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to the source.
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ABSTRACT

Conventional economic theory assumes that firms always minimize costs given the output they produce. News articles and interviews with executives, however, indicate that firms from time to time engage in cost-cutting exercises. One popular belief is that firms cut costs when they are in economic distress, and grow fat when they are relatively wealthy. We explore this hypothesis by studying the response of the stock market values of gold mining companies to changes in gold prices. The value of a cost-minimizing, profit-maximizing firm is convex in the price of a competitively supplied input or output, but we find that the stock values of many gold mining companies are concave in the price of gold. We show that this is consistent with fat accumulation when a firm grows wealthy. We then address a number of potential alternative explanations and discuss where fat in these companies might reside.

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I. Introduction

Organizations do not generally minimize costs or maximize value. There is sheer inefficiency or rent dissipation. These stark and — to economists, although probably only to economists — mildly shocking hypotheses suggest a variety of economic research topics. In this paper we take a simple empirical look at one possible measure of the importance of such "fat," by testing a rather general theoretical property of value maximization. The empirical results suggest that many gold mining companies grow fat when they get rich, and that the amounts concerned may be quite large.

In section II, we present an approach to diagnosing wealth-related rent dissipation. Our approach is to estimate the second derivative of the value of the firm as a function of (exogenous) prices: simple maximizing theory would imply that this value function should be convex, while we show that if wealth creates fat, the value function may tend to be more concave.

We apply this approach to the gold mining industry in section III, estimating the relationship between the price of gold and the stock market valuation of 17 gold mining firms. We find that in many of the firms the relationship is significantly concave, as the "fat" theory might suggest, and contrary to the simple maximizing theory.

Section IV discusses a number of possible alternative explanations for the significant concavity that we find in the valuation function of nearly half the firms in our sample. Section V asks where the fat may plausibly be coming from. We conclude in section VI.

II. The Response of Firm Value to Price Shocks

A. *The Value Response of a Fat-Free Firm*

Quite generally, the maximized value of any firm is a (non-strictly) *convex* function of any exogenously-determined price it faces (holding other prices constant).[1] This fundamental (and well known) result holds whether the price is that of an input, an output, or

[1] More generally, holding constant the other constraints and terms of trade facing the firm.

a good that is sometimes an input and sometimes an output. The result does not depend on any assumptions about production technology, slopes or elasticities of demand curves, etc. All it requires is that the price in question be exogenous to the firm.

To recall why this is so, note that for any fixed production plan, the firm's value is linear in each price. (Throughout this paper, we use the term "linear" to denote a relationship of constant slope; we do not imply that the relationship passes through the origin.) For example, if a gold mining company ignored any changes in the price of gold and just mined a given quantity, say x ounces, the value of this company would be $v(p_g, x) \equiv p_g x - C(x)$, which changes linearly with the price of gold, p_g. Thus, if p_g were to change from \$300 to \$400 per ounce, this would increase the value of the firm, $v(p_g, x)$ by \$100x, which is exactly as much as the firm's value would change if p_g went from \$400 to \$500 per ounce.

A similarly linear relationship would hold if, for instance, it were the price of an input such as labor, rather than the price of the firm's output, that was changing while the firm kept the same production plan. Instead of the slope being $+x$, it would now be $-L$, where L is labor input under that production plan; but, just as before, the slope would not change with the price.

Thus, given a production plan x, the value $v(p_g, x)$ of the firm would be linear in the price of gold p_g, but the firm can switch among production plans so as to maximize its value. Gold mining firms expand output when the price of gold increases and reduce output, *e.g.,* by closing mines, when gold prices fall. Since the firm can profitably change production plans when the price changes, the firm's value, as a function of that price, is an upper envelope of straight lines, $V(p_g) \equiv \max_x v(p_g, x)$, and hence is convex. This is illustrated in figure 1.

As the argument suggests, the degree of convexity is closely related to the extent to which the firm profitably adjusts quantities in response to price changes. Since (by the envelope theorem) $V'(p) = x(p)$, it follows that $V''(p) = x'(p)$, and so a natural measure of the curvature of the V function, $pV''(p)/V'(p)$, the elasticity of the slope of V with respect to price, is equal to the elasticity of the firm's supply with respect to price, $px'(p)/x(p)$.

While this argument for convexity of the firm's value function is straightforward and intuitive when only one price is changing at a time, other prices that the firm faces (of either inputs or outputs) may also vary. For example, when we observe changes in the spot price of gold, (expected) future prices of gold are presumably also changing. Thus we need to consider simultaneous changes in multiple prices.

The basic theoretical result goes through in a natural generalization, whose proof is the same as the argument above except that maximized value V is now an upper envelope of hyperplanes rather than of straight lines. Without any claim of originality, we state:

Proposition 1. Consider a firm that maximizes value V taking as given (input and/or output) prices $\mathbf{p} \equiv (p_1, \ldots, p_N)$. The maximized value $V(\mathbf{p})$ is a convex function of the vector $\mathbf{p}$.

If we observed the entire vector $\mathbf{p}$ of relevant prices, this proposition would let us test directly for value-maximization. Also, those prices that do not change can of course be dropped from the price vector without affecting the prediction. However, there may well be omitted prices that in fact vary in the sample. Indeed, what we do empirically below is track the empirical relationship between *one* price — "the" price, p_g, of gold, the primary output — and the stock market's assessed value of the firm. How is the logic of this relationship affected if other, excluded, prices change in a way that is correlated (in the sample) with p_g? We address two versions of this question. First, we ask about prices that the firm and investors can observe, but that we do not include in our regressions. Second, we ask about prices that are unknown at the observation date.

First, suppose that certain excluded prices are perfectly linearly related to p_g in the sample. Then the price vectors in the sample lie on a straight line in price space, and the observed function $\hat{V}(p_g)$ is the slice of the convex value function that lies above that straight line. Consequently, it is convex as one moves along that straight line, and empirically will appear convex as an apparent or reduced-form function of p_g alone.

In particular, of course, a gold-producing firm's maximized value will depend on the future prices of gold. By the argument just given, if future gold prices were deterministically and linearly related to our single (quasi-spot) gold price measure, p_g, convexity would still hold. Similarly, if the price of a scarce input (such as, perhaps, skilled labor) changed linearly with the price of gold, the theoretical prediction of observed convexity would go through, even if we failed to include wage rates in our regressions.

Two potential problems emerge from these reassuring comments. First, if an excluded price that is observed by the firm and investors at the date of observation is *non-linearly* related to the observed (by the econometrician) price, p_g, the reduced form may not be convex. And, second, we need to analyze the consequences for convexity of the fact that future prices are *uncertain* conditional on the observed (quasi-spot) price.

Non-linear deterministic relationship: To illustrate the issues here, suppose for simplicity that we are dealing only with two prices, $N = 2$, and examine the observed relationship between p_1 and V when (1) V is indeed a convex function of the full price vector (p_1, p_2), and (2) $p_2 = f(p_1)$, where f is nonlinear (but note that any causality between p_1 and p_2 is not important here). Then we can denote the reduced-form or observed relationship between V and p_1 by $\hat{V}(p_1) \equiv V(p_1, f(p_1))$.

To study the convexity of $\hat{V}$, we calculate:

$$\hat{V}''(p) = V_{11} + 2f'(p)V_{12} + f''(p)V_2 + [f'(p)]^2 V_{22}. \qquad [1]$$

Thus the observed relationship $\hat{V}$ will be convex unless

$$f''(p)V_2 < -\left[V_{11} + 2f'(p)V_{12} + (f'(p))^2 V_{22}\right], \qquad [2]$$

where the expression in square brackets is positive by convexity of V in the vector (p_1, p_2). Thus $\hat{V}$ will still be convex unless $f(\cdot)$ is "sufficiently" nonlinear, p_2 is "sufficiently" important in V, and either f is convex and good 2 is an input or else f is concave and good 2 is an output.

Uncertainty: If some prices are uncertain and their distribution is unaffected by changes in the observed price p_1, then convexity follows because value can be expressed as an expected value:

$$\hat{V}(p_1) = \int V(p_1, p_2)\mathrm{d}F(p_2), \qquad [3]$$

and this is a sum of convex functions of p_1 provided that the distribution function F does not shift with changes in the observed price p_1. This argument holds regardless of how much or little the firm will be able to re-optimize as further information about currently unobserved prices arrives: that affects the shape of V as a function of p_2, but that is irrelevant for this argument.

More difficult questions arise if the distribution of unobserved prices varies with the observed price, as is of course likely (especially when the unobserved prices are future spot prices of gold). When the expected value of each future price moves linearly in the observed spot price, so that for instance $\mathrm{E}(p_{t+1}|p_t) = a + bp_t$, there is a natural intuition that convexity will carry over. Broadly speaking, V is convex in future prices as well as in today's price, and if expected future prices are linear in today's price, one might expect $\hat{V}$ to be convex in today's price. This argument would of course be just a special case of the analysis in equation [2] if the relationship among prices were deterministic. It also goes through (by the previous paragraph) if the firm were unable to respond to later news about future prices. The argument does not completely work, however, if the firm will be able to respond to future prices: in that case, the option value resulting from the variability in those prices may vary with today's price.

As an example, imagine that extreme values of p_1 (high or low) correspond to low conditional variances of future prices, so the conditional variance is an inverted U-shape as a function of p. If the option value is an important part of expected profits in the second period, extreme values of p_1 would then correspond to low expected second-period profits, and potentially to low present values.

To investigate this problem, consider the following illustrative two-period model. At the beginning of period 1, the firm is endowed with a stock S of ore. It learns the first-period price, p_1, and then it chooses first-period extraction (and sales), x_1. Its costs in the first period of extracting x_1 are $x_1^2/(2S)$, so its marginal cost is increasing linearly in x_1 and decreasing in total stock or reserves. It knows (in choosing x_1) the conditional distribution of the second-period price p_2, and it knows that at the beginning of period 2, it will learn the value of p_2 and will then choose second-period output x_2, at cost $x_2^2/(2[S-x_1])$.

