volatility of gold returns, the level of diversification by the firm, and the amount of its production that it hedges. Also, exposures are larger for firms with greater financial leverage. There is surprisingly little evidence to show that exposures are a function of a firm's operating costs, counter to the predictions of these models. I find that larger firms experience gold shocks more strongly than do small firms, which may be partially explained by the speed with which their stock prices incorporate gold price shocks. Interest rates are negatively associated with exposures. Finally, the results in the paper suggest that simple fixed-production (or discounted cash flow) valuation models predict levels of exposures reasonably well much of the time, but can systematically overestimate exposures, presumably due to their failure to reflect managerial flexibility or real optionality.

The remainder of this paper is divided into six sections. Section I describes the sample and discusses the measurement of the gold price exposure using

[1] On foreign exchange exposures, see Jorion (1990) and Bartov and Bodnar (1994). On interest rate exposures, see Flannery and James (1984), Scott and Peterson (1986), and Sweeney and Warga (1986). On inflation exposure, see French, Ruback, and Schwert (1983). On commodity price exposures, see Bilson (1994) and Strong (1991). With respect to gold price exposures, McDonald and Solnik (1977) use a two-factor model to determine gold price exposures of South African and U.S. firms. Brown and Hoover (1996) calculate the gold price exposures of portfolios of gold mining firms. Blose and Shieh (1995) calculate the gold betas of 23 publicly traded gold companies. In their empirical work, they also find that the level of firm value is a function of the price of gold, the mining firms' cash production costs, and their reserves.

gold return betas. Section II provides two analytical models for valuing gold mining firms, one based on a fixed-production schedule, and the second based on a flexible-production or real-option schedule. These analytic models are used to predict how various factors affect gold price betas. Section III describes the variables that measure market and firm characteristics. Section IV tests the exposure predictions from the valuation models. Section V analyzes how the levels of betas predicted by the analytic models relate to empirically observed betas. Finally, Section VI concludes the paper.

I. Measuring Stock Price Exposures with Daily Data

This paper studies the risk exposures of 48 North American firms engaged in gold mining in the period January 1990 to March 1994, in particular how firms' share returns are affected by changes in the price of gold (or its return). This sample, described in greater detail in Tufano (1996), includes 48 United States and Canadian gold mining firms that meet the following three criteria[2]:

1. The firm's risk management activities are reported in the "North American Gold Monitor," or the succeeding publications by Ted Reeve, which provide data on quarterly hedging activities.
2. The firm has common shares whose price and dividend history are reported by Reuters, in its ReuterLink database of U.S. and Canadian exchanges.
3. The firm is covered by COMPUSTAT.

Typically, managers and investors express share price exposure to gold prices in terms of elasticities; for each percentage change in gold prices they estimate that mining shares would change by 2 to 10 percent, due to financial and operating leverage.[3] These predictions can be confirmed by estimating a multifactor market model, as in Jorion (1990). Applying this methodology to the gold mining industry to calculate the exposure of gold mining firms to changes in gold prices, I calculate a *gold beta* (β_{ig}) for each firm by empirically estimating the following market model:

$$R_{it} = \alpha_i + \beta_{ig} R_{gt} + \beta_{im} R_{mt} + \epsilon_t \tag{1}$$

[2] Whereas this paper examines the entire North American mining industry, there are two detailed examinations of individual firms in this industry. Tufano and Serbin (1993) detail the risk management activities of American Barrick, one of the most aggressive proponents of risk management in the industry. Petersen and Thiagarajan (1996) compare American Barrick and Homestake Mining.

[3] While attending a meeting of the managers of approximately 50 major North American mining firms in 1994, I informally polled participants regarding their estimates of their stock's sensitivities to moves in gold prices. I was told that a 1 percent increase in gold price would produce a 3 to 10 percent increase in their mines' stock price values. Brimelow (1996) writes "Historically (gold stocks) outperform any bullion price move by a factor of at least two or three to one. If gold moves up 10%, you can look for moves of 20% or 30% in mining stocks."

where R_{it} is the daily return on stock i from $t - 1$ to t including dividends, R_{mt} is the daily return on the CRSP NYSE/AMEX/Nasdaq composite value-weighted index, and R_{gt} is the total return on gold.[4] The coefficient, β_{ig}, or the *gold beta*, represents the sensitivity of stock i's return for a 1 percent return to holding gold, after controlling for movements in broad equity indices that affect the return on these stocks independent of gold price movements.

Many prior studies using market models to measure exposures estimate exposures using weekly, monthly, or quarterly return data over a multiyear horizon. However, if exposures are not stationary, one would prefer to use higher frequency (daily) data to measure exposures on an annual or quarterly basis. This is relevant in this study, as the observed betas for gold mining firms have *not* been stable over the period, as I show later in the paper. Unfortunately, there is a drawback to using daily data: Scholes and Williams (1977) show that using daily data to calculate exposures can introduce meaningful biases into reported exposure measures, especially for infrequently traded stocks. This generic problem is particularly severe in this sample because the observed "closing gold price" from the COMEX (a division of the New York Mercantile Exchange) is set at 2:30 p.m. (EST), well before the close of the American or Canadian stock exchanges. Furthermore, a few of the mines in the sample trade infrequently, with some not trading every day.

In order to obtain unbiased beta estimates, I use the approaches suggested by Scholes and Williams (1977) and by Dimson (1979), as corrected by Fowler and Rorke (1983), and calculate nine sets of gold and market betas for each gold mining firm over the entire sample period (January 1990 through March 1994). These nine sets of betas differ by the method of adjustment (unadjusted; Scholes and Williams; and Dimson, Fowler, and Rorke), and the periodicity of observations (daily, weekly, and monthly). The adjustments use one lead and one lag term, because adding more than one lead or lag term does not change the measured mean betas in the sample significantly. The results are shown in Table I. Once one corrects for the biases using either the Scholes and Williams or Dimson technique, gold betas calculated using daily data are statistically indistinguishable from those calculated with weekly or monthly data. The two corrections produce similar beta estimates, regardless of ob-

[4] This includes the return from buying gold, lending it temporarily, and then selling it. The return to lending is captured by the gold lease rate, which reflects the premium an owner of gold could earn for lending out the gold for a short term. (The gold lease rate is approximately 1 to 2 percent per annum, and typically changes slowly over this period, so it contributes very little to the total gold price return.) I also calculate gold betas using the returns on gold price only, assuming that the holder of gold would not have access to the lending market; the results using this measure are statistically equivalent to those shown in the paper and are not reported here. Also, I estimate betas using a three-factor model, adding interest rates. The return (measured by change in yield) on long-term Treasury bonds, short-term bills, or the gold lease rate does not enter as a significant third factor, nor does it materially change the gold betas when added to the market model.

Table I

Correcting for Nonsimultaneous Trading in Measuring Exposures in the Gold Mining Industry

For each of 48 North American gold mining firms, exposures to changes in the price of gold as well as to the return of the CRSP value-weighted NYSE/AMEX/Nasdaq index are calculated using data from the period January 2, 1990 through March 31, 1994. Both market and gold betas are calculated, using daily, weekly, and monthly data. Three sets of betas are reported: unadjusted betas, Scholes and Williams (1977) betas using two factors (the total return on the value-weighted CRSP index and on gold), and Dimson (1979) betas with the Fowler and Rorke (1983) correction. The table shows the results of multiple t-tests (Fisher's Least Significant Difference) between the different means and of Kruskal–Wallis tests on the medians. Means that are statistically equivalent to a significance level of 5 percent belong to the same t-grouping. Medians that are statistically equivalent to a significance level of 5 percent belong to the same Kruskal–Wallis grouping. Panel A reports the gold betas and Panel B reports the market betas.

Panel A: Gold Betas

Observation Frequency	Beta Adjustment	Mean Gold Beta	t-Grouping	Median Gold Beta	Kruskal–Wallis Grouping
Daily	Unadjusted	1.03	1	1.13	1
	Scholes–Williams	1.73	2	1.82	2
	Dimson	1.87	2	1.97	2
Weekly	Unadjusted	1.41	3	1.60	3
	Scholes–Williams	1.58	2	1.58	3
	Dimson	1.65	2	1.80	2 3
Monthly	Unadjusted	1.72	2	1.90	2 4
	Scholes–Williams	1.84	2	2.28	4
	Dimson	1.88	2	2.03	2 4

Panel B: Market Betas

Observation Frequency	Beta Adjustment	Mean Market Beta	t-Grouping	Median Market Beta	Kruskal–Wallis Grouping
Daily	Unadjusted	−0.05	1	−0.12	1
	Scholes–Williams	0.10	2	−0.01	2
	Dimson	0.38	2 3	0.37	2 3
Weekly	Unadjusted	0.27	2	0.24	2
	Scholes–Williams	0.26	2	0.22	2
	Dimson	0.43	2 3	0.45	2 3
Monthly	Unadjusted	0.48	2 3	0.54	3
	Scholes–Williams	0.50	3	0.58	3
	Dimson	0.55	3	0.60	3

Table II

Distribution of Gold and Stock Market Exposures of North American Gold Mining Firms

Descriptive statistics of firm-quarter gold and market betas are given for the sample of 48 North American gold mining firms from April 1990 to March 1994. The original sample has 768 (48 × 4 × 4) firm-quarters, but some firms' shares were infrequently traded, and stock price data for some days was missing. Firm-quarter observations in which 75 percent of the daily returns could not be calculated are dropped from the sample, reducing the sample to 651 firm-quarter observations. Two firms are completely eliminated from the sample (32 firm-quarters) and 13 firms are partially eliminated due to these data constraints. In each quarter, Dimson gold and market betas are calculated. Also see Figure 1 for plots of the time-series and cross-section distributions.

Risk Factor	Gold	Market
Number of observations	651	651
Mean	2.21	0.33
Standard deviation	2.38	1.78
Median	2.09	0.37
5th percentile	−0.44	−1.71
95th percentile	5.68	2.18
Number statistically different from 0:		
Statistically significant at the		
10% level	404	74
5% level	366	40
1% level	246	9
Number greater than 0:	600	426
Statistically significant at the		
10% level	404	69
5% level	366	37
1% level	246	8
Number less than 0:	51	225
Statistically significant at the		
10% level	0	5
5% level	0	3
1% level	0	1
Minimum	−23.77	−18.42
1st quartile	1.13	−0.27
3rd quartile	3.13	0.97
Maximum	18.88	14.87

servation frequency, and there is no statistically significant difference between the mean adjusted gold betas and unadjusted monthly betas. For the remainder of the paper, I report gold betas generated from daily data by the Dimson, Fowler, and Rorke method.

