Centre for Energy and Value Issues

Energy and Value Letter

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Energy and Value Letter

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The Energy and Value Letter brings together academics and practitioners worldwide to discuss timely valuation issues in the energy sector. It publishes news from the Centre for Energy and Value Issues (CEVI), its linked organisations and others (including calls for papers), practitioners' papers: short articles from institutions, firms, consultants, etcetera, as well as peer-reviewed academic papers: short articles on theoretical, qualitative or modelling issues, empirical results and the like. Specific topics will refer to energy finance in a broad sense. Most of the publications are on invitation, but the journal welcomes unsolicited contributions. Please e-mail to **energyandvalue@gmail.com**, c/o Özgür Arslan, a copy of a news item or a completed paper. Include the affiliation, address, phone, and e-mail of each author together with appropriate JEL classifications with your contribution. A news item should not have more than 400 words and a paper should not exceed 3.000 words.

Energy and Value Letter

INTRODUCING THE THIRD ENERGY AND VALUE LETTER

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With this issue, the Energy and Value Letter enters its second year of publication. Increasingly, the journal acts as a platform for academics and practitioners worldwide to discuss timely valuation issues in the energy sector. It contains news from the Centre for Energy and Value Issues (CEVI) and others, as well as practitioners' papers and academic papers. News items with at most 400 words and papers not exceeding 3.000 words can be sent to **energyandvalue@gmail.com**, c/o Özgür Arslan.

The EVL is not just a product of the team whose names can be found on the former page, but is rather made by the authors of the articles, the CEVI sponsors and various others. I am grateful for their support thus far. Especially I want to recognize the editorial assistance of Ellie Jelsema of the University of Groningen. You may recall her from the Amsterdam conference in 2007. If you want to be sure that you receive your private copy of the EVL on time, you can simply mail to e.t.jelsema@rug.nl.

At the time of writing this editorial for EVL, I could not help but notice a small article by Rotman (2009) who notes that the USA has huge reserves of natural gas in the form of black shale in parts Eastern USA in New York, Pennsylvania, Ohio, West Virginia, Maryland and Kentucky and advanced drilling technology is felt to have enabled economic extraction. Pennsylvania has already commenced drilling and expects to generate around $3.8 billion in sales and more than 48,000 jobs in 2009/2010. Although there can be drawbacks in terms of soil decline that Henk von Eije and Wim Westerman of the University of Groningen value economically in this issue, using a greater amount of natural gas rather than coal or petroleum of course makes sense.

Coal fired plants still generate 50% of US electricity requirements, but produce over 80% of the power industry's carbon dioxide emissions. This number might be cut to up to 50% if natural gas replaced coal fired electricity generation. There would be less reliance on imported energy sources. However, a major consideration in the development of the resource will need to be the necessary fundamental technological transformation away from coal fired plants. Coal at present is a less expensive energy source and there are other considerations on the decision to mine any energy source be it black shale, oil or coal. In this edition of EVL, John Gould of Curtin University in Australia presents a novel approach by considering a model framework that includes contrary influences on the mining decision and in turn provides an indication for the optimal extraction rate.

Reference

Rotman, D., (2009) "Natural Gas Changes the Energy Map" *Technology Review*, MIT News, Volume 112, Number 6, pp. 45-51, www.technologyreview.com

Energy and Value Letter

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THE STORY OF CEVI: Energetic Steps to Long Term Success

A long time ago Huxley had said that "the great end of life is not knowledge but action". The cooperation of a group of finance and economic professors and specialists who believed in this idea was a coincidence at the beginning but the outcome of this cooperation resulted in systematic efforts and a series of actions. These people were mostly from the Netherlands, Turkey and Australia. They know each other from their membership of the Multinational Finance Society. They were not only interested in the theoretical side of the recently developing energy markets, but also in its practical aspect.