Given x_1 and p_2, the second-period choice of x_2 maximizes $p_2 x_2 - x_2^2/(2[S-x_1])$, whence we derive that second-period profits are equal to $(S-x_1)p_2^2/2$. Consequently, given p_1, the first-period choice of x_1 maximizes

$$\tilde{V}(p_1, x_1) \equiv p_1 x_1 - x_1^2/(2S) + \frac{\delta}{2}(S-x_1)\mathrm{E}[p_2^2|p_1]. \quad [4]$$

The reduced-form value function $\hat{V}(p_1)$ is of course simply $\max_{x_1} \tilde{V}(p_1, x_1)$. By the envelope theorem, $\hat{V}'(p_1) = \partial\tilde{V}/\partial p_1$, so differentiating again,

$$\hat{V}''(p_1) = x_1'(p_1)\frac{\partial^2\tilde{V}}{\partial p_1 \partial x_1} + \frac{\delta}{2}(S-x_1)\frac{\mathrm{d}^2}{\mathrm{d}p_1^2}\mathrm{E}[p_2^2|p_1]. \quad [5]$$

From the implicit-function theorem, $x_1'(p_1)$ has the same sign as the mixed partial derivative of $\tilde{V}$. Consequently, $\hat{V}$ is convex unless $\mathrm{E}[p_2^2|p_1]$ is sufficiently concave in p_1. It is worth noting that this would be surprising in the following sense: $\mathrm{E}[p_2^2|p_1] = (\mathrm{E}[p_2|p_1])^2 + \mathrm{var}[p_2|p_1]$, and the first term is convex in p_1 under the assumption that price follows a martingale. Thus considerable concavity of the conditional variance would be required to overturn convexity of the observed value function.

Casual observation might suggest that we would expect the opposite: that is, that extremely high values of p_1 probably correspond to high, rather than low, conditional variances (gold prices are high in times of uncertainty). We discuss this further in section IV below.

B. *Value Response and Fat Accumulation*

We saw that value functions should be convex in price if firms maximize value. Now we consider an alternative hypothesis. If firms systematically tend to accumulate fat when they become wealthy, then the convex relationship could be reversed: the higher is the (maximized) value V, the more fat accumulates, and the net $V - F$ function could potentially be concave. In general terms the idea that there may be fat that grows as financial constraints are loosened has been much discussed, for instance by Jensen (1986) and other work on agency and free cash flow, and earlier by Leibenstein (1966). We argue that a particular pattern of fat accumulation might explain the empirical findings we describe below.

In the gold mining industry, we hypothesize that high gold prices could induce fat, or rent-dissipating behavior. As we will show, if fat is a sufficiently convex function of wealth, this can reverse the value convexity result, and lead to a concave relationship between the price of gold and the net-of-fat value of the firm. Consequently, empirically examining the curvature of the function relating stock-market value to gold prices may give us some information on the existence and nature of rent dissipation in the industry.

Consider a gold mining company that has value V if it is operated with no fat, where V is the present value of the stream of future profits in the fat-free company. The actual stock market value of the firm, S, will be $S = V(p_g) - F(V(p_g))$, where $F(V)$ is the present value of fat, *i.e.,* the present value of profits dissipated through inefficiency, which we take to be a function of V.

Taking the derivative of stock market value with respect to p_g, we have then that

$$S'(p_g) = V'(p_g)[1 - F'(V(p_g))], \qquad [6]$$

which will have the same sign (presumably positive for gold-mining companies) with or without the presence of fat so long as fat does not consume more than 100% of marginal wealth changes to the firm. Differentiating [6] with respect to p_g to get the second derivative of the impact of p_g on stock valuation gives

$$S''(p_g) = V''(p_g)[1 - F'(V(p_g))] - V'(p_g)^2 F''(V(p_g)). \qquad [7]$$

Hence,

$$\frac{S''(p_g)}{S'(p_g)} = \frac{V''(p_g)}{V'(p_g)} - \frac{F''(V)}{1 - F'(V(p_g))} V'(p_g). \qquad [8]$$

In a simple gold mining company (one with no other investments whose value is affected by p_g), the first term on the right in [8] is non-negative; it is the ratio of marginally economic reserves (those barely worth extracting at price p_g) to total economic reserves (all those worth extracting at price p_g). The second term is a measure of the curvature of the fat function, and is positive if the fat function is convex. Since the second term is subtracted, if the firm has little opportunity to reoptimize when p_g changes — so that the first term is small — and if the fat function is sufficiently convex, $\frac{S''(p_g)}{S'(p_g)}$ will be negative, implying that S is concave in price.

Therefore, if empirically S is concave in p_g, this may provide evidence of fat, or at least investors' *expectations* of rent dissipation. It may also enable us to estimate the amount of fat that investors anticipate. The technique is illustrated in figure 2. Since

$$F(V(p_g)) \equiv V(p_g) - S(p_g), \tag{9}$$

we can differentiate and divide by $V'(p_g)$ to get

$$F'(V(p_g)) = 1 - \frac{S'(p_g)}{V'(p_g)}. \tag{10}$$

Now suppose we have observations at two prices: a low price, p_g^L, and a higher price p_g^H. Since theory tells us that $V'(p_g^H) \geq V'(p_g^L)$, and since we presume that fat increases in wealth and hence in price (*i.e.,* F' and V' are positive), we have $V'(p_g^H) \geq V'(p_g^L) \geq S'(p_g^L)$, whence

$$F'(V(p_g^H)) = 1 - \frac{S'(p_g^H)}{V'(p_g^H)} \geq 1 - \frac{S'(p_g^H)}{S'(p_g^L)}. \tag{11}$$

This gives us an observable lower bound on the fraction of the marginal dollar of wealth gain from an increase in p_g near p_g^H that is dissipated as fat, *i.e.,* the quantity $F'(V(p_g^H))$, or "marginal fat." It is one minus the slope on the S function at point B divided by the slope at point A. The bound is strictly positive when S is concave so that $S'(p_g^H) < S'(p_g^L)$.

We also can get an observable lower bound on the total rent dissipation. We have, from convexity of V,

$$V(p_g^H) \geq V(p_g^L) + (p_g^H - p_g^L)V'(p_g^L). \tag{12}$$

Since fat is non-negative (so $V \geq S$) and, we assume, weakly increasing in wealth (so $V' \geq S'$), the right-hand side is at least equal to

$$S(p_g^L) + (p_g^H - p_g^L)S'(p_g^L), \qquad [13]$$

so

$$F(V(p_g^H)) \equiv V(p_g^H) - S(p_g^H) \geq (p_g^H - p_g^L)S'(p_g^L) - [S(p_g^H) - S(p_g^L)], \qquad [14]$$

and this lower bound on total fat at p_g^H is positive when S is concave.

Equations [11] and [14] form the basis for interpreting our empirical results in terms of marginal and total fat. These will underestimate the total and marginal fat if (as one would expect) $V(\cdot)$ is *strictly* convex or if the firm has some fat even at p_g^L ($F(p_g^L) > 0$ and $F'(p_g^L) > 0$). This approach could lead to overestimates if other factors cause (part of) the concavity of the $S(\cdot)$ function. We discuss these alternative interpretations in section IV.

III. Gold Prices and the Valuation of Gold Mining Companies

The gold mining industry is a particularly attractive focus for studying the effects of wealth changes on corporate fat, or rent dissipation, because there are frequent shocks to the price of gold that are exogenous to the gold mining companies we study, and those shocks translate directly into wealth shocks for gold mining firms.

Gold mining companies view themselves as price takers in the gold market. The market for gold is worldwide, due to the metal's high value-to-weight ratio and homogeneity, and no producer controls more a few percent of the annual extraction of new gold. In addition, demand for gold for industrial/jewelry use can be fulfilled from existing stock. Annual production of gold from mines worldwide is less than 2% of existing stock of the metal. Gold mining companies make strategic decisions in response to changes in the price of gold — most importantly output changes, including prospecting for gold, and opening/closing mines — but individually no one company can exercise significant influence over the price. Thus, unilateral market power appears to be absent. Coordinated oligopoly interactions seem extremely unlikely given the large number of diverse gold mining firms and other holders of gold stocks, and we are aware of no evidence or even allegations of such behavior.

For the analysis outlined in the previous section to be applied directly, changes in the price of the important input or output should be exogenous to the firms observed. This means not only that no firm has market power, but also that price movements are not driven by aggregate shocks to the observed firms. If, for instance, gold price movements were frequently the result of new gold discoveries or revisions in the estimated reserves of the observed companies, the analysis would be much more complicated.[2] But in fact gold price changes are almost uniformly the result of demand-side news: world events that change the attractiveness of gold as a store of wealth, trends in the demand for gold jewelry, or policy decisions of central banks to hold more or less gold.[3] We searched the *Wall Street Journal* over the entire 21–year span of our sample for articles about gold prices and found almost no mention of gold supply (from gold mines) as a cause of gold price changes. Discussions with investor relations personnel at a number of gold mining companies also failed to uncover cases in which supply shocks from mines were thought to have significantly affected prices. The one case in which a supply shock from a mine was thought to have possibly moved gold prices was the Bre–X incident in May 1997, in which an area of Indonesia that had been touted as the largest gold find in history turned out to have no economic supplies — but even that case had no significant effect on the price of gold.[4]

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[2] In an earlier exploration of this topic, Borenstein and Farrell, 1996, we analyzed the value response of oil companies to changes in the price of oil. We now analyze gold instead because it avoids a serious problem in doing the exercise in oil. Even if one assumed that there was no market power — a less compelling assumption than in gold — and ignored the complexity resulting from the fact that these companies were also in the oil refining business, an alternative explanation for a concave value function remained. The shocks we observed to oil prices were mostly (expected) supply shocks, and in many cases shocks to the supply of some firm in our sample. In that case, the price movements would be movements along a demand curve. If total revenue were concave in price along that demand curve, as seems quite possible, then the aggregate value of firms in the sample would very likely be concave in the price of oil. This points out the importance of analyzing shocks that are exogenous to the firms that we are studying.

[3] One could of course regard these central banks' decisions as supply shocks, but they are not shocks to the supply of the firms we study.