Table II provides descriptive statistics on the Dimson-adjusted gold betas calculated using daily data. Rather than estimating one gold beta per firm over the entire period as in the prior table, betas are estimated for each firm each quarter using daily data to allow for nonstationarity. There are potentially 768 firm-quarter (48 × 4 × 4) observations, but after excluding firm-quarters where less than 75 percent of the daily returns are available, the final sample includes 651 firm-quarters. Two firms are completely eliminated from the sample (32 firm-quarters) and 13 firms lost at least one quarterly observation.

Not surprisingly, gold mining firms have substantial gold price exposure. From Table II, for a 1 percent return on gold, the mean and median gold firm's stock moves by about 2 percent, which represents the lower bound of practitioner "guesstimates." Part of the variation in betas is attributable to time-series variation, and the remainder to cross-sectional differences in exposures, as shown in Figure 1. The top plot shows that gold betas are not stationary from quarter to quarter, and one can reject that all of the means and median are jointly equal in each year, with the p-values of the respective tests both being 0.0001. Given this nonstationarity, it is important to use high-frequency data. Additionally, the bottom plots show that for any one quarter there is substantial cross-sectional variation in gold betas among the mining companies. The remainder of the paper attempts to explain this time-series and cross-sectional dispersion in gold price exposure.

II. Theoretical Determinants of Risk Exposures for Gold Mining Firms

By constructing models of the value of a gold mining firm, one can predict how various factors affect the cross-sectional and time-series distribution of realized exposures. This section discusses three valuation models for gold mining firms and uses comparative statics to determine how market conditions (i.e., the price of gold and the volatility of gold), relatively "exogenous" firm factors (i.e., the firm's cost structure, reserves, and production levels), financing policy, and risk management policy interact to affect a firm's gold price exposure. In the first model, the firm operates with a fixed-production schedule. In the second model, the firm can exploit the real options of opening and closing operations, as discussed by Brennan and Schwartz (1985). Finally, as an extension to the fixed-production model, a third model analyzes the effect on exposures due to financial risk management programs. The comparative statics are summarized in Table III and are detailed in an Appendix that is available from the author.

A. Fixed-Production Model

First, consider a firm that has a production profile it cannot alter, and that engages in no financial risk management.[5] I model this hypothetical firm as owning a fixed quantity of gold reserves (R), which it mines over N years at a rate of R/N or Q. The mine incurs fixed costs (F), such as overhead expenses or financing costs. It also incurs set marginal mining and

[5] Blose and Shieh (1995) develop a similar model to this fixed-production model.

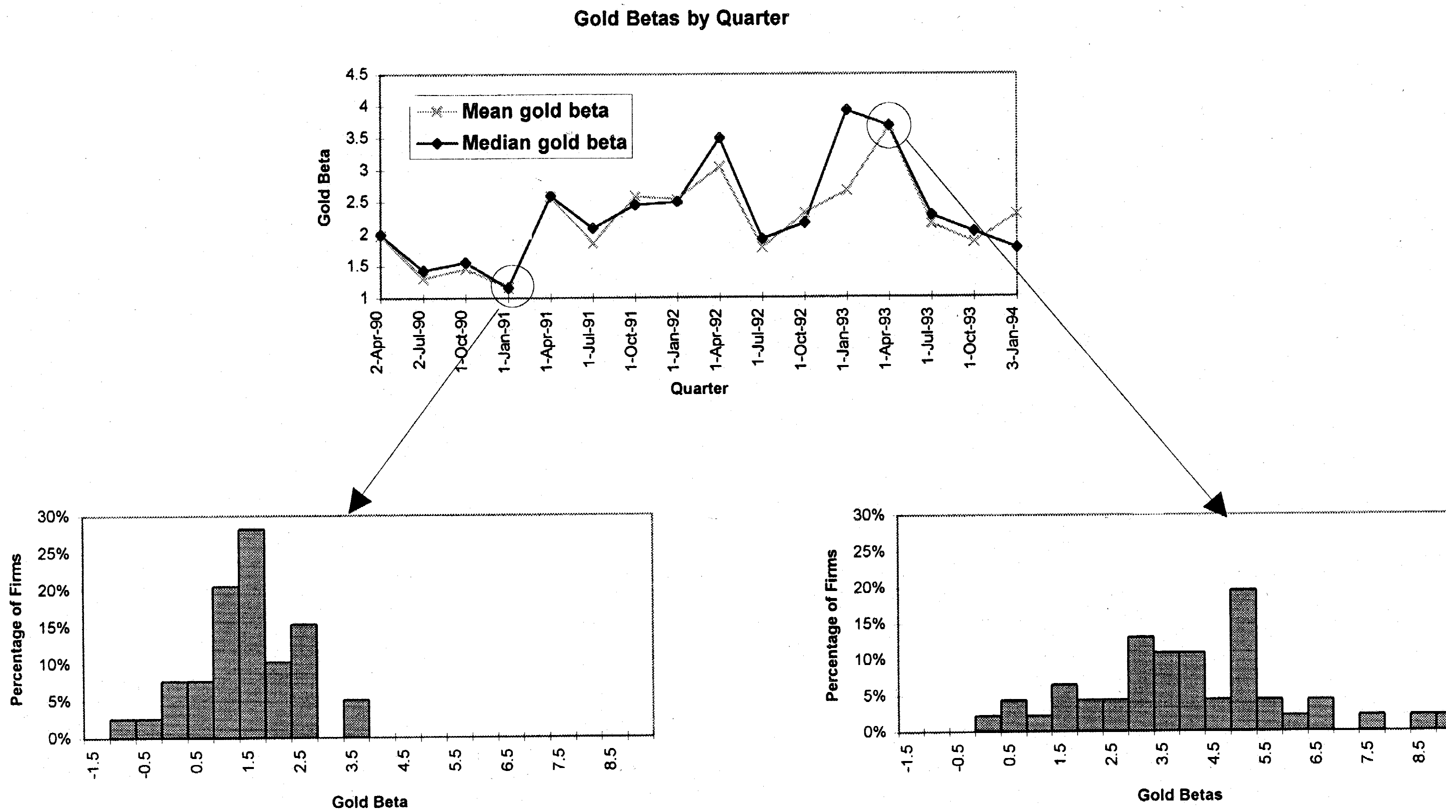

Figure 1. Time series and cross-sectional distribution of Dimson-adjusted gold betas. The top figure plots the quarterly mean and medians of the Dimson-adjusted firm-quarter gold betas for the sample of North American gold-mining firms during the period April 1990 to January 1994. The bottom figures plot the cross-sectional distribution of betas for two quarters, January 1991 and April 1993.

Table III

Predictions of the Effect of Various Factors on the Gold Betas of Mining Firms

The table below reports the comparative statics of the exposure predictions for three valuation models of gold mining firms. The Fixed Production; No Hedging model assumes that the firm's level of output is fixed and does not respond to the price of gold. The Flexible Production; No Hedging model is the real option model of Brennan and Schwartz (1985). The Fixed Production; Hedging model modifies the first model by assuming that the firm hedges a fraction of its production at a previously set forward price. The table shows how changes in the variables are predicted to affect the gold betas.

Variable	Fixed Production; No Hedging	Flexible Production; No Hedging	Fixed Production; Hedging
Gold price (P)	–	–	–*
Quantity of production (Q)	–	–	–
Reserves (R)	0	0	0
Variable and fixed costs (C, F)	+	+	+
Volatility of gold prices (σ)	n.a.	–	n.a.
Interest rates	Function of pattern of Q	Lease rate (GLR): + Capital cost (10YR): –	Function of pattern of Q
Percentage of output hedged (α)	n.a.	n.a.	–*
Hedge price (W)	n.a.	n.a.	–

* Coefficient could take on different signs under certain unlikely circumstances.

processing costs (C). The mine sells its commodity output at a market price, P, and acts as a price taker. In this instance, the firm's market value would be:

$$V = \sum_{i=1}^{N} \frac{[Q(P-C)-F](1-\tau)}{(1+r)^i}, \tag{2}$$

where Q = fixed annual production = R/N (total reserves/years of production); P = market price of gold; C = extraction and processing costs; F = fixed charges (general and administrative, fixed financial charges); r = firm's cost of capital; and τ = corporate tax rate.

Assuming that the firm has no flexibility in its production schedule, its gold beta, or the percentage change in firm value for a 1 percent permanent shock to gold prices would be:

$$\beta \equiv \frac{\partial V/V}{\partial P/P} = \frac{PQ(1-\tau)\sum_{i=1}^{N}\frac{1}{(1+r)^i}}{V} = \frac{PQ}{Q(P-C)-F}. \tag{3}$$

Examining the comparative statics of this beta, a firm's sensitivity to gold prices decreases as gold prices climb (P). The beta is inversely related to its quantity of production (Q). (The specification shown has N fixed, so an increase in Q translates into an increase in reserves. It can also be shown that an increase in Q, holding constant R, also lessens betas.) Beta is an increasing function of both its marginal (C) and fixed (F) costs, as sensitivity to gold prices increases with financial and operating leverage.[6] With level production, the firm's beta is unaffected by interest rates, but with nonlevel production levels, interest rates can influence betas. (If production levels are rising, interest rates and betas are positively related; with declining production, they are negatively related.) Increasing reserves (N), holding constant annual production, does not affect the gold beta in the model.

B. Flexible-Production Model

The fixed-production model is poorly specified in that gold mines offer classic examples of firms with real options. In fact, some of the seminal papers on real options use mining as an example (see Brennan and Schwartz (1985), and Brennan (1990)). For example, when the gold price falls below the firm's marginal costs, the firm can choose to temporarily or permanently suspend production. In general terms, mines hold a call option on gold, with the exercise price being their marginal production costs. Mining firms can

[6] If the firm's production quantities are fixed, but its marginal costs are positively related to gold prices (as would be the case if it shifted ore grades in response to market prices), then its beta would be smaller than shown in equation (3). More precisely, it would be $[PQ(1-C')]/[Q(P-C)-F]$, where $C'>0$ is the derivative of costs with respect to prices.

exploit other types of flexibility as well; for example, they can mine higher or lower grade ores, they can stockpile ore or finished gold, and they can change the rate of production (see Mardones (1993) and Davis (1996) for a discussion). Ignoring the optionality embedded in mine operating decisions will tend to overstate a mine's sensitivity to gold price shocks.

Brennan and Schwartz (1985) develop a real options model in which firms can open and shut mines. They assume stochastic commodity prices, and nonzero costs of closing and opening a mine. Firms optimally exploit the option to open and shut mines, and this optionality results in smaller gold betas than if the firm were locked into a fixed-production schedule—analogous to the observation that the delta of a call (a right) is typically lower than the delta of a forward contract (a commitment). When gold prices are low, the firm is not committed to continue to operate, and thus can suspend production and sales until later.

Using their model, one can show that the gold beta is a decreasing function of volatility; this result is similar to the finding that the elasticity of the value of a call option (sometimes called eta or η) is a decreasing function of volatility. Otherwise, the flexible-production model yields comparative statics similar to those of the fixed-production model: exposure is inversely related to gold prices and the level of production, and directly related to the level of costs faced by the mine.