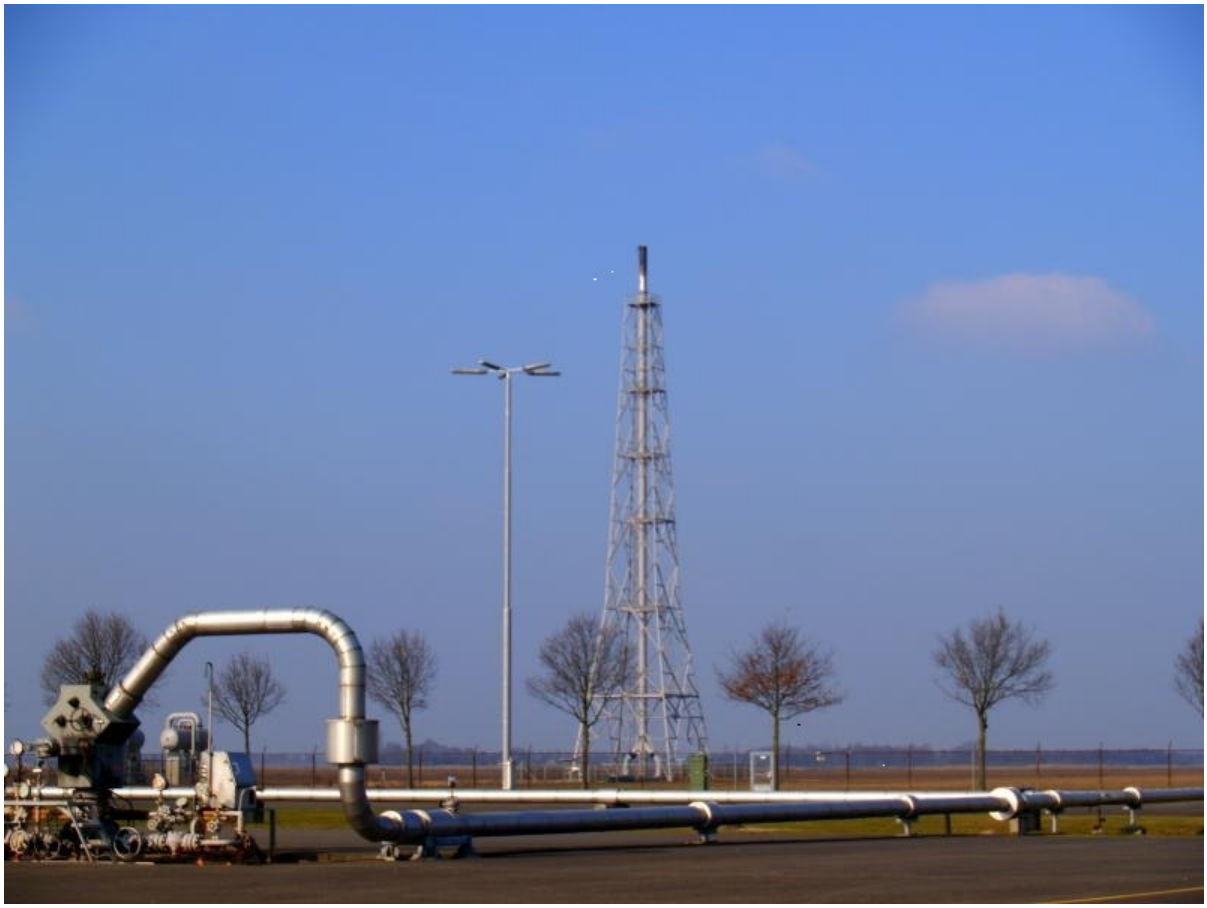
The short story of CEVI started in February 2007 with the demand of Wim Westerman, when I was the president of Multinational Finance Society. Wim Westerman asked for official support of MFS to promote a workshop on energy and value in Amsterdam for June 2007. MFS did not give support for any conference before. I thought that MFS might motivate small workshops and meetings to extend its influence and find new members. Thus, the official support of MFS was obtained and the first Energy and Value Conference was organized. The structure of the conference was based on academic research and presentations of practitioners by creating a discussing platform for academics and professionals. This format would be the base for the energy and value conferences in coming years. This small conference was an initial spark for future cooperation. The friendship of André Dorsman and me started during the conference. Wim Westerman, John Simpson, Jennifer Westaway and Özgür Arslan gave shoulder for joint works in future. With the active participation of Hasan Kazdağlı and Ephraim Clark, the team was almost ready to move. Then, the second energy and value conference was organized in Istanbul in 2009 with higher participation and success. At the time, we are discussing several possible venues for the 2011 conference. Afterwards, Paul Prabhaker wishes to organize the fourth conference in Chicago for 2013. So, this small group committed themselves with very significant responsibilities, walked towards to the formalization of the energy and value group. During the visit of Hasan Kazdağlı and myself to Amsterdam in late 2008, the official structure and name of the formal organization were determined; that is the Centre for Energy and Value Issues (CEVI).