[4] On May 6, the day that the stock of Bre–X fell 97% in value (confirming that the news of no economic

While the value of a gold mining firm should depend on spot and all information about future prices of gold, we believe it is sensible to analyze the relationship empirically using one (near-term futures) price. While we subject this assumption to robustness tests below, we believe it is sensible because the prices will tend to move together very closely. Gold is traded in an active and thick commodity market, and so is subject to strong arbitrage forces. The active commodity market and the very low storage cost of gold would make arbitrage comparatively easy if traders saw any signs of systematic inefficiency. One would thus expect the price of gold to be described quite closely as following a martingale. Augmented Dickey-Fuller tests using our weekly gold price series for 1977–1997 indicate that a unit root indeed cannot be rejected.[5] Figure 3 shows the price of gold over our sample period (in constant 1997 dollars). Descriptive statistics for gold prices over our sample period are shown in table 1.

To analyze the effect of gold prices on a gold mining firm's stock market value one would want to control for market-wide stock price movements, because those movements may represent, among other things, interest-rate changes or expected changes that would affect gold mine stock prices directly.[6] Thus, we begin with the standard CAPM market model of equity returns:

$$R_{it} = R_{ft} + \beta_i(R_{mt} - R_{ft}) + \epsilon \qquad [15]$$

where R is the rate of return, the i subscript refers to the observed firm, the m subscript refers to the market, and the f subscript refers to the riskfree rate of return. We multiply both sides of [15] by the stock value of the firm at $t-1$ to get the equation in terms of the

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supplies was indeed news to the market), the price of gold *fell* about \$2/oz.

[5] The test statistic is -2.11 and the 95% critical value is -3.12. This is consistent with the findings of Pindyck, 1993. Selvanathan, 1991, found that a random walk hypothesis performed better than a panel of gold price forecasters.

[6] Over our sample period, the correlation between the return on the market index and the return on gold futures is about 0.1, which is significantly different from 0 at the 1% level.

change in firm value:[7]

$$R_{it}S_{it-1} = \Delta S_{it} = R_{ft}S_{it-1} + \beta_i(R_{mt} - R_{ft})S_{it-1} + \epsilon S_{it-1}, \qquad [16]$$

where Δ indicates the difference between the period t and period $t-1$ value of the variable. We then specify explicitly the effect of the price of gold, which would otherwise be included in the error term.

Recall that we are interested in the curvature of the relationship between S and p_g. This might be measured by the second derivative of a levels equation. Since our equation is in differences, we include the difference/derivative of a quadratic relationship between stock value and the price of gold. That is, if $S = \gamma_0 + \gamma_1 p_g + \gamma_2 p_g^2$, then $\mathrm{d}S = \gamma_1 \mathrm{d}p_g + 2\gamma_2 p_g \mathrm{d}p_g$. So, we estimate the equation

$$\Delta S_{it} - R_{ft}S_{it-1} = \alpha_1 \Delta p_{gt} + \alpha_2 p_{gt-1}\Delta p_{gt} + \alpha_3 S_{it-1}(\frac{I_t}{I_{t-1}} - 1 - R_{ft}) + S_{it-1}\epsilon, \qquad [17]$$

where S is the stock market value of the firm, p_g is the price of gold, I is a value-weighted stock market index,[8] and α's are parameters. In this model, α_3 is the estimate of the CAPM β.[9] The coefficient α_2 indicates the convexity (if $\alpha_2 > 0$) or concavity (if $\alpha_2 < 0$) of the relationship between the price of gold and the value of the firm.

We examine the stock market values of 17 gold mining companies that are traded in the U.S or Canada. We arrived at this dataset by examining lists of U.S. and Canadian gold producers and including each firm that (a) produced at least 10,000 ounces of gold in 1996, (b) mined gold predominantly or exclusively in the U.S., Canada, and Australia, (c) was primarily in the gold mining business, and (d) was publicly traded and is covered

[7] We focus on just the equity value of the firm. In section IV, we discuss debt as a (omitted) cost that the firm faces.

[8] Using an equally-weighted index instead does not affect the results.

[9] Note that the equation does not include a constant term. We also estimated the equation with a constant term and found practically identical results. Similarly, since theory dictates that the coefficient on $R_{ft}S_{it-1}$ is 1, we subtract this term from both sides of [16]. Including this term on the righthand side and estimating an unrestricted coefficient makes virtually no difference in the results, though it does yield very noisy estimates on the riskfree rate term.

by the CRSP stock market data. This produced 21 firms. We then eliminated 4 firms for which fewer than 104 weekly stock observations (2 years of observations) were available. For all 17 firms used in the analysis, estimation of [17] with just a linear gold price term indicated that the value of the firm has a positive and statistically significant relationship to the price of gold.

The full sample period we use is weekly observations for January 1977 through December 1997, a total of 1095 weeks. Not all firms are in the sample for this full period. Some firms came into existence after 1977. Also, some firms have recently diversified and gold mining has become a relatively small share of their operations. We therefore drop recent years of operations for these firms.

The stock market values are taken from CRSP data. Since they can lead to large valuation changes, we drop all weeks in which the stock goes ex-dividend or the number of shares outstanding changes.[10] We use the nearest-contract gold futures price (traded on the COMEX division of the New York Mercantile Exchange; price data obtained from Tick Data Inc.) to represent the price of gold. While that contract changes every other month, the gold price change that we use is always the change for a given contract, not a comparison of prices on two different contracts.

For the riskfree rate, we use the one-year T-bill yield on the day of observation transformed to a weekly interest rate. For each company we use weekly observations (closing price on the last trading day of each week) to estimate the value of the firm as a function of the price of gold.

Since the rent dissipation or fat effect that we hypothesize is a function of the real wealth of the firm, we need to deflate all variables. We deflate S, p_g and I to 1997 dollars using the consumer price index (all items – urban consumers). We translate the nominal T-bill yield used for R_f to a real yield by $R_f^r = \frac{1+R_f}{1+\pi} - 1$, where π is the inflation rate calculated from the CPI for the month of the observation.

[10] The results are virtually the same when we include these weeks and add back in the value of dividends paid.

The error term in the regression we estimate will be heteroskedastic, both because the equation is in terms of the value of the firm (as indicated in [16]) which changes over time, and because exogenous factors affect the volatility of stock market returns. We address this problem in two different ways. First, we estimate [17] by OLS, but we report White's heteroskedastic-consistent standard errors. Second, we estimate by GLS, explicitly controlling for heteroskedasticity caused by the presence of S_{t-1} in the error term.[11]

A. *Results from estimation of a Quadratic Value Function*

We begin by estimating [17] for each of the 17 firms in the sample. The sample periods differ across firms, but each regression includes at least 166 observations. The results of these regressions are shown in table 2. These results support a *concave* relationship between the price of gold and the aggregate values of many of the gold mining firms. The estimated second derivative is negative for 12 of the 17 firms, significantly negative (at the 5% level) for 8 of these firms. Of the 5 estimated positive second derivatives, 1 is statistically significant. Calculating the z-statistic for the 17 estimated second derivatives yields a test statistic of -42.38 with a standard error of $\sqrt{17} = 4.12$, which is significant at the 1% level.

The other parameters estimated are reasonable and consistent with expectations. The implied first derivative of stock market value with respect to the price of gold is positive for each firms at the median price of gold in the sample and is positive for nearly all gold price values that occur while the firm is in the sample. The CAPM β parameter estimated for these firms varies, but is statistically distinguishable from 1.0 in only three cases.

To interpret the magnitude of the curvature of the estimated value function, we create a benchmark slope for each firm in its lean state. We calculate the estimated slope of each firm's value function when the price of gold is \$411.00, its 25th percentile value in the full 1095 week sample. We then calculate by how much the slope is estimated to change

[11] We do this by dividing both sides of equation [17] by S_{t-1}. We also tested for cointegration of firm value and the (nearest contract) futures price of gold. In all cases, the null hypothesis of no cointegration was strongly rejected (t-statistics above 15 in all cases compared to a critical value that varies with number of observations, but is around 3).

when the price of gold increases to \$482.15, its median value over our entire sample period. These figures are given in the first columns of table 3.

Graphically, this is a comparison of the slope at point B to the slope at point A in figure 2. In terms of our equation [11], this is $S'(p_g^H)/S'(p_g^L) - 1$. For Alta Gold, if the 4.6% decline in the slope were due solely to fat, this would suggest that when the price of gold increases slightly starting from its median level, at least 4.6% of the incremental gain is dissipated, *i.e.,* is not reflected in increased shareholder wealth. Recall that this is a lower bound since the V function is (weakly) convex.

Using the separate estimates for the 17 firms, one can construct an estimated change in the value of the 17-firm portfolio as a function of p_g. We calculate this by taking a weighted average of the slopes of the value functions where the weights are the average market capitalization of each firm over the time period it is in the sample. We then again calculate by how much the slope of S is estimated to change for an increase in the price of gold from its 25th percentile to the 50th percentile value, as a percentage of the slope when the price of gold is at its 25th percentile. The result is an estimated decline of 12.3% (of the slope at $p_g = 411.00$), and is significant at the 5% level.[12]

If the concavity were due solely to fat, our estimates would also imply a lower bound on the total fat that the firm would accumulate when the price of gold increases as a proportion of the theoretical increase in wealth, which in figure 2 is ΔF divided by ΔV. Even if the firm is fat-free when the price of gold is at \$411.00/oz., the aggregate estimate for the 17 firms implies that at least 6.1% of the total potential wealth gain when the price increases to \$482.45 is either not realized or not passed along to shareholders.

We have also estimated the quadratic relationship by GLS on the assumption that the heteroskedaticity in the residuals is solely caused by the presence of S_{it-1} in the residual, as shown in equation [17]. The resulting convexities/concavities for the firms are shown in column (2) of table 3. Although there are substantial differences for a few of the firms

[12] The variance of this estimate is calculated on the assumption that the estimates for each firm are statistically independent.

– Echo Bay, Getchell, and Goldcorp – the general pattern is robust to this alternative estimation approach. The remaining columns of table 3 we refer to in the next section in the context of testing for alternative explanations for the concavity we have found.