Unlike the fixed-production model, where interest rates may have no effect on betas, in the flexible production model, they explicitly do. Brennan and Schwartz's setup uses two interest rates: a standard corporate rate used to discount expenses and a convenience yield (or gold lease rate) that is effectively used to discount revenues (where future revenues are a function of the forward price of gold). The former has a predicted inverse relationship with betas, the latter a positive relationship.

C. Fixed-Production Model with Hedging

By selling forward its entire production profile, a firm eliminates its exposure to gold prices, thereby driving its gold beta toward zero.[7] Thus, firms that engage in greater hedging should experience lower gold betas. Additionally, however, the *price* at which the gold has been sold forward also affects the observed gold beta for those firms that sell forward less than their entire future gold production.

Consider a firm that sells forward a portion α of its future annual production Q with a forward contract which stipulates that the firm will receive a payment of W per ounce of gold at the time of delivery. At the time the forward contract was struck, W would represent the market forward price, and all firms executing forward contracts at this time should have identical

[7] This statement would not be correct if interest rates are correlated with gold price movements. For example, a fixed-rate Treasury bond or a fully hedged mine would appear to have gold price exposure if there is correlation between interest rates and gold prices.

contract terms (ignoring credit risk). In a cross section of firms that hedged their production at different points in the past, one would observe differing contract prices. The hedged firm's beta would be

$$\beta_P \equiv \frac{\partial V/V}{\partial P/P}$$
$$= \frac{(1-\alpha)PQ}{(1-\alpha)Q(P-C)+\alpha Q(W-C)-F} = \frac{(1-\alpha)PQ}{Q[(P-C)-\alpha(P-W)]-F}. \qquad (4)$$

If the fraction hedged (α) is zero, then equation (4) reduces to equation (3). If the fraction is one, then the sensitivity to gold price fluctuations is zero. In all but pathological cases (where a firm enters into a forward price below its costs), as the amount hedged increases, exposure falls. The firm's gold exposure is also a function of the contract price, W. Holding constant the amount of gold sold forward (α), the higher the contract price, W, the lower the exposure.[8] Examining the other comparative statics of the hedged firm's beta to other factors, the hedged firm's sensitivities are much like the unhedged firm's, inversely related to its production quantity and directly related to its costs. Finally, in all but extreme instances a hedged firm's sensitivity to gold prices decreases with increasing gold prices.[9]

III. Sample Description

By measuring the variables described above, and comparing them to the observed levels of exposures, one could test whether these models help us understand how actual exposures are set. This section describes the data used to measure these variables, and Table IV provides simple descriptive statistics for each of the variables as well as the correlations among them.

Gold Prices (P): As a measure of market gold prices, I collect daily closing COMEX prices, which average \$361.48 per ounce for April 1990 through March 1994, ranging from a high of \$423 to a low of \$326 in this period. These prices represent the market-closing prices for spot gold used by the settlement committee of the COMEX in marking-to-market futures contracts on gold, and they represent a combination of the final five spot trades (see Kolb (1991), pp. 79–80).

[8] Incorporating both of these factors at once can produce seemingly anomalous results. A firm that *hedges more* can have *more* exposure than an otherwise identical firm that hedges less if the latter has sold forward its output at a higher contract price. The reason for this apparent anomaly is that the firm with less gold sold forward has previously sold it at a higher forward price, thus the larger total forward sale proceeds can be thought of as "negative leverage" in the sense of fixed income to be received by the firm. Just as fixed charges increase observed betas, fixed income decreases observed betas.

[9] For the special case in which the revenue from the hedge is greater than the *total* costs of operating the mine, the gold beta actually *increases* with increasing gold price. This condition would imply a very high hedging fraction, α, or a high contract price, W.

Production Quantity (Q): One simple measure of production is the annual production of gold in ounces. In a cross section, one would also want to control for the amount of reserves. (However, as discussed earlier, when production is held constant, increases in reserves should not change betas.) Yearly production quantities and total reserves (proven plus probable) are obtained from firms' annual reports.

Costs (F,C): Gold mines typically report their cash costs of producing gold. Cash costs are usually reported annually, and represent the per ounce costs of producing gold, excluding noncash items such as depreciation, depletion, and amortization as well as financing costs, but including royalty payments. Cash costs vary with the quality of ore deposits and operating efficiencies; in the short-term they reflect the firm's fixed-production technology, but over longer periods of time they may vary. Cash costs do not break out fixed and variable cost components. In theory, one could estimate the breakdown of fixed and variable costs by regressing cash costs against production quantities, but given that I have only four years of annual data on these two variables, this approach seems imprudent.

Financial Leverage (F): One particular fixed cost borne by mines is the fixed financial charge imposed by borrowing. Observed exposures should increase as a firm's financial leverage increases. To measure financial leverage, I divide the end-of-year book value of long-term debt plus the current portion of long-term debt (from COMPUSTAT) by the end-of-year market value of the firm (from ReuterLink). I also calculate net debt, which is defined as (the sum of long-term debt and the current portion of long-term debt less cash and cash equivalents) divided by the end-of-year market value of the firm.

Volatility (σ): According to the flexible-production model, observed exposures should decrease as the volatility of gold prices increases. Ideally, one would use implied volatilities as forward-looking measures; but as these data are not easily obtainable, I calculate the annualized volatility of gold price returns from historical gold price data in each quarter.

Fraction Hedged (α): Tufano (1996) describes the data available that document the extent of hedging by North American gold mines, and constructs measures of the extent of financial risk management undertaken. The entire portfolio of financial risk management activities is reduced to a delta that represents the change in value of the risk management portfolio with respect to a small change in the price of an underlying asset. The delta also represents the equivalent long or short position in the underlying asset necessary to construct a replicating portfolio. In this case, the portfolio delta represents the ounces of gold that the firm has effectively sold short through its financial risk management activities. This delta is estimated from the information in the Reeve surveys, which reports the firms' risk management activities over a three-year horizon.

It is necessary to scale the firm's financial risk management portfolio against its natural exposure in order to understand its economic impact. Tufano (1996)

Table IV

Description of Data Describing Potential Factors Affecting Gold Price Exposures

Panel A reports descriptive statistics for the sample of 48 North American gold mining firms from 1990 through March 1994. The gold price, volatility, and interest rates are market-wide variables. The remainder of the variables are firm-specific and the summary statistics reflect the average over the panel for all periods. Panel B shows the correlations between the variables affecting the gold betas. Because some of the variables are reported quarterly and some are reported yearly, quarterly vs. yearly variable correlations are computed by first averaging the quarterly variable over the year. The shaded area in Panel B corresponds to variables where quarterly data are averaged over a year. V represents the market value of the firm, which equals the average market value of the firm's equity plus the book value of its debt. The last row shows the correlations of the gold betas with the variables affecting the gold betas (β).

Panel A: Description of Variables

Factor	Effect on Gold Beta	Observed Variable	Definition and Source of Data	Mean Std. Dev. Median
Gold price (P)	−	Average gold price over quarter	Average of daily COMEX closing prices, in US$ per ounce, as of 2:30 p.m. EST. (ReuterLink)	Mean: \$361 SD: \$16 Med: \$360
Volatility (σ)	−	90-day annualized gold return volatility	90-day annualized volatility of gold returns. (Calculated from ReuterLink)	Mean: 0.13 SD: 0.04 Med: 0.14
Interest rates	+	Gold lease rate (GLR)	Quarterly average of daily gold lease rates. (Commodity dealers)	Mean: 1.02% SD: 0.52% Med: 0.79%
	−	10 year Treasury bond rate (10YR)	Quarterly average of daily 10-year T-bond rates. (Datastream)	Mean: 7.17% SD: 1.08% Med: 7.31%
Production quantity (Q)	−	Production in millions of oz.	Production in millions of ounces. (Annual reports)	Mean: 0.37 SD: 0.51 Med: 0.15
Financial leverage (F)	+	Debt to equity ratio	(Year-end long-term debt + current portion)/Year-end market value of firm. (Compustat)	Mean: 0.30 SD: 0.59 Med: 0.15
Cost structure	+	Yearly cash costs (C)	Yearly cash costs in \$/oz. (Annual reports)	Mean: \$237 SD: \$58 Med: \$223
		Proxies for potential economies of scale (firm size)	Reserves in millions of ounces. (Annual reports) (R)	Mean: 5.18 SD: 6.80 Med: 2.28
			Year-end market value of firm in millions. (COMPUSTAT) (V)	Mean: 749 SD: 1159 Med: 210

Percent hedged	−	Delta-percentage-of-production ($D\%P$)	Delta of risk management portfolio/estimated production. (Reeve reports, market data)	Mean: 0.27 SD: 0.33 Med: 0.20
		Delta-percentage-of-reserves ($D\%R$)	Delta of risk management portfolio/total reserves. (Reeve reports, market data)	Mean: 0.05 SD: 0.07 Med: 0.02
Forward prices	−	Average-forward-contract-price (W_1)	Sum of quarterly forward price times quarterly hedged amount, divided by sum of hedged amount. (Reeve reports)*	Mean: \$419 SD: \$37 Med: \$419
		Average-delta-contract-price (W_2)	Average contract price, weighted by ounce, where options included at delta-equivalent at spot. (Reeve report)*	Mean: \$418 SD: \$174 Med: \$401
Percent in mining	+	Percent of firm assets in mining ($\%M$)	Yearly percent of firm assets in mining. (COMPUSTAT)	Mean: 92 SD: 22 Med: 100

Panel B: Correlation among Potential Factors Affecting Gold Exposures

	P	σ	$\Delta\ \%R$	$\Delta\ \%P$	W_1	W_2	GLR	10YR	Q	R	F	C	$\%M$	V
σ	0.52†													
$\Delta\ \%R$	0.11#	0.12†												
$\Delta\ \%P$	0.11#	0.05	0.50†											
W_1	0.05	0.22†	−0.06	−0.09‡										
W_2	−0.06	−0.04	−0.08	−0.10#	0.75†									
GLR	0.04	0.31†	0.05	−0.01	0.10‡	0.03								
10YR	0.13†	0.53†	0.07	0.00	0.45†	0.02	0.39†							
Q	−0.06	−0.05	0.02	0.02	0.12	0.30†	−0.02	−0.04						
R'	−0.03	−0.04	−0.05	0.09	0.10	0.31†	−0.02	−0.05	0.90†					
F	−0.01	−0.09	0.07	−0.06	0.03	−0.04	−0.10	−0.05	−0.15†	−0.16†				
C	0.16‡	0.07	0.06	0.01	−0.02	−0.05	0.05	0.01	−0.23†	−0.16†	0.14†			
$\%M$	0.04	0.02	−0.11	−0.14	0.02	0.04	−0.01	0.01	0.02	0.03	−0.13†	0.22†		
V	0.00	−0.01	0.05	0.16‡	0.10	0.27†	0.02	−0.03	0.83†	0.90†	−0.12†	−0.27†	−0.19†	
β	−0.13†	−0.15†	−0.06	−0.13†	−0.06	0.02	−0.11†	−0.012†	0.22†	0.20#	0.11	0.05	0.24†	0.05

* Statistics calculated only for firms that engage in some risk management.