I would like to express that the informal cross functional teams have been organized spontaneously and a nearly perfect work specialization has been achieved. As André Dorsman was planning the organizational design with my cooperation, Wim Westerman loaded the website works and informal inspection of activities. Jennifer Westaway and Özgür Aslan focused on the research part of the CEVI. The contribution of John Simpson was not limited to research; he also provided the initial capital for the establishment of CEVI by donating from his research fund. We will always be grateful for his support. Hasan Kazdağlı and Erik van Dijk coordinated the works with national and international energy institutions and Ephraim Clark shouldered us with his Frontiers in Finance and Economics journal. He made it possible that a special about Energy and Value Issues was published in the October 2009 number of this journal. This special was based on the papers presented during the Energy and Value conference in Amsterdam in 2007.

Finally, CEVI has been formally established in February 10, 2010 in a snowy morning of Amsterdam. The agenda of CEVI has already been loaded with the Springer book series, the CEVI Energy School and next conferences. The Springer book series will start with "Financial Aspects in Energy: The European Perspective" which is due to be published before the 2011 bi-annual conference. The CEVI energy school is planned during the months September in Ankara and February in Amsterdam, with the sponsorhips of APX Endex and TenneT, the Ministry of Energy of Turkey and others.

All of them are very significant projects for a newly developing organization. However I believe that the CEVI team will easily overcome them and launch new projects that can lead us to long term success.

Mehmet Karan
Ankara, April 15 2010



Energy and Value Letter

THE BUY-OFF VALUE OF WATER WORKS FOR COMPENSATING GAS EXPLORATION INDUCED SOIL DECLINE IN THE NETHERLANDS

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Abstract
We measure the long term value of the costs of soil decline caused by natural gas exploration in the Netherlands. Especially regional water councils are hurt by the soil decline and their ever recurring damage may be bought off by the natural gas explorer. As components costs have gone up and risk free rates have fallen, the amount involved has increased over time. We show that a conflict of interest may prevent the parties from coming to an agreement. As the exploration effects are irreversible, the term of a buy off settlement arrangement must be very long. This may increase the present value of the costs of a typical compensation project by itself, but it also implies that historical interest rates used in discounting future cash flows are too large. It is therefore fair to add a sizable amount on the present value that can be calculated from historical interest rates. By comparing this reasoning with alternative estimates, we show that a real discount rate of 2% does well.

Key words: gas exploration, soil decline, water works, cost components, long run cost of capital, present value projections, arrangement term, buy off settlement

1. Introduction

The northern part of The Netherlands lies around see level. This is also an area where natural gas exploration is very important. The so-called "Slochteren field", discovered in 1959 is one of the biggest in the world and covers an area of around 900 km² and had an original producible gas reserve of about 2,700 billion m³ and it still had an estimated reserve of 1,500 at the end of 2002[1]. A side-effect of the gas exploration is a gradual soil decline, which in the Slochteren area is around 0,3 meter as of today. This decline disorders the water balance in the area and generates irregular small earthquakes. Because of the gradual decline, water works have to be carried out.

The NAM, a joint venture of Shell and Esso, is the gas explorer. The NAM has contributed to a compensation fund for those that are affected by the soil decline. All costs declared, if recognised, are paid for from this fund. The fund is in principle closed-end, yet inflation-adjusted, unless the decline will be larger than expected at the moment of installing the fund. Thus, it may be attractive for those who are sure to be harmed to buy off the present value of their estimated claims before others might make their (unexpected) claims. The regional water councils, that are quite likely to be the major claimants, studied this

[1] Based on the websites of its explorer (NAM) and Wikipedia.

possibility with the NAM in 1998 [1]. Despite basic understandings, the parties were, however, not yet ready for such a major operation at that time.

In 2007, the water councils asked the authors to update the results of the 1998 study ("EWM") as to costs of energy and materials (we added labour), to determine the relevant cost of capital to discount the operational (including investment) costs with, and to assess value of the claims if these were estimated for a future period of 75 years or for an eternal period. Moreover, the water councils asked us to estimate the management costs of investing the buy-off lump sum.