B. *Results from Estimation of a Piecewise-Linear Value Function*

Estimation of the value function as quadratic in the price of gold is a natural starting point since we are interested in the curvature of the relationship, but the quadratic is quite restrictive. As an alternative and a sensitivity test, we also estimated the relationship between the firm value and the price of gold as a piecewise linear function, with breaks at the 25th and 75th percentiles of the distribution of p_g during the sample used for each firm. For regressions with less than the entire sample, breaks at the 25th and 75th percentiles during the relevant sample period were used rather than the values shown in table 1. To accommodate tests of slope differences, the regressions are run with a slope term in effect over all prices (Δp_{gt}), and additional slope terms that are relevant only for prices in, respectively, the lowest (Δp_{gt}^L) and highest (Δp_{gt}^H) quartiles of the gold price distribution.

The results, shown in table 4, are consistent with the quadratic estimation. For 9 of the 17 firms the slope in the lowest quartile of gold prices is estimated to be significantly (at the 5% level) steeper than in the middle range of prices, indicating concavity. In no case is the slope significantly flatter in the lowest quartile than in the middle range of prices. For 5 of the 17 firms the slope in the highest quartile of gold prices is estimated to be significantly (at the 5% level) flatter than in the middle range of prices, indicating concavity, while it is significantly steeper in the highest quartile for only one firm. An F-test of whether $\Delta p_{gt}^L = \Delta p_{gt}^H$ indicates that the slope is significantly (at the 5% level) smaller in the top quartile for 9 firms (7 of which indicated significant concavity in the quadratic function estimation), significantly greater in the top quartile for 1 firm, and the slope is not significantly different between the quartiles for the remaining 7 firms.

We calculated for each firm the ratio of the estimated slope in the top quartile to the estimated slope in the bottom quartile. The unweighted average of this statistic across the 17 firms is estimated to be 0.64, implying that the average slope of S in the top quartile of the gold prices faced by the firm is 36% smaller than in the bottom quartile. Thus, again there is strong evidence that for many of these firms the slope of the S function is greater when gold prices are low than when they are high.

IV. Alternative Explanations for the Concavity Result

We are tempted to interpret our finding of significant concavity for a number of firms in our sample as showing that these firms are not maximizing profits given the prices they face, and in particular as confirming the idea that increases in wealth will be (expected by Wall Street to be) dissipated in inefficiency. There are, however, a number of potential alternative explanations that we need to discuss.

A. *Progressive Corporate Profits Tax*

The progressive corporate profits tax in the U.S. — broadly, zero tax when the firm has negative earnings and a linear rate of 34%-48% (at different times in our sample period) when it has more than minimal positive earnings — might explain some concavity in the $S(p_g)$ function, to the extent that this progressivity makes after-tax flow profits a concave function of pre-tax flow profits. To consider an extreme possibility, suppose that at low values of p_g a marginal pre-tax dollar is untaxed, while at high levels it is taxed immediately at rate t. Then taxes would cause the slope of a flow-profit function at high gold prices to be only $1 - t$ times what it would be absent taxes, while there is no effect at low gold prices.

This calculation is misleading, however, because firms can carry forward losses to offset profits. To see that effect operating starkly, consider another extreme possibility: suppose that (1) positive profits are taxed at 48% each year and negative profits have no tax liability, (2) losses always can be carried forward long enough to offset future profits, and (3) the discount rate is zero. In that case, all firms would pay 48% on their net (over time) profits. Any change in wealth from a change in the price of gold would be taxed at 48% regardless of the level of gold prices. In that extreme case, the corporate profits tax would not affect the convexity or concavity of S.

In fact, neither of these extreme possibilities is accurate: the tax code is much more complex. In particular, tax losses can be carried forward only for a limited amount of time, and they lose value when they are carried forward, because of (time) discounting. Tax losses can also be carried backward. In addition, investment tax credits, opportunities for arbitrage (as when a firm with tax losses and a firm with tax profits merge), and international tax treaties greatly complicate the analysis. Still, the ability to smooth taxable income across years means that the marginal tax rate that a firm faces is likely to vary much less than would be suggested by a simple view of the corporate profit tax schedule.[13]

However, these arguments about the effect of taxes on accounting after-tax profits as a function of accounting pre-tax profits are not exactly on point for our analysis, because we are examining the stock market value of these firms, $S(p_g)$, not the year-by-year profits. When the implications of this are examined carefully, it turns out that the piecewise-linear tax rate is more likely to have a convexifying than a concavifying effect on S.

To see why, start by noting that all of the firms we study have positive stock market values. A positive stock market value implies that the present value of expected after-tax profits of the firm is positive. This immediately implies that the present value of expected before-tax profits of the firm is also positive.

Next, recognize that in the presence of the two-rate tax system described (no tax on negative earnings and a constant tax rate t on positive earnings), a firm with positive present value of future before-tax earnings faces a present value of tax liability that is *at least* a proportion t of the present value of its future before-tax earnings. The proportion will be exactly t if *either* the firm never makes a loss in any tax period *or* the firm can fully offset losses against earlier or later profits (which requires, among other things, no

[13] Altshuler and Auerbach (1990) examine the effect of asymmetries in the tax schedule on the marginal tax rate that corporations in fact face. They study all non-financial corporations, not specifically gold mining companies. They account for investment tax credits and credits for foreign income as well as a number of other complexities of the tax code. They find that at a time when the marginal corporate tax rate varied between zero and 46% according to the tax schedule, the effective expected marginal tax varied cross-sectionally from 18.9% to 38.6% depending on the tax position of the firm.

discounting). But if the firm ever makes losses and those losses cannot fully offset profits then the "present value average tax rate" — the present value of its tax liability divided by the present value of its future earnings — will be *greater* than t.[14]

Thus, for a firm with positive expected present value of earnings, the present value average tax rate is higher when the firm is more likely to have negative earnings years. The likelihood of negative earnings is almost certainly correlated with low gold prices, so the present value average tax rate is most likely to decline as gold prices rise. The S function is the residual after-tax value so if the corporate income tax were the only cause for non-linearity of S, then S would probably have greater slope when p_g is high than when p_g is low.

Empirically, it is worth noting columns (5) and (6) of table 3, which show results when the sample period is broken into 77-86 and 87-97, around the 1986 tax law changes in the U.S. These changes for the most part made it more difficult to carry losses forward and backward, making the effective marginal tax rate in any one year more responsive to earnings in the year. We find concavity of S functions in both periods.

B. *Omission of Relevant Correlated Prices*

As explained in section II, if a price were non-linearly related to the price of gold we examine and if that omitted price were important in the profit functions of the firms observed, a concave relationship between firm stock market value and the price of gold we examine could be falsely inferred. To be concrete, the most likely culprit if this were an important issue would be the omission of future gold prices from our regression. For instance, if the ten-year-out futures price of gold were concave in the gold price we include in the regression, our reported results could obtain even in the absence of a true concave relationship.

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[14] To illustrate the logic, assume that losses cannot be carried forward or back, the discount rate is zero, and the tax rate is 0.5. Then a firm that loses 20 one year and earns 100 the next will have a present value of future earnings of 80 and a present value of future tax liability of 50. This implies a present value average tax rate of 0.625.

Unfortunately, futures prices for gold have not generally existed for delivery more than two years in the future during our sample period. The longest contract for which prices are available throughout our time frame is the one for which delivery is due 12-14 months in the future (the 7th nearest contract). Still, if the futures price curve tends to be concave, one would still expect to see some indication of this in a contract that constitutes a claim more than a year in the future.

The simplest approach to testing this explanation would be to include both this longer futures price and the nearer futures price in the regression. These prices, however, are so highly correlated that doing so increases the standard errors of the estimates to the extent that the estimated second derivatives could not be statistically distinguished from zero or from the estimates that we had obtained without the long futures price.[15]

An alternative approach, however, produces results that are at odds with this explanation of the concavity. If long future prices are concave in nearby future prices, then it follows that nearby future prices are convex in long future prices.[16] Thus, omitting the nearby future gold price and using only the longer future gold price would be omitting a price that is convex in the included price and would lead to an *overstatement* of the convexity of the stock price function. We did this using the 12-14 month out futures price. The slope changes implied by these estimates and their standard errors are shown in column (3) of table 3. It is apparent that this substitution makes very little difference in the results, though it might be causing all estimates of second derivatives to be closer to zero. The estimated concavity of the aggregate portfolio implies that an increase in price from the 25th percentile to the median price of gold during our sample period would decrease the slope of the aggregate S function by 10.7%, which is smaller than the 12.3% we estimated when using the nearest futures price, but the difference is much smaller than

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[15] As stated earlier, we have carried out augmented Dickey-Fuller tests on the 1977-97 gold price series, which indicate the behavior of gold prices cannot statistically be distinguished from a random walk. Of course, longer-term mean-reverting behavior is very difficult to diagnose and, perhaps more importantly, investor beliefs with regard to patterns of mean reversion present an even greater challenge.

[16] Note that we are discussing here the actual relationship between these prices, not an estimated statistical relationship, for which this statement might not hold.

the one standard error of either estimate. Using a futures price that is nearly a year further in the future and omitting the next-to-nearest contract price does not tend to make the estimated S functions any more convex. Thus, the evidence lends no support to this explanation for the concave S functions we find.