†, #, ‡ Significant at 0.01, 0.05, and 0.10 levels, respectively.

scales the delta by the firm's *anticipated production* over the coming three years to capture the *managerial* decision to hedge. This is because managers think of, and describe, hedging policy in relation to near-term production. However, from the perspective of an *investor*, the percentage of the firm's total production profile (or its reserves) is an equally relevant, if not more relevant, measure of the extent to which the firm has moderated its value exposure. Therefore, I use two measures of the extent of hedging: (a) a mine's delta-percentage-of-*production*, defined as the delta of the risk management portfolio divided by the amount of gold the Reeve report shows is expected to be produced over the next three years, the same period over which the risk management data are reported; and (b) its delta-percentage-of-*reserves*, which corresponds to the delta of the portfolio divided by the proven and probable yearly reserves. These two measures are very highly correlated, as would be expected.

Hedging Contract Prices (W): If a firm only used forward contracts to hedge, one could calculate the average forward sale price, W_1, as the weighted-average forward prices at which it has sold its gold, where the weights are the ounces of gold under contract. This measure, W_1 or average-*forward*-contract-price, is relevant only for firms that have actually sold gold forward, and it ignores all options. This measure excludes options, which account for 16 percent of the portfolio deltas for the firms in the sample. An alternative measure that includes the effect of options is W_2 or average-*delta*-contract-price, defined as:

$$W_2 = \frac{\sum(Oz_i \times C\_Price_i) + \sum(\Delta_{option,j} \times P)}{\sum Oz_i + \sum \Delta_{option,i}}, \tag{5}$$

where $\Delta_{option,i}$ represents the equivalent short-position attributable to the option contract i, and P represents the spot price for the quarter. The variable $\Delta_{option,i}$ changes as the price of gold changes. Under a replicating portfolio, it is as if these ounces are sold short at the current market price P. *C_Price* represents the contract prices under the forward sale contracts, and *Oz* represents the ounces sold forward.

Interest Rates: The gold lease rate (GLR) is the convenience yield on gold (for a one-year term), and is collected from commodity dealers and industry consultants.[10] Ten-year Treasury rates (10YR) are obtained from Datastream.

Diversification: Each of the models assumes that the firms' only assets are their gold mines. However, a number of the firms in the sample are diversified into other businesses, such as oil or transportation. When firms operate businesses outside of mining, their share values should be less closely linked to gold. To measure the extent to which a firm is solely engaged in

[10] I thank the commodity desk at Morgan Stanley and Jessica Cross for helping me obtain these data.

mining, I determine the percentage of each firm's assets that are dedicated to mining for each year of the sample, using data from COMPUSTAT.

IV. Multivariate Tests: The Determinants of Gold Betas

A. Methodology

Using two sets of analyses, I examine the relationship between betas and the factors that should affect them. In the first set, I separately estimate the betas and analyze these estimated betas against the factors that should determine them (separate estimation); in a second set of analyses, I jointly conduct both analyses (joint estimation). These methods differ with respect to efficiency of the estimation procedures.

In the first set of results, there are two separate estimations. In the first step, I use the two-factor Dimson model to estimate a gold beta for firm i for each quarter using daily data:

$$R_{it} = \alpha_i + \sum_{k=-1}^{k=1} \beta_{ig,k} R_{g,t+k} + \sum_{k=-1}^{k=1} \beta_{im,k} R_{m,t+k} + \epsilon_{it}. \tag{6}$$

To implement the Dimson adjustment, the gold beta for firm i in quarter q is calculated as

$$\beta_{ig,q} = \beta_{ig,0} + \frac{1 + \rho_1 + \rho_2}{1 + 2\rho_1} (\beta_{ig,-1} + \beta_{ig,+1}), \tag{7}$$

where ρ_1 and ρ_2 are the autocorrelation coefficients of R_g.

In the second step, I use a panel of these quarterly betas (described in Table II and Figure 1) as dependent variables, and estimate the linear model

$$\beta_{ig,q} = a + \sum_{j=1}^{N} \phi_j F_{j,i,q} + \epsilon_{i,q} \tag{8}$$

over the j factors (F), which include the gold price, hedging levels, leverage, etc. I test whether the coefficients (ϕ_j) are consistent with the predicted signs. Of the potentially 651 firm-quarter observations in this second estimation, roughly 400 are useable given the data constraints imposed by the other variables, such as cash costs.

This dataset is a panel in that there are multiple observations for each firm over time. As the firm-specific variables used may not completely capture all of the variation among the firms, I report the OLS models with and without fixed effects in the tables. Fixed effects control for otherwise unmeasured firm-specific variation in exposures, and thereby allow for the analysis of within-effects. I also estimate the model using various alternative panel specifications including estimating the results by year, using Feasible Generalized Least Squares (FGLS) (see Greene (1997)), and implementing the panel procedure proposed by Fama and McBeth (1973). In general, these different techniques produce results identical to those reported in the tables, and where they differ, this is noted in the text.

In estimating equation (8), I give the same weight to each observed beta regardless of standard errors. To address this problem, I conduct a second procedure where I jointly estimate the betas and the determinants of betas in one step by substituting the linear expression in equation (8) for the betas in equation (6) and conducting a single estimation. In particular, I estimate the following equation over the nearly 21,000 firm-days in the sample:

$$R_{it} = \alpha + \sum_{k=-1}^{k=1} (a_g + \sum_j \phi_{g,j} F_{j,i,t}) R_{g,t+k} + \sum_{k=-1}^{k=1} (a_m + \sum_j \phi_{m,j} F_{j,i,t}) R_{m,t+k} + \epsilon_{tt}. \tag{9}$$

With this setup, the coefficients on the interaction terms ($F_{j,i,t}$ x $R_{g,t}$) represent the $\phi_{g,i}$ terms. I assume the same functional form for the ϕ's on the lead, contemporaneous, and lag return terms, and estimate this equation over the entire sample. The joint estimation procedure has the advantage of increased efficiency.

The six columns in Table V differ in the following ways: by the estimation method used (separate estimation in columns A, B, D, and E, and joint estimation in C and F); whether the specification includes fixed effects terms (B and E); and which measure of hedging activity is used (delta-percentage-of-production in columns A, B, and C, and delta-percentage-of-reserves in D, E, and F). Table V examines the main variables of interest, Table VI more closely examines the impact of firm size on betas, and Table VII examines the impact of interest rates on betas.

B. Results

All the specifications in Table V show that the *level of the gold price* is a significant determinant of the level of exposure that gold mining firms have to changes in the price of gold. As predicted, in higher gold price environments, gold price exposure drops. This result is both statistically and economically significant. Table V shows that if average gold prices in a quarter are one standard deviation or \$16/oz. lower, measured betas are higher by 0.53 to 0.60 (separate estimation) or 0.14 (joint estimation). Considering that the mean beta for this period is approximately two, these differences in sensitivity seem material.

The flexible-production model predicts that as volatility increases, exposures should fall. In each of the specifications, this result is observed, and in the joint estimation procedure the effect is statistically significant. If the volatility of gold returns increases by one standard deviation (4 percent), observed exposures drop by 0.08 (using separate estimation) to 0.34 (using joint estimation). Because volatility would not affect the value of a fixed-production mine, this evidence is consistent with the view that the market takes real optionality into account when valuing mines.

As noted earlier, practitioners have written about how hedging affects the gold play that mining stocks offer. The evidence in Table V confirms their concerns that hedging has a material effect on the gold price exposures of mining firms. Looking at columns A through C (which use delta-percentage-of-production as the measure of hedging), the amount of hedging done by companies is negatively and significantly associated with observed betas.[11] The results suggest that if two companies are otherwise identical, but one hedges all of its near-term (three-year) production and the other hedges none, the former firm's beta would be lower by 0.78 to 0.96 (separate estimation) or 0.65 (joint estimation). Again, in comparison to the mean industry beta of about two, this difference is economically large. The evidence suggests that investors incorporate firms' hedging decisions into their valuations. This result contradicts Petersen and Thiagarajan (1996) who study two firms (American Barrick and Homestake Mining) and find that hedging has no effect on equity price exposures. However, with only two data points, the authors can only carry out univariate tests of differences, and cannot control for the many factors that simultaneously determine exposures.

Theory suggests that firms that sell their gold at higher forward prices should experience gold price shocks less strongly.[12] We see mixed evidence of this in Table V. In the pooled results (column A) and the joint estimation (column C), there is a negative and significant relationship between forward prices and exposures as predicted.[13] However, the economic magnitude of these coefficients is quite small; for example, the coefficient on average forward price in columns A and C suggests that if a firm fully hedges its three-year production and locks in forward contracts \$36 higher (one standard deviation), its observed beta is lower by only 0.03. In the fixed-effects model, even this weak result vanishes. The overall lack of economic significance may suggest that investors have a difficult time interpreting this "second-order" hedging information. The lack of association between contract prices and exposures in the fixed-effect specification may also reflect that a firm's

[11] With the FGLS estimation, the coefficient (p-value) on delta-percent-of-production is 0.92 (0.0001). The Fama–McBeth (1993) procedure estimates the relationship by quarter, then calculates standard errors and p-values from the vector of quarterly coefficients. In this specification, gold price and volatility cannot be included, as they do not vary across firms in any quarter. In this specification which essentially uses 15 quarter-observations, the coefficient on delta-percent-of-production coefficient is 0.59, and the p-value is 0.12.

[12] The measures for average-forward/contract-price used in the multivariate analysis differ slightly from those described in Section IV. In particular, rather than normalizing by ounces hedged (or delta ounces in the case of W_2), I normalize by total production or total reserves. The reason for this choice is that the original variables are undefined for firms undertaking no risk management, which would force me to exclude them from the multivariate analysis.

[13] I find the same result using the W_2 measure that includes options, described earlier in the paper.

Table V

Multivariate Analysis of Factors Affecting the Gold Betas of Gold Mining Firms

This table reports the results of multivariate analyses of the factors affecting the gold beta of North American mining firms. The dependent variable in columns A, B, D, and E (separate regression) is the Dimson/Fowler-adjusted gold price beta, calculated by firm each quarter, using daily data. Delta-percentage-of-production (reserves) represents the delta-equivalent of the ounces of gold shorted in the firm's risk management program divided by its production (reserves). t-statistics are calculated using White (1980) robust standard errors. In columns C and F (joint estimation), the dependent variable is the daily stock market return for stock i, and the independent variables are the interaction terms representing the product of the variable listed times the gold return for that day. In the joint estimation, there are also interaction terms between the independent variables and the market return, which are not reported. p-values are reported in parentheses.