The remainder of this article is organised as follows. The research methodology is outlined in section 2. Costs of components are discussed in section 3. The discount rate for determining the lump sum is assessed in section 4. The term of a possible arrangement is studied in section 5. The present value of diverse alternatives is shown in section 6. The management costs of the investment of a possible lump sum are estimated in section 7. Our conclusions and recommendations follow in section 8.

2. Methodology

Our research updates the data of the EWM study, which included cost data and their development up to 1996. If applicable, we refer to the same specific water work as in the 1998 study, in order to make both studies comparable. Our qualitative reporting is augmented by quantitative calculations.

We use the following data sources without reference: 1) data series on interest and inflation by the Dutch Central Bureau of Statistics (CBS) and the Dutch Central Bank (DNB), 2) specific components price data bases of international market parties and 3) interviews on management costs of low risk investments with two Dutch financial intermediaries: a director of a (government bodies) treasury consulting bureau and an investment manager of a specialised mid-sized bank.

3. Cost components developments

The CBS distinguishes as relevant cost categories labour costs, materials costs and raw materials costs. If labour costs developments will not change substantially in the coming years, these costs will on average go up slightly more than the inflation rate. Costs of energy have risen above average in the last decade and we expect the increase to be around 3% per year in the next ten years. However, prices may rise further, as soon as the energy production falls short. Costs of steel on average rise by about 4% per year, with a hike in the mid-00's. Concrete prices also mounted remarkably in the 00's. Other cost categories, including wood, have not shown exceptional movements though.

The joint effects of the distinct categories listed above are reflected in the overall CBS price index. The 1998 study subtracts this figure from the return on government bonds to arrive at real rates of return for the water councils and we follow the same procedure. It shows that the general price index increased by about 4½% per year, but in a rising economy and with a Pan-European monetary policy a further increase can be expected. The price index for the sector as such is very volatile, yet at an annual increase of 3½% it is smaller than the rise in the general price index. Lower wage costs mainly attribute to this. More specific recent CBS figures, however, show higher relevant wage increases. In our calculations we will therefore show the effects with and without a mark-up of 1% of wage increases above the increase in the sector price index.

4. Cost of capital and present values

The specific case of the soil decline settlement asks for a detour on discount rates and required return. Corporate shareholders require a risk adjusted return. The relevant risk is the systematic risk, caused by the standardized co-movements of the project returns with those of the general market index (also known as the beta). This risk cannot be waived without costs and therefore a premium on the risk free return is asked for. The value of future corporate investment projects should therefore not be determined with the risk free interest rate, but with a higher -risk bearing- rate.

Nevertheless, by law, the water councils are not allowed to invest in projects with systematic risks. They are forced to invest in virtually risk free objects. Therefore the return on government bonds is relevant for discounting

purposes. On average a return of 4% is relevant and with low risk ("AAA") investments an extra 0.25% can be earned.[2] NAM shareholders, however, will apply a higher discount rate for the same projects, given the alternative investment opportunities of the firm. So, future cash flows are discounted by a higher rate than the water councils are able to use. Thus, the present value of future outlays will be smaller for the NAM than for the water councils and this discrepancy may make it difficult to come to an agreement.

5. Arrangement term (75 years or eternal)

Settlement arrangements widely diverge. They are usually short, up to a few years. They foremost stipulate how damage costs should be calculated. Recent proposals in energy, water and nature fields meant to catch in principle eternal effects include a Greenpeace study on gas exploitation damage in a unique Dutch brackish estuary [3], a study on river flooding risks in The Netherlands [4] and a US study on Indian habitats recovery [5]. These studies also use real discount rates[3].

The Greenpeace study limits the discount term to 70 years and has rates of 2%, 4% and 6%. The authors of the Greenpeace study reckon with 4% too and limit the discount term to 50 years, because of the low present value of cash flows after such a period and maybe because the largest Dutch nature reserve organization also uses 50 years. The flood risk study calculates with a discount rate of 4%. They assume eternal cash flows, without any discussion. The Indian habitat study states that US government bodies apply discount rates of 3% or slightly more.