Finally, with the nearby and longer term futures price series, we can test directly for a non-linear relationship between these prices. A linear regression of the 12-14 month out futures price on the nearest futures price and the square of the nearest futures price yields an insignificant parameter estimate on the second order term. Thus, neither of the tests we have carried out indicates that the concavity we find is a result of nonlinearity in the relationship between nearby and longer futures prices of gold.[17]

The other potentially important omitted output price is the price of silver. Most gold producers also mine some silver since deposits are often co-located. Of the 17 firms in our sample, 7 exhibit a positive and statistically significant first-order effect of silver prices on firm value in a regression with the changes in the price of both gold and silver. Column (4) of table 3 presents the estimated convexities/concavitites (in gold price) after adding first- and second-order silver terms to the estimation of equation [17]. While the estimated second-order effects of gold price changes change somewhat, the basic result that the majority are concave in gold price remains. The S is still estimated to be a concave function of the price of gold for 11 of the 17 firms and for 4 of those the second derivative is statistically significant at the 5% level. Also, the second order effect of silver is estimated to be concave for most of the firms: 13 of the 17 have estimated concave effects of the price of gold and for 5 of those, the effect is statistically significant at the 5% level.[18]

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[17] Some readers have suggested that mean reversion in the price of gold might produce concavity in S. First, it is important to note that systematic mean reversion would imply profitable arbitrage opportunities that are not pursued by traders. Second, the empirical evidence mentioned earlier is that a random walk is consistent with gold price movements during our sample. Finally, mean reversion is actually just a special case of the omitted price analysis, where the omitted prices are the future prices of gold. For an omitted output price to explain the concavity we find, it would have to be concave in the included price. As discussed in the text, we find no evidence to support this.

[18] The most noticeable change in estimate is for Coeur D'Alene, which is the company the by far has earned the largest share of its revenues from silver, in some years more than its revenue from gold. Coeur D'Alene's S function is estimated to be significantly concave in the price of silver.

A second category of omitted prices that could potentially be important is input prices. If the industry faced increasing marginal costs of some input, then it seems conceivable that this could transfer (rather than dissipate) the rents generated from high gold prices. We do not believe this is likely to be very important for four reasons.

First, the industry executives we talked to did not think it plausibly important (although they did suggest that geologists are better paid when gold prices are high).

Second, firm-level increasing marginal cost does *not* have this effect: for instance, if the marginal exploration project is much more expensive than the inframarginal projects, it is still true that the firm can continue to do at a higher p_g what it was doing at a lower p_g, so the upper-envelope result still holds.

Third, and perhaps most important, although the industry-level supply curve of some inputs (such as geologists) may be sharply upward-sloping in the short run, so that the short-run effect of an increase in p_g is to make even inframarginal exploration projects substantially more costly, it is hard to believe that the *long-run* supply curve of geologists is so steeply upward-sloping as it would need to be to explain our results. Because we examine the effects of changes in p_g on the stock-market estimate of the present value of profits, effects that apply to current-year or near-term future profits but not to further-out profits will have limited effect on our results. (This is particularly true in a competitive extractive industry such as gold mining, where postponing production until a hypothetical large input-price spike has passed would not permanently lose production or market position as it might in some other industries.)

Finally, changes in the price of long-lived capital that the firm owns, rather than rents, would not explain observed concavity. If, for instance, increases in the price of gold raise the value of land on which the gold mine is located, that will not lead to concavity of the S function if the mining firm owns the land. While such changes affect the opportunity cost of mining, that is exactly offset by the capital gain or loss that the firm enjoys from owning the land. Changes in the price of gold are part of the owner's option value of owning the land and thus will convexify the value of the owning company. Another way to put this is that changes in the market value of an owned asset do not affect the basic argument that the firm *could* continue to use the same production plan — the argument that leads via an upper-envelope effect to convexity of V.

C. *Debt*

One important category of cost that deserves special attention is the cost of debt. In the regressions, debt was not considered part of the value of the firm. In fact, debt represents a cost to firm owners that varies with the value of the firm. As such, if it varied in a convex fashion with the price of gold, it could conceivably concavify S. We argue, however, that it seems much more likely to convexify S than cause it to be concave. For a given amount of outstanding debt, the cost to the firm (to the equity-holders, that is) to retire that debt varies with the net present value of the firm's earnings (before debt payments) in the way shown in figure 4. If the firm is relatively wealthy, then the cost of the debt is unaffected by marginal changes in firm wealth. If the firm is in some financial difficulty, then payments will vary approximately linearly with firm value, since debt holders become the residual claimants. And if the firm is worthless, then likewise the debt payments won't occur. An intuition that debt may concavify the equity value of the firm comes from thinking about firms whose value varies along segments A and B, in which case the cost of debt is convex in the firm's performance and might lead to concavity of the equity value.[19] However, we would argue that it is more likely that firms with ongoing operations are either on segment B or segment C. In contrast to the A-B segments, the B-C segments form a *concave* function representing the cost of debt as a function of firm wealth. In this region, the non-linearity of the debt payments tends to convexify the residual S function because the debt payments are concave in the firm value.[20]

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[19] Approaching this situation, however, would coincide with the firm having little equity value and greater opportunity to take advantage of the option value that bankruptcy law provides.

[20] Related to this discussion of debt is the possible effect of imperfect capital markets. If firms had to finance new exploration internally because external capital markets were unavailable, then increases in the price of gold would create financing for new investments, investments that would have progressively lower rates of return (though still greater than outside-the-firm investment options). This could result in a concave value function. We mention this only as a footnote because these firms seem to have unencumbered access to capital markets and in our interviews with managers we heard no

D. *Changing Variance in Gold Prices*

In section II we noted that the concave relationship that we find between the current price of gold and the stock market value of some firms could possibly obtain if the real option value of gold mining, which increases with the variance of gold prices, were a concave function of p_g. We showed above that this would require that the conditional variance of prices be a strongly concave function of the price of gold.

We have attempted to address this concern by estimating the relationship between the level and the expected future variance of gold prices. To do this, for every observation, we calculated the variance of the next 26 weekly gold price observations (for the next-to-nearest gold futures contract). We then regressed this measure of *actual* future variation in gold price on a constant, the gold price level and its square, using 42 observations spaced six months apart over the 21 year sample period. We found a *positive* and significant relationship between the gold price and the actual future variance of price, but we found no significant concavity or convexity in the relationship.

E. *Hedging by Gold Mining Firms*

Many, though not all, gold mining firms take positions in the gold futures market in order to hedge the risk associated with gold price movements.[21] If a gold mining firm sells gold forward at a fixed price, this flattens out the firm's S function; the value of the firm is less affected by changes in the price of gold (*i.e.,* the firm has already sold some gold, and therefore owns less than otherwise).

Tufano (1996 and 1997) studies hedging by gold mining firms.[22] He finds that hedging

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mention of profitable projects that were not being pursued due to capital constraints. See Blanchard, Lopez-de-Silanes, and Shleifer (1994) for evidence of the response of investment to cash windfalls. They interpret their results as supporting an agency theory in which managers act to maximize their length of tenure.

[21] One of the executives we spoke with said that banks now often require or prefer this, when the gold mining firm borrows from a bank.

[22] Tufano (1997) also explores the relationship between gold prices and firm values, but does so in terms of rate of return or percentage changes. He shows that the *rate of return* on a mining stock would be less sensitive to the rate of return on gold when the price of gold is high than when it is low, if

varies substantially across firms. He describes two types of financial hedging that are common in the industry: linear strategies, such as selling gold forward, which reduce the overall exposure of the firm's value to changes in gold prices, and non-linear strategies, such as buying put options, which act as insurance, protecting the firm's value only if the price of gold falls below a certain level. Of course, linear strategies generically should have no effect on the concavity or convexity of S. The non-linear insurance strategies used in the industry, such as buying put options, should have a convexifying effect on S.[23]

These generic conclusions could possibly be misleading, however, if in the time period we examine firms happen to have systematically engaged in more risk management when gold prices were high than when they were low. Such behavior could lead to a fortuitously flatter S function at high gold prices than at low gold prices, that is, concavity of S. Unfortunately, Tufano's data are for only a relatively short time span and one in which risk management practices were changing in the industry. Thus, it is difficult to infer from his results whether a systematic relationship between the level of risk management and the price of gold could explain the concavity that we find.[24]

As an empirical check on the possible effect of hedging on the concavity of S, we examined firms that engage in little or no hedging. Peter Tufano has provided us a list of firms that engaged in no hedging activities in 1990 or 1992. We assumed that if a firm showed up as engaged in *no* hedging in either of these years, then it was engaged in little or no hedging in previous years.[25] We then examined the two firms on this list that were

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the firm has no flexibility in its production plan. His equation (2) also confirms that, in that case, the value of the firm would be linear in the price of gold.

[23] Whenever the firm acquires an option (whether to buy or to sell), its value function becomes more convex; if it sold options to others, its value function would become more concave. The non-linear strategies of gold mining firms fall almost entirely into the first category.

[24] Related to the issue of hedging is purchases and sales of mines which change a firm's exposure to gold prices. In fact, mines (or shares of mines) are frequently sold among firms. We have found no evidence that the firms in our sample tend to sell mines when prices are high and buy them when prices are low, which would be necessary to explain the concavity we find. Furthermore, the fact that the firms we observe, in aggregate, display concave value as a function of gold prices makes it even less likely that the concavity could be explained in this way, to the extent that transfers are among these firms.

[25] Our discussions with industry participants suggest that hedging has tended to become more common

also in our dataset for at least four years prior to 1992 — Coeur D'Alene and Homestake Mining — and we used only data from prior to 1992.

For each of these firms, the estimated stock value functions were very significantly concave: the estimated second derivative terms were significant at the 5% level in both cases. The proportional declines in the slopes of the firms' value function when the price of gold increases from $411.00 to $482.45 are estimated to be 9.2% and 6.1% respectively. Thus, for both theoretical and empirical reasons, hedging practices are unlikely to explain the concavity we find for some firms.[26]

F. *Optimal Labor/Executive Compensation Contracts*

For incentive or risk-sharing reasons it might be optimal to give managers or workers equity or options in the company. Giving them equity would of course not affect our analysis,[27] but giving them options would concavify the (remaining) value function of the firm.

Similarly, if wages and salaries increase more than linearly with p_g as part of an optimal labor contract (explicit or implicit), this could account for concavity of the observed S function, because an increasing share of wealth gains from gold price increases would be distributed to workers, rather than shareholders. Indeed, it would do so in a way very like the "fat" mechanism described above, although we might interpret it somewhat differently.

Given the magnitude of the concavity we find in a substantial fraction of our sample, it seems very unlikely that executive compensation tied to earnings could account for more than a trivial fraction of the explanation. Gold mining companies pay a very small

over time.

[26] Even today, firms seldom hedge more than the equivalent of a few years of their production, so most of their expected future production at any time remains unhedged, especially in light of the "replace your output" rule of thumb discussed below.