		(A)	(B)	(C)	(D)	(E)	(F)
		Dependent Variable and Estimation Method					
Independent Variables	Pred. Sign	Beta Separate	Beta Separate	Return Joint	Beta Separate	Beta Separate	Return Joint
Intercept		13.08	19.05	4.25	13.55	19.08	4.24
		(0.000)	(0.000)	(0.002)	(0.000)	(0.000)	(0.002)
Average gold price	−	−0.034	−0.035	−0.009	−0.036	−0.038	−0.009
		(0.000)	(0.000)	(0.005)	(0.000)	(0.000)	(0.005)
Gold return volatility	−	−3.251	−2.824	−8.121	−2.849	−1.940	−8.408
		(0.119)	(0.127)	(0.000)	(0.179)	(0.295)	(0.000)
Gold production (oz mil)	−	0.429	−0.604	0.051	0.697	−0.775	0.247
		(0.094)	(0.351)	(0.810)	(0.004)	(0.262)	(0.244)
Gold reserves (oz mil)	na	−0.003	0.056	0.005	−0.026	0.056	−0.011
		(0.864)	(0.180)	(0.713)	(0.148)	(0.179)	(0.471)
Cash costs ($/oz)	+	0.001	−0.005	−0.001	0.001	−0.003	−0.001
		(0.762)	(0.339)	(0.246)	(0.794)	(0.488)	(0.299)
Leverage (net debt/equity ratio)	+	0.365	−0.036	0.244	0.371	−0.181	0.265
		(0.123)	(0.972)	(0.001)	(0.141)	(0.827)	(0.000)

Delta-percent-of-production	−	−0.781	−0.960	−0.646			
		(0.001)	(0.000)	(0.001)			
Delta-percent-of-reserves	−				0.895	1.867	−1.263
					(0.619)	(0.475)	(0.248)
Avg-forward-contract price/production	−	−8.09E−04	1.53E−04	−7.92E−04			
		(0.050)	(0.768)	(0.034)			
Avg-forward-contract price/reserves	−				−1.14E−08	−5.52E−09	−4.49E−09
					(0.043)	(0.307)	(0.211)
Percentage of assets in mining	+	0.020	−0.024	0.017	0.019	−0.023	0.017
		(0.000)	(0.123)	(0.000)	(0.000)	(0.130)	(0.000)
Firm dummies included		No	Yes	No	No	Yes	No
Number of observations		398	398	20781	399	399	20781
Adjusted R^2		0.207	0.291	0.131	0.190	0.280	0.131
F-statistic		12.5	4.4	53.1	11.4	4.2	53.1

hedging contracts tend to change slowly over time (as long-term commitments such as gold loans would be in place for years). I find the same result using the W_2 measure that includes options, described earlier in the paper. To conserve space, these results are not reported.

Columns D, E, and F repeat the analysis, substituting hedging activity expressed as a fraction of total *reserves* for hedging activity as a percentage of production. This alternative measure is not associated with measured gold price exposure for these specifications (as well as for the unreported FGLS and Fama–McBeth procedures). Given the strong association between exposures and the production-based measure of risk management, this result is puzzling. In principle, it could reflect a statistical artifact if hedging/reserves varied less than hedging/production. However, the variation in the former measure is no smaller than in the latter.[14] It may also reflect an inherent weakness with the data used; firms with larger reserves may be hedging well beyond a three-year horizon, thus the reserve-based measure may be less informative than the production-based one. More likely, this nonresult probably reflects the noisiness in the measurement of reserves. Technically, reserves are "proven and probable" (vs. possible) reserves, which are subjective engineering estimates of the amount of ore in the ground. Typically, engineers must extrapolate from drilling samples to make these estimates, so there is inherently some noise in the process. Complicating this problem, the size of reserves is implicitly a function of the gold price in that engineers must establish a "cut-off grade" to ascertain the amount of gold that could be extracted economically, given a gold price environment. Were engineers in different firms to use different cut-off grades, they would arrive at different estimates. For these reasons, reserves may be much more noisy than estimated production.

The market seems to take diversification into account when determining exposures. In all the non-fixed-effects models, the percentage of assets in mining has a strong and statistically significant impact on the observed beta, as predicted. As the percentage of assets devoted to mining increases, gold price exposure increases. The magnitude of the coefficient on the diversification variable is sensible; betas of a firm with none of its assets in mining and another with all of its assets in mining would differ by 1.7 to 2.0, which is approximately equal to the mean beta in the sample.

When one estimates the model using fixed effects, there appears to be no statistically significant relationship between the amount of diversification and the level of gold price exposure, and the sign of the coefficient becomes negative. However, this result should not be construed to mean that diversification doesn't matter; rather a plausible, alternative interpretation is that investors understand and react to permanent levels in diversification,

[14] To test this, I normalize the hedging/reserves and hedging/production distributions to the range [0, 1]. The data show that hedging/reserves actually has *higher* variability than hedging/production, with a larger normalized standard deviation (0.10 vs. 0.09) and a larger normalized interquartile range (0.093 vs. 0.089).

but place less emphasis on quarter-by-quarter changes, which may not be persistent. The negative sign in the fixed-effects specification could indicate that investors may expect short-term deviations from long-run diversification to be quickly reversed.

In the pooled, non-fixed-effects specifications, there is a positive relationship between financial leverage and measured exposures, and in the joint estimation specifications, this coefficient is statistically significant. The parameter estimates indicate that if a firm leverage (measured as the book value of debt divided by the market value of equity) is higher by one standard deviation, or 0.59, its observed beta would be 0.14 to 0.22 higher. In the fixed-effects specification, the leverage impact disappears; it is plausible that investors take into account a firm's long-run leverage (or target capital structure) in determining its exposure to gold, but pay less attention to quarter-to-quarter changes in the observed leverage. These results are unchanged when I use net debt (debt less cash holdings) as a measure of leverage. Under FGLS and Fama–McBeth estimation procedures, the leverage effect becomes statistically insignificant (p-values of 0.6 to 0.7), suggesting that although there may be a positive relationship between leverage and exposures, it is sensitive to the estimation procedure chosen.

Contrary to the predictions of the valuation models, firms' operating costs, measured directly by cash costs, are *not* materially associated with the level of exposure in any of the specifications. This result is quite unexpected, because the firm's cost structure should have a material impact on its operating leverage and the degree to which this leverage amplifies price shocks. (Perhaps the cash cost data are not very good; however they are commonly regarded by analysts as the best information available on firms' costs of extracting gold.) It is also curious that although the level of production should be inversely related to exposures, either there is no relationship between production levels and betas (columns B, C, E, and F), or a positive relationship.

A possible clue to explain these results might be found in the correlations shown in Table IV, Panel B. Production quantities are positively correlated with reserves, and negatively with costs; and the correlations among these independent variables are greater than their correlations with the dependent variable. The valuation models suggest that costs, production quantities, and reserves must all be included in the regression, but it becomes difficult to interpret the results when all of these multicollinear variables are included. In such a situation, it is common practice to drop multicollinear variables from the analysis as a diagnostic tool.[15]

In Table VI (Columns A through D), I reestimate the relationship from the prior table, introducing the size-related variables (cash costs, production quantities, and reserves) one at a time. The table also introduces another correlated firm-size variable: the market value of the firm, measured as the average market value of the firm's equity plus the book value of its debt. From the

[15] Greene (1993) discusses other alternatives (ridge regression and principal components analysis), but these methods have the disadvantage of creating biased estimators.

Table VI

Impact of Firm Size on Gold Price Exposures

This table reports the results of multivariate analyses of the factors affecting the gold betas of North American mining firms. The dependent variable is the Dimson-adjusted gold price beta, calculated by firm each quarter, using daily data. In the first four columns, the adjusted beta includes one lead and one lag term, and in the second four columns, it includes two lead and lag terms. Delta-percentage-of-production (or reserves) represents the delta-equivalent of the ounces of gold shorted in the firm's risk management program divided by its average annual production over the coming three years (or total reserves). This analysis adds firm size, measured as the market value of the firm's equity plus the book value of its debt. This analysis is conducted on the full pool, without fixed effects. t-statistics are calculated using White (1980) robust standard errors. p-values are reported in parentheses.

	Dependent Variable							
	Dimson Beta with One Lead/Lag				Dimson Beta with Two Leads/Lags			
Independent Variables	A	B	C	D	E	F	G	H
Intercept	9.06	8.95	9.05	13.40	8.57	8.49	8.62	8.86
	(0.003)	(0.003)	(0.003)	(0.000)	(0.043)	(0.046)	(0.043)	(0.029)
Average gold price	−0.022	−0.022	−0.022	−0.034	−0.022	−0.022	−0.022	−0.022
	(0.011)	(0.012)	(0.011)	(0.000)	(0.064)	(0.066)	(0.061)	(0.080)
Gold return volatility	−3.64	−3.70	−3.65	−3.32	−4.31	−4.32	−4.32	−4.42
	(0.105)	(0.100)	(0.105)	(0.109)	(0.044)	(0.044)	(0.043)	(0.038)
Gold reserves (oz mil)	0.0332				0.0194			
	(0.001)				(0.160)			
Gold production (oz mil)		0.550				0.289		
		(0.000)				(0.113)		
Market value (millions US $)			8.4E−05				3.0E−05	
			(0.082)				(0.643)	
Cash costs ($/oz)				−2.0E−04				−2.3E−03
				(0.924)				(0.439)
Leverage (debt/equity ratio)	0.13	0.14	0.09	0.33	0.29	0.30	0.27	0.30
	(0.661)	(0.624)	(0.766)	(0.163)	(0.012)	(0.010)	(0.022)	(0.020)

Delta-percent-of-production	−0.52	−0.47	−0.51	−0.81	−0.94	−0.89	−0.92	−0.90
	(0.021)	(0.041)	(0.034)	(0.000)	(0.007)	(0.009)	(0.009)	(0.008)
Avg-forward-contract price/production	−5.5E−04	−6.3E−04	−6.0E−04	−7.0E−04	5.8E−04	5.2E−04	5.6E−04	6.2E−04
	(0.179)	(0.114)	(0.145)	(0.091)	(0.289)	(0.337)	(0.301)	(0.262)
Percentage of assets in mining	0.018	0.018	0.020	0.021	0.024	0.024	0.025	0.026
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Firm dummies	No	No	No	No	No	No	No	No
Number of observations	398	398	398	398	398	398	398	398
Adjusted R^2	0.206	0.209	0.199	0.218	0.088	0.089	0.085	0.087
F-statistic	13.90	14.12	13.43	12.88	6.49	6.53	6.27	6.42

table we cannot conclude that multicollinearity is an obvious explanation for the lack of a relation between costs and betas. Even when other multicollinear size variables are omitted, cash costs have no significant relationship with betas. Additionally, when one adds reserves, production, market value, and costs to the regression one at a time, each of these three measures—which are alternative measures of firm size—is *positively* related to betas. Larger firms experience gold shocks more strongly.[16]

One possible explanation for a systematic positive relationship between firm size and betas is that information is impounded into the prices of larger firms faster than into smaller firms. In the correction of betas for nonsimultaneous trading, I use one lead and one lag term because adding more terms does not affect the *average* beta for the sample. However, failing to use more terms could systematically underestimate betas for firms that tend to trade less frequently. If smaller firms tend to be less frequently traded, this would lead to a systematic underestimate of their exposures. To examine this possibility, I conduct two analyses. First, I stratify the sample in quartiles by firm size (the market value of equity), and examine whether adding more than one lead and lag term affects small firms' adjusted betas differently than it does larger firms. For all four size quartiles, going from zero to one lead/lag term in the correction process leads to a significantly different mean measured beta, with the *t*-statistic on the differences between these means being significant at 0.0001 or higher. In *none* of the four size quintiles, including the smallest firms, did adding two or three lead/lag terms lead to a significant change in mean betas, as defined above. This evidence is inconsistent with the speculation that betas are systematically misestimated for smaller firms using a single lead/lag term.

As a second test of whether misestimation of betas might provide the explanation for a relationship between firm's size and betas, in Table VI, columns E through H, I reestimate the OLS model using a dependent variable that is the Dimson beta with *two* leads and lags. Adding a second set of lead/lag terms decreases the explanatory power of the model substantially, with the R^2's falling by about 60 percent. Although most of the results described above persist or are statistically strengthened using the 2-lead/lag beta, the size-based relationships with betas all become marginal or insignificant. This evidence suggests that the size effect is capturing something about the speed at which prices adjust to gold shocks. However, the reduced level of explanatory power of the analysis leads one to question whether the longer lead/lag period introduces unnecessary noise to the beta estimation and thereby makes these results suspect.

Finally, there is evidence that the betas explain less of the variation in the values of smaller firms than of larger firms. In a separate analysis, I calculate the correlation between the adjusted R^2 of the Dimson beta estimates

[16] The table only shows results for the separate estimation (no fixed effects) to save space. With the joint estimation, the coefficients on the size and cost variables are the same magnitude, but *p*-values tend to be lower.

from Table II with production, reserves, and market value. The three size variables are each strongly and positively correlated with the beta estimation model's goodness-of-fit (the correlations of adjusted R^2 with production, reserves, and firm value are 0.60, 0.60, and 0.47, and each of these is significant at the 0.01 level). This may simply reflect that the level of idiosyncratic risk (and hence unexplained variation in prices) is greater for smaller firms than for larger firms.

In fixed-and-level production models, gold betas are not a function of interest rates, as interest rates proportionally affect the change in the value of the firm and the market value of the firm. However, with nonlevel production, interest rates can affect betas. To test this proposition, I interact interest rates with a dummy that equals one if the firm experienced a positive growth rate of production calculated over the period 1990 through 1994.[17] In Table VII, column A shows the relationship between interest rates (proxied by the ten-year bond yield) and betas, and column B adds the interaction term. There is a negative relationship between rates and betas, but for firms with growing production levels, the interaction term is strongly positive, as predicted.

In Brennan and Schwartz's model, the convenience yield on gold (or gold lease rate, which they use to value the revenues from the mine) has positive impact on betas, and the firm's cost of capital (which they use to value the costs of production) has a negative impact on betas. Column C shows the gold lease rate by itself, and column D incorporates both the gold lease rate and the ten-year Treasury yield. When one includes both the gold lease rate and the long-bond rate, both have a negative, but statistically weak, relation to the gold betas. The negative relation between the gold lease rate and betas is inconsistent with predictions of their model.

V. The Levels of Predicted and Observed Exposures

The analysis in the prior sections examines whether differences among gold betas are consistent with the comparative statics of valuation models. Yet, by applying accounting data to the models described in Section II, one can calculate predicted levels of exposures analytically. In this section I test whether the levels of *empirically observed betas* correspond to the *analytically predicted betas*.

A. Calculating Analytically Predicted Betas

In principle, the flexible-production model is a better description of gold mines than is the fixed-production model. However, I lack the relevant firm-level data to estimate the former, such as closing and reopening costs for

[17] Growth rates are calculated from four-year compound annual growth rates. The firm's growth rate is signed using all four years of data. There are 254 firm-quarters associated with firms with positive growth rates, and 144 firm-quarters associated with negative growth rates.

Table VII

Impact of Interest Rates on Gold Price Exposures

This table reports the results of multivariate analyses of the factors affecting the gold betas of North American mining firms. The dependent variable is the Dimson-adjusted gold price beta, calculated by firm each quarter, using daily data. The independent variables are listed in the table, and fixed effects are not included. Delta-percentage-of-production represents the delta equivalent of the ounces of gold shorted in the firm's risk management program divided by its average annual production over the coming three years. Additional dependent variables are the average yield on ten-year Treasury bonds, and the one-month gold lease rate, and an interaction term which is the product of the ten-year Treasury bonds times a dummy that equals one if the firm's production growth rate was positive in the period 1990 through 1994. t-statistics are calculated using White (1980) robust standard errors. p-values are reported in parentheses.

	Separate Estimation, No Fixed Effects			
Independent Variables	A	B	C	D
Intercept	14.35	14.54	13.56	14.47
	(0.000)	(0.000)	(0.000)	(0.000)
Average gold price	−0.035	−0.035	−0.035	−0.036
	(0.000)	(0.000)	(0.000)	(0.000)
Gold return volatility	−1.48	−1.59	−2.28	−1.06
	(0.518)	(0.479)	(0.312)	(0.649)
Gold production (oz mil)	0.417	0.301	0.434	0.424
	(0.103)	(0.242)	(0.090)	(0.097)
Gold reserves (oz mil)	−0.003	−0.006	−0.004	−0.003
	(0.873)	(0.746)	(0.845)	(0.855)
Cash costs ($/oz)	0.001	0.000	0.001	0.001
	(0.787)	(0.881)	(0.747)	(0.769)
Leverage (debt/equity ratio)	0.36	0.38	0.36	0.36
	(0.136)	(0.125)	(0.136)	(0.144)
Delta-percent-of-production	−0.862	−0.888	−0.781	−0.846
	(0.000)	(0.000)	(0.001)	(0.000)
Avg-forward-contract price/ production	−4.3E−04	−5.3E−04	−8.1E−04	−5.2E−04
	(0.305)	(0.214)	(0.047)	(0.240)
10-year T-bond rate	−0.152	−0.202		−0.120
	(0.033)	(0.003)		(0.146)
10-year T- bond rate × growing production dummy		0.086		
		(0.003)		
Gold lease rate			−0.278	−0.226
			(0.055)	(0.166)
Percentage of assets in mining	0.021	0.018	0.020	0.020
	(0.000)	(0.000)	(0.000)	(0.000)
Number of observations	398	398	398	398
Adjusted R^2	0.209	0.227	0.209	0.209
F-statistic	11.49	11.61	11.52	10.58

plants, costs of switching among various ore grades, mining technologies employed, etc. Given these constraints, I use a fixed-production (or discounted cash flow) model to predict betas. I modify the fixed-production model, allowing the firm to sell forward a portion α of the *next three years* of production Q with a forward contract which stipulates that the firm will receive a payment of W per ounce of gold at the time of delivery. In this modified fixed-production/hedging model, a firm's gold beta would be:

$$\beta^* = \frac{P}{V}\frac{\partial V}{\partial P} = \frac{\displaystyle\sum_{i=1}^{3} \frac{(1-\alpha)QP(1-\tau)}{(1+r)^i} + \sum_{i=1}^{N} \frac{QP(1-\tau)}{(1+r)^i}}{V}. \tag{10}$$

Many of the parameters in this expression have already been discussed: Q is the mine's annual production, P is the average market price of gold over the year, α is the delta-percentage of production over the coming three years, and N is Reserves/Production. We observe V, the market value of the firm, which equals the market value of its equity plus the book value of its debt. Using the value of the firm as an observable quantity frees one from having to separately estimate cost elements, nongold operations, and the price at which gold has been sold forward. As one needs to discount only gold revenues in the numerator, one can use the convenience yield for gold (gold lease rate) as the discount factor for the spot prices, which is essentially analogous to discounting the forward prices by the risk-free rate (see Brennan and Schwartz (1985)). Finally, one needs a tax rate τ, for which I use the average tax rate for the sample over the four-year period studied (12 percent), taken from COMPUSTAT.[18] The analytically predicted fixed-production betas (β^*) are calculated annually in the period 1990 to 1993, with data constraints limiting the sample to 139 useable firm-year observations, reflecting 46 firms. I recalculate Dimson-adjusted betas, β_g, using daily data over the same annual periods.

B. Comparing Analytically Predicted and Empirically Observed Betas

Figure 2 and Table VIII show the plot of empirically observed and analytically predicted betas (β_g and β^*, respectively), as well as the descriptive statistics for the two quantities. Even though the fixed-production model is quite simple, its mean analytically predicted beta (2.16) is statistically indistinguishable from the mean empirically observed beta (1.96). However, inspection of the scatter plot as well as the higher moments of these two distributions suggests that the fixed-production predictions have a wider range, higher variance, excess kurtosis, and more pronounced skewness than do empirically observed betas. Visually, it appears that the fit is reasonably good, up to a point where predicted betas rise above about three.

[18] This average rate is 12 percent for the sample, and this low rate seems to result from various mining taxes, subsidies, progressive rates for smaller companies, and carryforwards. The results presented here do not change if one uses a statutory marginal rate of 34 percent.