[27] This assumes that they do not hold many more shares when the price of gold is higher in the sample; since equity holdings by managers have generally been increasing over time while gold prices have been decreasing, this seems a plausible assumption.

fraction of firm value as executive compensation.[28] One would expect this to be the case for natural resource extraction companies because a comparatively large share of firm value is represented by tangible, transferable assets. That is, much of the firm value is due to its holdings of land or rights to mine, not value creation by the operations of the firm. Furthermore, in the case of gold mining, firm value *changes* are largely due to events (in this case, gold price shocks) that are completely exogenous to the firm. Although we are unable to make a quantitative comparison, we suspect that this was more true of gold mining than of most industries during and around the sample period. Incentive/compensation theory would then suggest that optimal compensation plans should not award managers a significant share of firm value changes that result from exogenous events.[29]

Mining labor costs are a much larger share of firm operating costs than managerial compensation. We discuss this in the following section.

G. *Environmental Liabilities*

A further potential non-fat explanation of concavity would be that gold mining firms, which are viewed as causing extensive environmental damage, might be required to pay disproportionately more for "clean-up" if they are relatively rich. We believe that this is unlikely to explain the concavity we observe. First, according to our industry and government sources, most environmental legislation bearing on mining companies applies to all mining, not to specific sectors such as gold mining. Second, the reaction we elicited from government regulators when we mentioned this hypothesis was that is was an interesting idea, but that they were aware of no examples of such behavior. Third, although the environmental liabilities are non-trivial — one source put them at about 15 percent of

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[28] For some of the largest firms in our sample — with market capitalizations from \$1 billion to \$4 billion — CEO compensation including valuation of stock options, was less than \$1 million per year in 1996.

[29] Milgrom and Roberts (1992) call this the "informativeness principle." It is possible that despite the (we believe greater than average) role of exogenous events in changes in firm value, shareholders might want to give managers strong incentives to respond efficiently to gold price movements by opening or closing mines (and perhaps overcome the managers' own tendencies towards risk aversion). In this case, they might want to give some of the value change to managers. But, especially in view of how simple it would be to design a compensation scheme that neutralized at least a substantial part of the role of gold price changes, it would seem surprising if managers were given a large share of the value changes resulting from gold price shocks.

"hard" costs — they seem not to be viewed in the industry as being very much subject to discretion or variation. Finally, for environmental liabilities to explain any of the concavity we find, they would have to not only increase with the price of gold, but would have to be convex in the price of gold, *i.e.,* the proportion of marginal wealth required by new liability would have to increase with the price of gold.

While the foregoing discussion may apply more to "ordinary course of business" liabilities, we also note that "asbestos-style" liabilities, which with some probability will bankrupt the firm, would also not make for concavity, but would simply reduce the value of the firm by some probability largely independent of (or at least not particularly convex in) the price of gold.

H. *Royalty Payments*

Sometimes governments (or owners of auriferous properties who delegate the mining) require payment of royalties for gold extraction. A linear royalty schedule (whether on units, revenues, or profits), like a linear tax schedule, would not affect the predictions of convexity. However, royalty rates that increase with the price of gold (or with the total revenues attributable to a mine, for instance) could potentially cause concavity of the value function. Accordingly, we asked our industry and government contacts to comment on this possibility. It appears from our discussions that royalties are most often linear. There are some royalties that kick in above a certain point, and others that are capped; thus some would contribute to concavity and others tend towards convexity. Some ("NPI") royalties are based on accounting net profits, but one well-informed commentator suggested that it is viewed as unwise for an agent who can extract royalty payments to take a percentage of the net, because doing so stimulates cost accountants' creativity in undesirable ways, somewhat as it is said to do in the case of Hollywood movies.

It is also notable that the hypothetical examples this source used in discussing the matter with us had royalty rates of 1 percent or a few percent, except for one that was ten percent of accounting profits. Although this is merely suggestive at this point, we think it is some evidence that royalties as a whole are unlikely to be driving our results. Other industry sources also tended to come up with examples involving a few percentage points. Thus, although our contacts suggested that large-percentage royalties might happen, informed informal opinion did not seem consistent with this being a major explanation of our results.

Finally, we also learned of Centurion, a company that specializes in exploration and royalty collection: it sells properties on which gold deposits have been found to mining companies and collects royalties. If it imposed more-than-linear royalties, one would expect its $S(\cdot)$ function to be correspondingly convex. In fact, our estimated S function for Centurion was concave (although not statistically significantly concave).[30]

V. Where's the Fat?

We believe that the results above strongly suggest two things. First, there is some kind of fat in at least a substantial fraction of the companies we study. Second, firms may well vary considerably in the extent to which they are subject to such fat.

We wish to be particularly cautious, however, about this second possible inference, which is *not* proved, but only suggested, by our results. While we find statistically and economically significant variations in the curvature of different firms' S functions, since we do not observe V we cannot confidently infer anything about variations in the fat functions. In fact, we would expect that the curvatures of the V function would differ markedly across firms. Consider two firms, one of which owns a single mine with extraction costs of \$50 per ounce for all gold in the mine and the other of which owns a larger portfolio of mines with an array of extraction costs from \$10 to \$1000 per ounce. The former firm would have a virtually linear S function, while the latter's would be quite convex.

Nonetheless, a natural response to our findings is to ask wherein this fat consists, and what determines how much of it there is. This has been a main focus of our interviews with

[30] Centurion may have been in financial distress during this period; however, we believe that should if anything bias results towards finding its value function to be convex (through the usual bankruptcy-option effect).

industry executives. Below, we discuss two places we have looked for fat and for factors affecting the extent of fat.

A. *Exploration Costs.*

All the managers we spoke with seemed to believe that — either as an obviously sound business policy, or because of pressure from stock-market analysts — it is imperative for a gold-mining firm to "replace" its extraction, either by exploration for new reserves or by acquisition of existing mines (or of their owners). Several suggested that when gold prices are high, firms found themselves "having to", or perhaps "able to", engage in quite unpromising exploration projects.

Because it is much harder to verify whether an exploration decision is value-increasing than it is to verify whether a mine is being well managed, it seems a likely locus for potentially value-reducing expenditures. In this connection, when we tested for and found concavity of S and then looked for sources of fat in the oil industry (Borenstein and Farrell, 1996), we were told by oil industry commentators that the industry dissipated a great deal of the value increase during the early 1980s by "excessive" (at least *ex post*) exploration. Clearly, a price increase should induce some increase in exploration activity, but it is suggested that the oil industry's response was excessive.[31]

In the gold mining industry, the apparent rule of thumb that firms believe they must replace extraction also suggests a possible simple principal-agent theory for value dissipation after gold price increases. Suppose that mine managers have incentives to increase output when p_g rises, in a way that takes account of increased *extraction* costs but does not take account of the marginal cost of finding more gold. (This might plausibly happen if mines are run as profit centers.) Then it could easily be that their output-increasing decisions, while optimal if the firm optimized overall, would reduce the firm's value conditional on the firm following the rule of thumb that it must replace all extraction. Another possible theory would be that some firms try to resist this rule of thumb and are penalized

[31] See also Jensen (1986) for evidence of value-reducing exploration in the oil industry.

by stock-market analysts who are trained to look for growth or at least sustainability of revenue flows. Several executives told us that they believe analysts behave in this way.

B. *Non-Optimal Labor Compensation.*

As mentioned earlier, if labor takes an increasing fraction of firm wealth as the latter grows, it could account for concavity of the net (*i.e.*, stock market) value function. To the extent that this goes beyond an optimal ex ante contract and becomes an inefficient ex post holdup or asset-stripping, one might characterize it as a form of fat. Though it is sometimes difficult to distinguish efficient from inefficient variations in labor compensation, it is difficult to see how it would be efficient to reward miners for changes in firm value driven by exogenous changes in the price of gold. Empirically, while such labor rent-sharing has been documented in some industries,[32] our discussions with industry participants suggested that it is not likely to be much of an issue in gold mining. None reported that wages moved noticeably with the price of gold.

VI. Conclusion

Once one is willing to consider the idea that there could be inefficiency in firms, it might be natural to suspect that firms will engage in more waste as corporate wealth grows. We have examined this theory empirically in the gold mining industry. We found that many gold mining firms' stock-market values do not increase as much in response to gold price increases when the price of gold is already high as when it is lower. This empirical result contradicts the theoretical convexity result that stems from the upper-envelope, or real option, effect.

The concavity result is particularly striking in the gold mining industry, as real options play a major role in business decision making in gold mining. Firms make substantial changes in their scope of operations and level of production in response to changes in the price of gold. Such flexibility in production plans would seem (following standard theory) to suggest strong convexity in the value of the firm as a function of the price of gold.

[32] See, for instance, Rose (1987).

We posit that much of the observed concavity results from investors' beliefs that (some) firms will dissipate a share of wealth gains and that this share will be larger when the firm is wealthy than when it is under greater financial pressure. We also discuss a number of alternative explanations for the concavity results and conclude that (1) the progressive corporate profit tax seems more likely to create convexity than concavity in the stock market value functions, (2) ordinary mean reversion in gold prices would not yield concavity; a particular form of stochastic evolution in gold prices could explain concavity, but we find no evidence of this pattern, (3) observed forms of hedging by gold firms are likely to increase, not decrease, the convexity of firm value as a function of the price of gold, (4) optimal (or observed) executive compensation contracts are unlikely to explain more than a tiny fraction of the concavity, (5) environmental liability is not likely to be a substantial part of the explanation, and (6) royalties are unlikely to explain more than a small fraction of the concavity.

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Appendix: List of Industry Contacts

In addition to the academics listed in the title footnote, we are very grateful to the following government and industry contacts who have kindly supplied information.