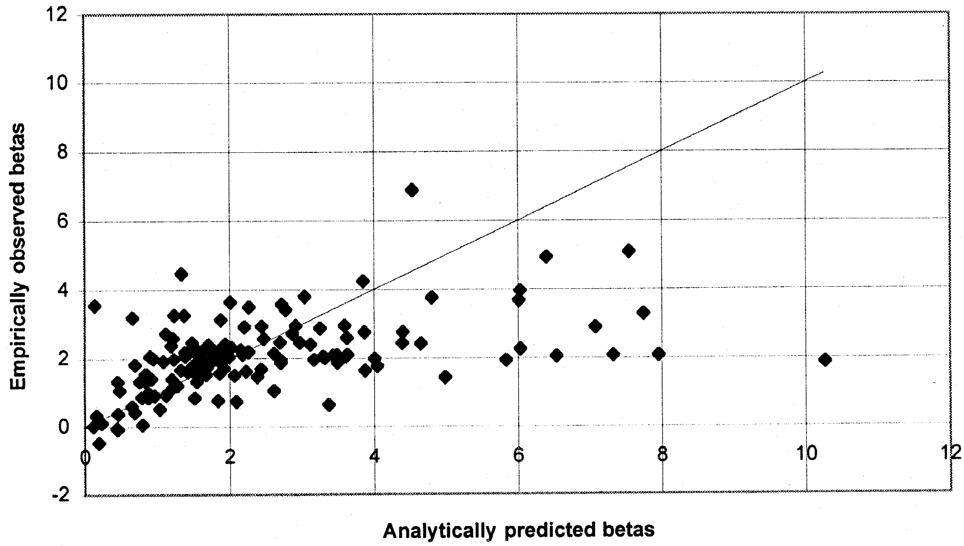

Figure 2. The relationship between empirically observed and analytically predicted betas. This figure plots empirically observed betas and analytically predicted fixed-production betas (β_{ig} and β^*, respectively). The analytically predicted fixed-production betas are calculated annually in the period 1990 to 1993 using accounting and stock price data and equation (10) in the paper. Data constraints limit the sample to 139 useable firm-year observations, reflecting 46 firms. The empirically observed betas β_{ig} are recalculated using the two-factor market model with daily data over the same annual periods. The betas are adjusted for nonsynchronous trading using the method proposed by Dimson (1979) and Fowler and Rorke (1983). The line represents those points where the empirically observed betas and the analytically predicted betas are equal.

To more formally test the goodness-of-fit of the analytically predicted production betas, I estimate the OLS fit of the equation

$$\beta_{ig} = \alpha_0 + \alpha_1 \beta_i^* + \epsilon, \tag{11}$$

where β_{ig} and β_i^* are defined above. If the fixed-production model is the proper model of gold price valuation, and if the two betas are measured without error, then α_0 should equal zero, α_1 should equal one, and the R^2 on this fit should be 1.0. There is reason to suspect that the fixed-production model may become a worse approximation of reality when it predicts high gold-price exposures. In these instances, for example where gold prices fall close to a firm's variable costs, firms may exercise real options to shut-in mines, change ore grades, and change production technologies, thereby lowering their exposures. Given this, I estimate equation (11) using a piecewise linear regression, testing the performance of the fixed-production model in different regimes. Table IX reports these results.

Table VIII

Distribution of Empirically Observed and Analytically Predicted Betas

This table shows the distribution of empirically observed betas and analytically predicted fixed-production betas (β_{ig} and β^*, respectively). The analytically predicted fixed-production betas are calculated annually for the period 1990 to 1993 using accounting and stock price data and equation (10) in the paper. Data constraints limit the sample to 139 useable firm-year observations, reflecting 46 firms. The empirically observed betas β_{ig} are recalculated using the two-factor market model with daily data over the same annual periods. The betas are adjusted for nonsynchronous trading using the method proposed by Dimson (1979) and Fowler and Rorke (1983).

	Distribution of Betas		
	Empirically Observed	Analytically Predicted	Test of Equality
Mean	1.96	2.16	−1.36
Standard error	0.08	0.14	
Median	1.97	1.66	6.32*
Standard deviation	0.94	1.65	
Sample variance	0.88	2.74	
Kurtosis	0.31	3.11	
Skewness	−0.13	1.65	
Range	5.33	9.27	

*Significant at the 0.01 level.

If we examine the entire sample all together, it appears as if the fixed-production model has little predictive power. Although there is a positive and statistically significant relation between the analytically predicted and empirically observed betas, one can reject that α_1 (0.14) equals one, and that α_0 (1.61) equals zero. However, when I estimate the model using a piecewise specification, dividing the sample into two, and then four, equal segments on the basis of the predicted beta, the intercept becomes statistically indistinguishable from zero, and the coefficient on the analytically predicted beta becomes indistinguishable from one, at least in the range of observations where the fixed-production model's estimate is below the median. For example, when one divides the data into quartiles defined by the analytically predicted beta, one cannot reject the hypotheses that α_0 equals zero, and that α_1 in the first two regions equals one. The surprisingly good news is that the simple fixed-production model—implemented using relatively crude accounting and stock price data—produces informative predictions of betas, at least for moderate levels of analytically predicted exposures. The bad news is that, above a certain point, observed exposures appear capped, and the analytical model systematically overestimates exposures.

Table IX

Piecewise Regressions of Empirically Observed Betas and Analytically Predicted Betas

This table shows the results of the regression $\beta_{ig} = \alpha_0 + \alpha_1\beta_i^* + \epsilon$ where β_{ig} and, β_i^* are given by equations (1) and (10) respectively, and the index i corresponds to a firm-year observation for the period 1990–1993. The Dimson-adjusted empirical gold betas β_{ig} are calculated using equation (1) for each firm-year using daily market and gold return data. In addition to the regression coefficients, I show in parentheses the t-statistics of the t-test: H_0: $\alpha_0 \neq 0$ and the t-test H_0: $\alpha_1 \neq 1$. Panel A shows the results of the regressions for the entire 139 observations for the fixed and flexible production models. Panel B shows the results of a two-segment piecewise linear regression, where the breakpoint occurs at the median expected beta. Panel C shows the coefficients and tests for a four-segment piecewise linear regression where the breakpoints are at the first quartile q_1, the median q_2, and the third quartile q_3.

Panel A: Piecewise Regression: One Region	
α_0	1.61
	(12.72)***
α_1	0.14
	(416.75)***
Adjusted R^2	0.068
Panel B: Piecewise Regression: Two Regions	
α_0	0.53
	(2.31)**
$\alpha_{1,1}$	0.96
$\beta <$ median ($N = 70$)	(0.06)
$\alpha_{1,2}$	−0.03
$\beta >$ median ($N = 69$)	(434.44)***
Adjusted R^2	0.230
Note: Median beta	1.873
Panel C: Piecewise Regression: Four Regions	
α_0	0.17
	(0.531)
$\alpha_{1,1}$	1.42
$\beta < q_1$ ($N = 35$)	(1.705)
$\alpha_{1,2}$	0.50
$q_1 < \beta < q_2$ ($N = 35$)	(1.852)
$\alpha_{1,3}$	0.15
$q_2 < \beta < q_3$ ($N = 35$)	(17.92)***
$\alpha_{1,4}$	−0.05
$\beta > q_3$ ($N = 34$)	(200.34)***
Adjusted R^2	0.234
Note: First quartile beta (q_1)	1.216
Median beta (q_2)	1.873
Third quartile beta (q_3)	3.166

***, ** Significant at the 0.001 and 0.01 levels, respectively.

C. Possible Explanations

The fixed-production model may systematically misestimate betas for a variety of reasons. This error can arise from the simple model's failure to account for the dynamics of the gold market, real options held by firms, financial options held by equity-holders of firms, and the empirical regularity that larger firms tend to have more gold price exposure.

If price changes are mean-reverting, gold betas would be smaller, that is, current values would move less in reaction to short-run movements in gold prices than if shocks are permanent. Bessembinder et al. (1995) estimate mean reversion parameters for a variety of commodities. While they find substantial mean reversion in some commodities (e.g., 55 percent of spot oil price shocks are reversed over the subsequent eight months), there is much less mean reversion in gold prices. After eight months, only 5.7 percent of shocks to gold prices are reversed. To account for possible mean reversion, I revise equation (10) to accommodate mean reversion. Even extraordinarily high levels of mean reversion (50 percent per annum) are too small to explain the magnitude of divergence of actual and observed betas.

A second, and more likely, explanation for the systematic overprediction of betas results from the fixed-production model's unrealistic assumptions about firm policies. As discussed earlier, the fixed-production model will overestimate exposures when firms adjust operating policies in response to market conditions. For example, if costs increase with gold prices, the expected beta is smaller than if costs are fixed. There is some evidence that operational flexibility is very relevant in this industry. The data in Table IV show a strong positive correlation between cash costs and the market price of gold, which is consistent with firms changing their extraction plans conditional on gold prices. (In their examination of two mining firms, Petersen and Thiagarajan (1996) find a similar result.) In addition to the optionality to shut mines, firms also have the option to obtain additional gold, through either exploration and acquisition. To the extent that the fixed-production model ignores these options, it may misestimate exposures (and underestimate them).

Another important simplification in the fixed-production model used to estimate betas is its failure to account for the fact that the equity in the gold mine is a financial option, or, more precisely, a call on the assets of the firm. In the fixed-production model, leverage—like other fixed costs—increases betas. However, just as equity holders can voluntarily choose not to produce and thereby exercise their real option, they can voluntarily choose not to pay the fixed costs due to debt, and thereby put the firm back to the debtholders. By ignoring this financial option, one would overestimate a levered firm's gold beta, when compared to the beta of a firm with the same level of fixed costs, but which costs it was unconditionally *committed* to make.

Sheer firm size (e.g., the amount of reserves held by a firm) would not affect betas under any of our models. However, as noted earlier, there is some evidence that firm size is positively related to gold exposures in that firms with larger production, larger reserves, and larger market values have larger betas. If the fixed-production model fails to capture this factor, then it might cause a systematic bias.

D. Factors Associated with Model Error

To test whether these factors can help explain the model's systematic errors, Table X compares observations for which the fixed-production model works better and worse with respect to the factors listed above (operating flexibility, financial flexibility, and firm size). To identify where the fixed-production model works poorly, I categorize firm-year observations using two sets of criteria: (1) the empirically observed beta is more than 0.5 larger or smaller than the analytically predicted beta; or (2) the empirically observed beta is more than 50 percent larger or smaller than the analytically predicted beta. Using these partitions of the data, I examine whether there are any systematic differences between observations where the model seems to estimate betas reasonably well, and where it over- and underestimates them.

In terms of *cost flexibility*, there is no evidence that firms whose betas the model systematically overpredicts are those with a wider range of realized cash costs and more cost flexibility. To gauge the flexibility firms have to adjust costs, I calculate the variability of annual realized cash costs per ounce (over the period 1990 through 1994), measured as the range between each firm's highest and lowest cash costs, as well as this range normalized by its average costs. The obvious flaw in this measure, however, is that it reflects the realized flexibility in costs, not the potential flexibility in costs. In theory, a better measure could be constructed by analyzing the coefficients from costs as a function of production quantity and gold price, but with only four years of cost data, this approach is impractical.

To identify *flexibility to add new mines*, I collect information on the firms' acquisition and exploration activities, which might reflect their ability to acquire additional gold assets. Acquisition activities are measured by the total acquisitions announced (but not necessarily completed) over the prior three years, divided by the market value of the firm. Exploration activities are measured by annual exploration expenses divided by the market value of the firm. The degree to which the fixed-production model misestimates betas does not seem related to either of these variables.

As gold prices fall closer to a firm's operating costs, and a firm comes closer to *distress*, two types of optionality come into play. At an operating level, the firm can shut in production, exercising its real options. Alternatively, the equity-holders can exercise their financial option to default on debt and put the firm back to the debtholders. Under either scenario, overpredictions of betas by the fixed-production model should be more pronounced when the margin between a firm's cash costs and the price of gold narrows. Observations where the fixed-production model's overestimates exceed 0.5 have price-cost margins 22 percent lower.