Earl Amey, U.S. Geological Survey
Paul Bateman – VP of Gold Institute
Margo Bergeson – Alta Gold
Pierre-Paul Bleau – Cambior
Mike Brown – Amax Gold
Ronald Cambre – Newmont Mining
Jerry Cooper – Asarco
Steve Dawson– Campbell Resources
Larry Drew – Environmental manager for Hecla
Jane Engert – Mining industry specialist at the U.S. EPA
Tom Ferrell – Environmental coordinator for Sante Fe Mesquite Mine, owned by Newmont.
Robert Gilmore – Dakota Mining
Shannon Hill – Placer Dome
Denise Jones – Director of California Mining Association
Robbin Lee – Echo Bay
John Lutley – President of Gold Institute
Greg Pelka – California State Lands
Michael Steeves – Homestake Mining
Les Van Dyke – Battle Mountain Gold
Dennis Wheeler – Coeur D'Alene
Richard Young – Barrick Gold
Les Youngs – California Office of Mine Reclamation

Table 1: Descriptive Statistics on Gold Price, 1977-1997
(Constant 1997 Dollars)

		Percentiles	
Mean:	543.37	10th:	385.45
Std Dev:	197.87	25th:	411.00
Min:	283.26	50th:	482.15
Max:	1695.18	75th:	612.76
		90th:	746.40

Table 2: Results from Quadratic Value Function Regresssions

COMPANY	Δp_{gt}	$p_{gt-1}\Delta p_{gt}$	CAPM β	R^2	Obs	Period
Alta$^-$	293.	-0.15	0.74	0.315	1033	77-97
	(35.)	(0.03)	(0.18)			
Amax	1912.	5.60	0.79	0.429	511	87-97
	(1948.)	(4.20)	(0.27)			
Barrick$^-$	35510.	-51.19	1.00	0.311	282	87-94
	(10168.)	(17.01)	(0.20)			
Campbell$^-$	243.	-0.16	1.03	0.147	1040	77-97
	(27.)	(0.02)	(0.15)			
Canyon$^-$	1205.	-1.99	0.70	0.177	566	86-97
	(133.)	(0.23)	(0.26)			
Coeur D'Alene$^-$	1171.	-0.99	0.95	0.329	407	82-90
	(290.)	(0.48)	(0.16)			
Dakota	-167.	0.75	1.03	0.078	396	90-97
	(410.)	(1.00)	(0.50)			
Echo Bay	5749.	-1.61	1.04	0.320	694	83-97
	(3449.)	(7.07)	(0.17)			
Getchell$^-$	8470.	-16.45	1.02	0.132	476	88-97
	(2020.)	(4.19)	(0.36)			
Glamis	619.	0.96	0.30	0.301	232	93-97
	(1374.)	(3.35)	(0.20)			
Goldcorp$^-$	1542.	-2.23	0.46	0.089	545	87-97
	(407.)	(0.73)	(0.24)			
Homestake$^-$	5639.	-3.68	0.64	0.310	996	77-97
	(375.)	(0.29)	(0.12)			
Meridian$^+$	212.	5.62	1.02	0.393	538	87-97
	(1146.)	(2.51)	(0.26)			
Newmont	31329.	-29.39	0.79	0.398	166	86-91
	(15289.)	(28.44)	(0.19)			
Placer Dome	30152.	-23.84	0.93	0.379	280	87-97
	(12631.)	(27.02)	(0.18)			
Royal Oak	3539.	-2.71	0.82	0.309	311	91-97
	(3443.)	(8.45)	(0.25)			
Vista	-105.	0.89	1.53	0.272	577	86-97
	(262.)	(0.54)	(0.38)			

$^+$ indicates statistically significant convexity at the 5% level.
$^-$ indicates statistically significant concavity at the 5% level.
White Heteroskedastic-Consistent Standard Errors in Parentheses.

Table 3: Estimated Change in Slope of S Function when p_g increases from its 25th percentile ($411.00) to median ($482.45) price

COMPANY	(1)	(2)	(3)	(4)	(5)	(6)
Alta	-4.6%	0.5%	-3.5%	-5.4%	-4.3%	-10.6%
	(1.0%)	(1.6%)	(1.2%)	(2.9%)	(1.3%)	(5.7%)
Amax	9.5%	7.4%	8.4%	7.2%		9.5%
	(7.1%)	(4.8%)	(6.1%)	(8.3%)		(7.1%)
Barrick	-25.2%	-8.3%	-21.1%	-29.7%		-25.2%
	(8.4%)	(10.3%)	(7.3%)	(11.7%)		(8.4%)
Campbell	-6.6%	-6.2%	-5.4%	-6.7%	-6.0%	-17.7%
	(0.8%)	(1.2%)	(0.7%)	(1.5%)	(1.3%)	(6.4%)
Canyon	-36.5%	-32.6%	-30.1%	-42.2%		-35.1%
	(4.3%)	(7.9%)	(3.5%)	(5.4%)		(4.0%)
Coeur D'Alene	-9.2%	-9.2%	-8.9%	51.1%	-10.6%	41.6%
	(4.5%)	(3.8%)	(3.2%)	(40.2%)	(4.3%)	(21.3%)
Dakota	37.7%	25.1%	37.4%	23.6%		37.7%
	(50.1%)	(24.2%)	(52.7%)	(42.5%)		(50.1%)
Echo Bay	-2.2%	-24.7%	-4.1%	29.8%	18.1%	10.6%
	(9.9%)	(3.3%)	(8.0%)	(26.7%)	(8.0%)	(9.8%)
Getchell	-68.4%	-0.7%	-49.6%	-73.9%		-68.4%
	(17.4%)	(34.0%)	(12.6%)	(18.8%)		(17.4%)
Glamis	6.7%	3.6%	20.2%	5.8%		6.7%
	(23.6%)	(17.5%)	(24.7%)	(25.7%)		(23.6%)
Goldcorp	-25.4%	17.1%	-19.4%	-41.4%		-25.4%
	(8.3%)	(10.4%)	(6.5%)	(13.7%)		(8.3%)
Homestake	-6.3%	-5.8%	-5.4%	-6.0%	-5.7%	-11.9%
	(0.5%)	(0.5%)	(0.5%)	(0.8%)	(0.5%)	(4.6%)
Meridian	15.9%	11.9%	13.3%	20.7%		15.9%
	(7.1%)	(6.1%)	(6.0%)	(11.1%)		(7.1%)
Newmont	-10.9%	-7.7%	-8.8%	-8.0%		-8.4%
	(10.5%)	(13.9%)	(10.0%)	(16.2%)		(8.9%)
Placer Dome	-8.3%	-2.4%	-7.8%	0.4%		-8.3%
	(9.4%)	(5.7%)	(8.0%)	(12.9%)		(9.4%)
Royal Oak	-7.9%	-8.0%	-19.8%	-29.7%		-7.9%
	(24.8%)	(27.2%)	(21.0%)	(38.0%)		(24.8%)
Vista	24.3%	15.2%	25.9%	18.4%		32.1%
	(14.9%)	(13.2%)	(13.5%)	(23.7%)		(15.0%)

(1) OLS with White standard errors (from table 2)
(2) GLS with correction for heteroskedasticity caused by S_{it-1} in residual
(3) same as (1) except using 7th nearest gold futures price instead of nearest gold futures price
(4) same as (1) except including linear and quadratic terms for nearest silver futures price
(5) same as (1) except including only observations during 1977-1986
(6) same as (1) except including only observations during 1987-1997

Table 4: Results from Piecewise Linear Regresssions

COMPANY	Δp_{gt}^L	Δp_{gt}	Δp_{gt}^H	CAPM β	R^2	Obs
Alta[−]	222.	157.	-47.	0.79	0.285	1033
	(65.)	(19.)	(35.)	(0.19)		
Amax	-211.	4478.	421.	0.78	0.425	511
	(698.)	(485.)	(708.)	(0.27)		
Barrick[−]	18617.	9914.	-6213.	0.95	0.335	282
	(6944.)	(2708.)	(2824.)	(0.21)		
Campbell[−]	530.	130.	-93.	1.10	0.158	1040
	(108.)	(23.)	(27.)	(0.16)		
Canyon[−]	449.	248.	-232.	0.70	0.182	566
	(107.)	(47.)	(48.)	(0.26)		
Coeur D'Alene	-39.	558.	18.	0.92	0.320	407
	(151.)	(53.)	(150.)	(0.17)		
Dakota	-73.	170.	-7.	0.96	0.076	396
	(82.)	(48.)	(74.)	(0.52)		
Echo Bay[−]	2823.	5085.	-760.	1.04	0.328	694
	(1272.)	(474.)	(945.)	(0.17)		
Getchell[−]	3838.	569.	-44.	1.11	0.164	476
	(1133.)	(192.)	(210.)	(0.35)		
Glamis	-113.	1037.	-23.	0.30	0.302	232
	(324.)	(170.)	(217.)	(0.20)		
Goldcorp[−]	1091.	324.	-56.	0.48	0.109	545
	(375.)	(71.)	(85.)	(0.24)		
Homestake[−]	8912.	3749.	-2820.	0.68	0.321	996
	(1368.)	(355.)	(423.)	(0.12)		
Meridian[+]	-117.	2516.	981.	1.02	0.392	538
	(461.)	(271.)	(448.)	(0.26)		
Newmont[−]	11889.	12576.	2374.	0.82	0.408	166
	(3824.)	(2396.)	(4138.)	(0.19)		
Placer Dome	551.	23473.	-9369.	0.89	0.399	280
	(5063.)	(2478.)	(3554.)	(0.18)		
Royal Oak	710.	2239.	196.	0.84	0.312	311
	(770.)	(395.)	(489.)	(0.25)		
Vista	147.	282.	124.	1.52	0.269	577
	(128.)	(53.)	(99.)	(0.39)		

[+] indicates statistically significant convexity (at 5% level) when comparing slope in top and bottom quartile.
[−] indicates statistically significant concavity (at 5% level) when comparing slope in top and bottom quartile.
White Heteroskedastic-Consistent Standard Errors in Parentheses.

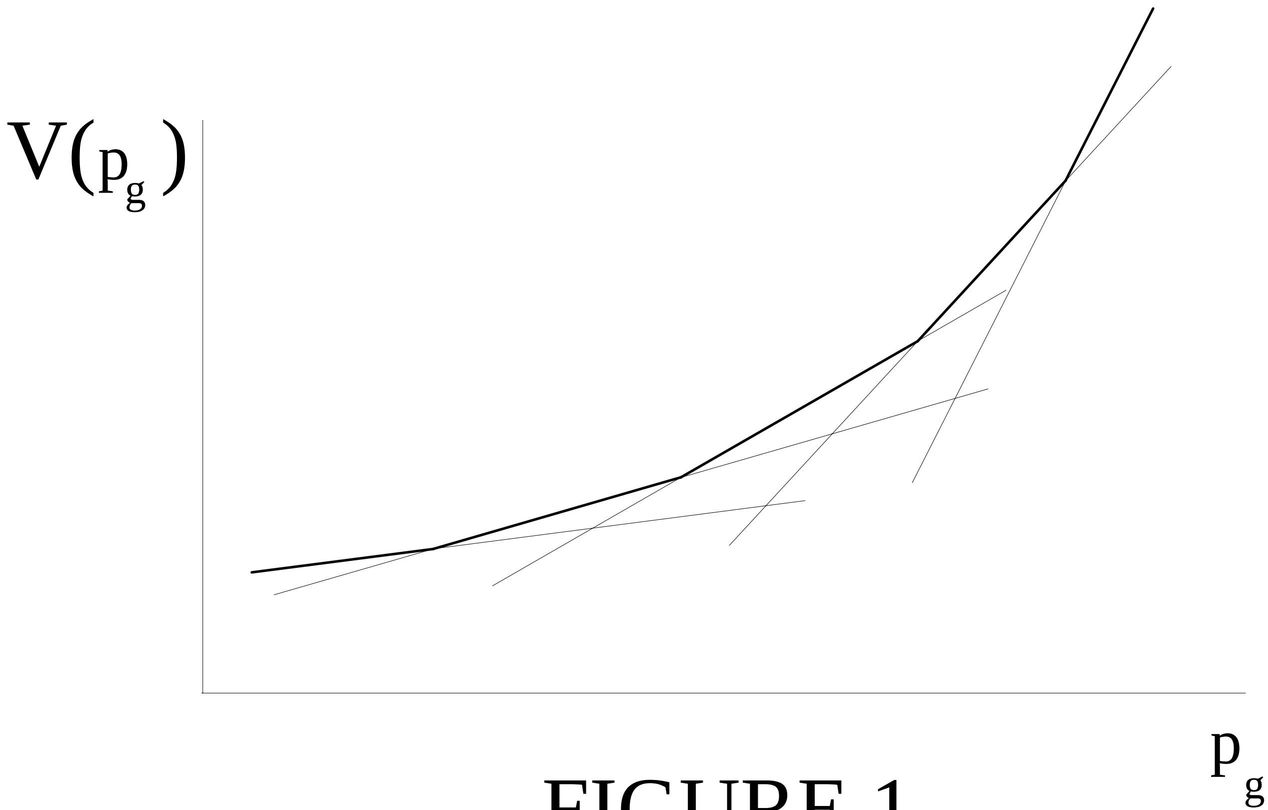

FIGURE 1

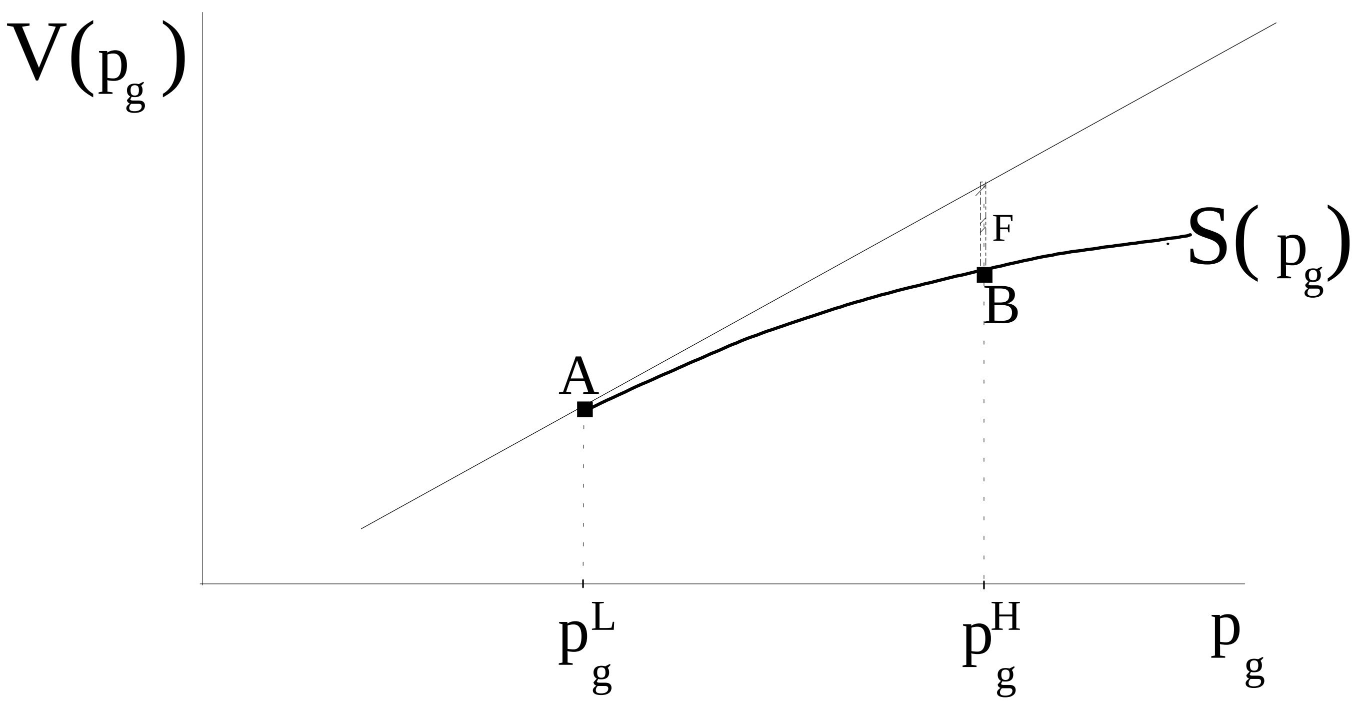

FIGURE 2

Figure 3: Gold Prices, 1977-1997

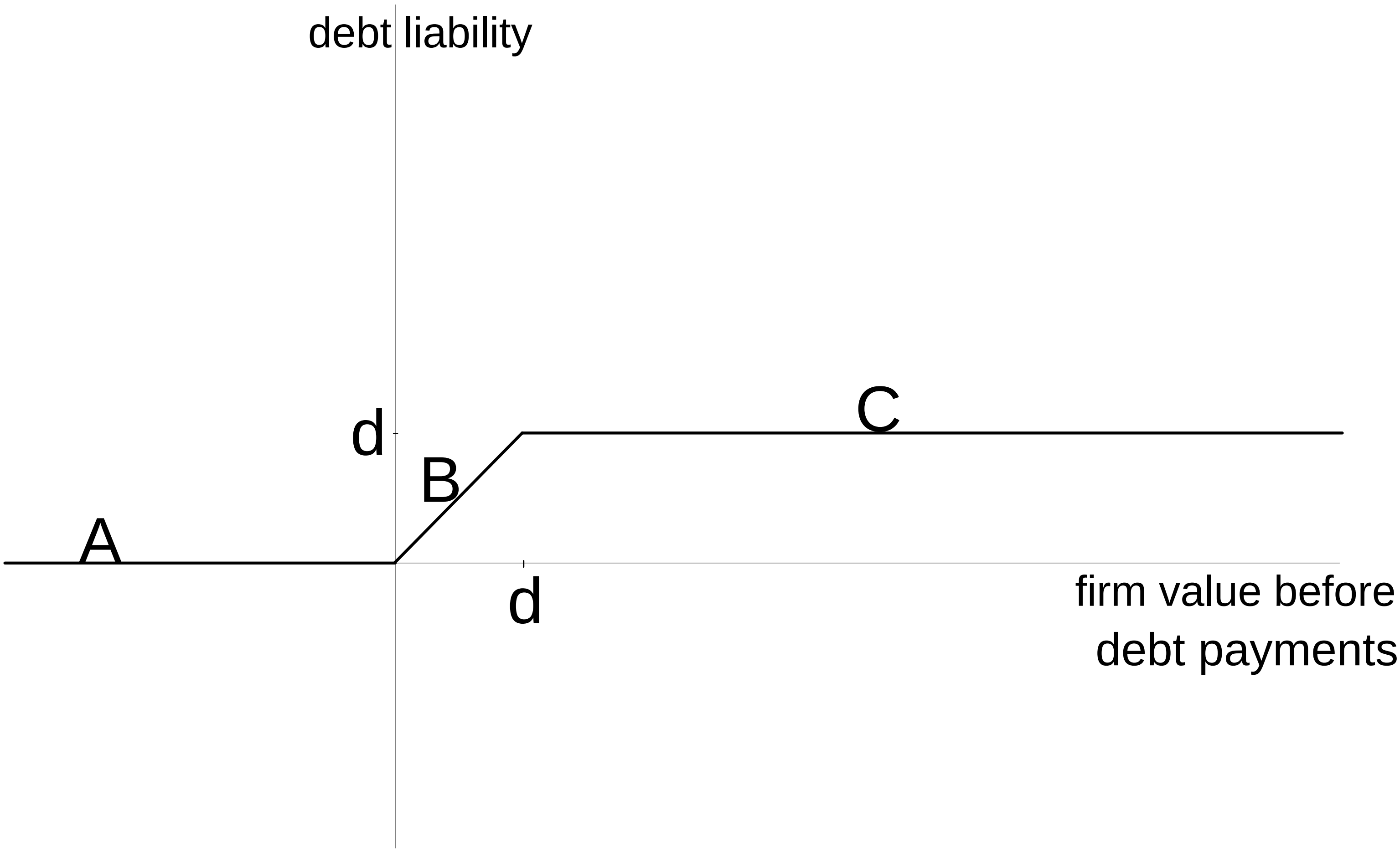

FIGURE 4