Table X

Characteristics of Firms Partitioned by Level of Analytically Predicted Fixed-Production Beta

This table compares the characteristics of firms partitioned by how well the fixed-production model's analytically predicted gold beta estimates the empirically observed gold beta. Observations are categorized by the divergence between empirically observed betas against analytically predicted betas, defined as ±0.5 in the second set of columns and within 50 percent of the analytically predicted beta. Acquisition activities/firm size is measured as the dollar value of attempted acquisitions over the prior three years scaled by firm market value. Exploration activities/firm size is the dollar value of exploration expenditures and expenses divided by firm market value. I test the differences between the within-range sample and the below- and above-range samples, and only report the significance levels of the t-statistics to conserve space.

	Range = (Predicted ± 0.5)			Range = (0.5*Predicted, 1.5*Predicted)		
	Observed Within Range	Observed Below Range	Observed Above Range	Observed Within Range	Observed Below Range	Observed Above Range
		(Overprediction)	(Underprediction)		(Overprediction)	(Underprediction)
Number of observations	49	48	42	85	26	28
Number of firms	28	25	26	39	19	29
Average analytically predicted beta	1.56	4.11***	1.44	2.33	4.09***	1.05***
Average empirically observed beta	1.59	1.82	2.54***	2.09	1.09***	2.33
Operating flexibility						
Range of cash costs (max-min)	$63.9	$46.9	$47.8	$50.8	$60.0	$58.6
Range/Average costs	0.31	0.21*	0.24	0.25	0.28	0.29
Call options on gold						
Acquisition activities/firm value	0.10	0.16	0.10	0.12	0.16	0.09
Exploration activities/firm value	0.02	0.02	0.02	0.02	0.02	0.02
Financial and operating options						
Gold price-cash costs (US$)	$169	$131**	$165	$154	$143	$169
Leverage	0.25	0.41*	0.36	0.23	0.54**	0.49
Firm size						
Market value (M US$)	$1365	$373***	$1156	$996	$655	$1130
Production (M oz.)	0.48	0.20**	0.54	0.48	0.13***	0.43
Reserves (M oz.)	6.85	3.27**	6.55	6.66	2.00***	5.32
Other characteristics						
Percentage of assets in mining	83%	95%*	94%*	94%	81%	89%
Production hedged (%)	28%	24%	27%	23%	30%	31%
Interest rates						
Gold lease rate	1.02%	1.02%	0.98%	0.99%	1.03%	1.00%
1-year Treasury Bill	5.18%	5.30%	4.42%*	4.92%	5.50%	4.74%
10-year Treasury Bond	7.32%	7.38%	6.78%	7.15%	7.55%*	6.93%

***, **, * Significant at the 0.001, 0.01, and 0.10 levels, respectively.

The financial flexibility to put the firm back to its debtholders is only relevant for levered firms. Therefore, I examine whether model error is related to leverage levels. The analytically predicted betas account for differences in total cost; therefore, by partitioning by leverage, I can examine whether firms with higher debt charges have systematically misestimated betas. As predicted, firms where the fixed-production model seems to overpredict betas are those with greater debt—firms that therefore might be able to exploit the financial option to put the firm to its lenders. Firms whose betas are overpredicted have 64 to 130 percent more debt (expressed as a fraction of firm value) than do firms where model error is small.

Finally, the model seems to systematically overpredict betas for *smaller firms*, where firm size is defined by either market value, production, or reserves. Firms for which the fixed-production model overestimates betas are 34 to 70 percent smaller than firms for which the model error is small. The systematic failure of the model to deal with firm size underscores the observation that firm size seems to have a positive impact on exposures. This size discrepancy persists when using observed betas calculated using two lead and lag terms, so it cannot be attributed to a failure to adjust betas for nonsimultaneous trading over a sufficiently long time-window.

Where does the simple fixed-production model seem to break down? A fixed-production (or naive discounted cash flow) model is a poor predictor of exposures for small, highly levered mining companies with thin margins. One plausible interpretation of this finding is that the managers of these firms have many options—both operational and financial—that the naive model fails to capture. This confirms the findings of Berger, Ofek, and Swary (1996) and Davis (1996) that markets take real optionality into account in valuations.

VI. Conclusions

This paper investigates the determinants of exposures, using gold mining firms as the laboratory in which to study this question. I document that there is substantial cross-sectional and time-series variation in gold betas. Because of the latter, it is important to use high frequency (daily) data to measure exposures, requiring the adjustments first suggested by Scholes and Williams (1977). With these types of adjustments, one can measure quarterly exposures confidently.

The paper constructs models of gold firm valuation to determine the factors that should influence gold price exposure, and then tests whether the observed exposures are well predicted by the models. As predicted, gold exposures are negatively related to the level of the gold price, the volatility of gold prices, the degree to which the firm has activities outside mining, and the amount of hedging done by the firm, at least as measured by the percentage of near-term production that is hedged. Also, as predicted by theory, the amount of exposure is positively related to the amount of financial leverage held by the firm. The study finds no evidence that gold price exposures are related to the firm's operating cost structure. Finally, exposures seem larger for larger firms, where firm size is measured by either current production, reserves, or market value, although part of this result might be attributable to the slower speed at which the prices of smaller firms seem to adjust to new information.

The paper provides evidence that very simple valuation models, such as those assuming that firms follow a fixed-production schedule, can be applied to make useful inferences about the empirically observed levels of gold price exposure. The limitations of these models is their failure to capture the relationship between firm size and exposures, and to fully incorporate operating and financial flexibility, which leads to overestimates of predicted exposures at certain levels.

The study shows that capital markets take firm-specific and market-specific factors into account when determining exposures of firms and, if given information on hedging activities, incorporate it into their valuation of the firms. Financial engineering has played a material role in changing the risk exposures of gold mining firms, and the stock market recognizes this reality.

REFERENCES

Bartov, Eli, and Gordon Bodnar, 1994, Firm valuation, earnings expectations, and the exchange rate exposure effect, *Journal of Finance* 44, 1955–1985.

Berger, Philip, Eli Ofek, and Itzhak Swary, 1996, Investor valuation of the abandonment option, *Journal of Financial Economics* 42, 257–287.

Bessembinder, Hendrik, Jay Coughenour, Paul Seguin, and Margaret Smoller, 1995, Mean reversion in equilibrium asset prices: Evidence from futures markets, *Journal of Finance* 50, 361–375.

Bilson, John F. O., 1994, Managing economic exposure to foreign exchange risk: A case study of American Airlines, in Yakov Amihud and Richard M. Levich, eds., *Exchange Rates & Corporate Performance* (New York University Stern School of Business, New York).

Blose, Laurence E., and Joseph C. P. Shieh, 1995, The impact of gold price on the value of gold mining stocks, *Review of Financial Economics* 4, 125–139.

Brennan, Michael J., 1990, Latent assets, *Journal of Finance* 65, 709–730.

Brennan, Michael J., and Eduardo S. Schwartz, 1985, Evaluating natural resource investments, *Journal of Business* 58, 135–157.

Brimelow, John, 1996, Gold: The hazards of hedging, *Forbes*, February 12, 1996, p. 180.

Brown, David, and Scott Hoover, 1996, Returns on gold-mine shares, Unpublished manuscript, University of Indiana, Bloomington.

Davis, Graham, 1996, Option premiums in mineral asset pricing: Are they important?, *Land Economics* 72, 167–186.

Dimson, Elroy, 1979, Risk measurement when shares are subject to infrequent trading, *Journal of Financial Economics* 7, 197–220.

Fama, Eugene, and James McBeth, 1973, Risk, return and equilibrium: Empirical tests, *Journal of Political Economy* 71, 607–636.

Flannery, Mark J., and Christopher M. James, 1984, The effect of interest rate changes on the common stock returns of financial institutions, *Journal of Financial Economics* 39, 1141–1153.

Fowler, David J., and C. Harvey Rorke, 1983, Risk measurement when shares are subject to infrequent trading comment, *Journal of Financial Economics* 12, 279–283.

French, Kenneth R., Richard S. Ruback, and G. William Schwert, 1983, Effects of nominal contracting on stock returns, *Journal of Political Economy* 91, 70–96.

Greene, William H., 1997. *Econometric Analysis* (Macmillan Publishing, New York).
Hu, Henry, 1996, Behind the corporate hedge: Information limits of "shareholder wealth maximization," *Journal of Applied Corporate Finance* 9, 39–51.
Jorion, Philippe, 1990, The exchange-rate exposure of U.S. multinationals, *Journal of Business* 63, 331–345.
Kolb, R. W., 1991. *Understanding Futures Markets* (Kolb Publishing Company, Florida).
Mardones, Jose L., 1993, Option valuation of real assets: Application to a copper mine with operating flexibility, *Resources Policy 19*, 51–65.
McDonald, John G., and Bruno H. Solnik, 1977, Valuation and strategy for gold stocks, *Journal of Portfolio Management* 3, 29–33.
Petersen, Mitchell, and S. Ramu Thiagarajan, 1996, Risk measurement and hedging, Unpublished manuscript, Northwestern University.
Reeve, Ted, *North American Gold Monitor* (First Boston Corporation, Feb. 1990, May 1990, Aug. 1990, Nov. 1990, Feb. 1991).
Reeve, Ted, *Global Gold Hedge Survey* (First Boston Corporation, June 1991, Aug. 1991, Nov. 1991, Feb. 1992, June 1992, Sept. 1992, March 1993).
Reeve, Ted, *Gold Hedge Survey* (Sanwa McCarthy Securities, Aug. 1993, Dec. 1993).
Reeve, Ted, *Gold Hedge Survey* (Burns Fry Limited, Feb. 1994).
Scholes, Myron, and Joseph Williams, 1977, Estimating betas from nonsynchronous data, *Journal of Financial Economics* 5, 309–327.
Scott, William L., and Richard L. Peterson, 1986, Interest rate risk and equity values of hedged and unhedged financial intermediaries, *Journal of Financial Research* 9, 325–329.
Strong, John S., 1991, Using oil share portfolios to hedge oil price risk, *Quarterly Review of Economics* 31, 48–63.
Sweeney, Richard J., and Arthur D. Warga, 1986, The pricing of interest rate risk: Evidence from the stock market, *Journal of Finance* 41, 393–409.
Tufano, Peter, 1996, Who manages risk? An empirical analysis of risk management practices in the gold mining industry, *Journal of Finance* 51, 1097–1138.
Tufano, Peter, and Jon Serbin, 1993, American Barrick Resources Corporation: Managing gold price risk, Harvard Business School case number 293-128.
White, Halbert S., 1980, A heteroscedasticity-consistent covariance matrix estimator and a direct test for heteroscedasticity, *Econometrica* 48, 817–838.