According to Cowen [6], Weitzman [7] and Hepburn [8], damage restitution should cross generation borders (of e.g. 70 or 75 years), this being social. For altruistic reasons, discount rates may have to fall over time, as future generations can do nothing about present damage after all. This goes even more when they are harmed in their development. However, this is unlikely to hold for the settlement arrangement studied here.

Nevertheless, the approach of Weitzman in his study on economists' estimations of discount rates may be relevant. He finds that economists that use a low discount rate will get by definition a higher weight in the total present value than economists that use a high discount rate and this effect increases if longer arrangement terms are used. So the real discount rate falls from 4% for cash flows up to 5 years, next to 3% for cash flows up to 25 years, then to 2% for cash flows up to 75 years, following to 1% for cash flows up to 300 years and later to 0% (others say 0.1%) for remaining cash flows. Based on various statistical assumptions Weitzman derives that the relevant real discount rate is 1.75%.

6. Determining the present value

We calculate present values for the example project as follows. We distinguish between an eternal buy off settlement (cut off to 1,050 years) and a 75 years buy off settlement. Effects of 1% extra inflation with current costs are also allowed for, as argued above. All prices are expressed in Dutch guilders of 1992 and the cost structure of the reference project is used as our reference point. Three alternative calculations will be applied and are explained now.

(1) The first (basic) alternative uses a real discount rate of 3%, which is also equal to the EWM study of 1998 with an eternal settlement term (and no additional cost inflation). The value equals 9.810 million of guilders (indicated in bold in the table). (2) The second alternative uses the average real interest rate in 1949-2005 and the average real interest rate over the years 1996-2005 (the exceptional year 2006 with a negative real rate of interest is left out). When we weight these averages, we find a real interest rate of 1.935%. This increases the present value from 9.810 million to 17.121 million. (3) The third alternative uses a year by year approach. We calculate present values based on real interest rates for every year between 1949 and 2006 and averages the 58 amounts. In this alternative we set the real interest rate at a floor of 1.5%. This

[2] The credit crisis has shown that quite some of these ratings aren't applicable in extreme economic situations. Coval, Jurek and Stafford [2] suggest that this can in particular happen with senior structured bonds, which rating agencies evaluate at expected pay-offs, while investors might do wise to evaluate them lower, as their investments might be gone in situations when cash is mostly needed.

[3] The Dutch central government lowered the infrastructural projects discount rate to 4% in the 90's.

approach therefore does not use the history of interest rates in order to come at an average discount rate to be used in calculating the present value of cash flows, but it uses the present values for all historical interest rates in order to come at an average amount. The value is then 15.021 million.

The third alternative is fairly robust. Present values rise more with interest decreases than that they fall with interest increases. Calculations at an average interest rate therefore underestimate the large amounts needed if the water councils would be forced to invest at very low rates of interest for a very long time. This third approach averages the high amounts needed at persisting low interest rates against the low amounts needed if the water councils are able to invest at high interest rates. The third approach seems to be fair, because the buy-off provides the water councils with an amount. In the absence of a guarantee of the NAM for a real rate of interest on the amount received as redemption value the water councils do wise to be interested in receiving a fair cash amount, in stead of getting a fair assessment of future interest rates. Alternative 3 is also quite robust for a mid-long real interest rate shock (cf. Weizman [7] where lower discount rates generate heavier weights).

Table 1 The present value of future costs with the reference project for three alternatives and various inflation rates and settlement terms (in Dutch guilders of 1992*1000)

	Eternal settlement term		*75 years settlement term*	
	Without extra inflation in yearly costs	With 1% extra inflation in yearly costs	Without extra inflation in yearly costs	With 1% extra inflation in yearly costs
Alternative 1	**9810**	12420	8858	10255
Alternative 2	17121	25684	13223	15426
Alternative 3	15021	25899	11075	12884

Of course, in the eternal buy off settlement arrangement, the results of all alternatives are higher than in the 75 years settlement (see table 1). With 1% extra inflation of the costs for the water councils, the discounted values also rise. Especially alternative 2 gives higher results than alternative 1. Alternative 3 results are closer to alternative 2 than to alternative 1. All the values of table 1 go up in 2007 prices, but guilder prices are higher than euro prices. In effect one has to multiply the alternative results by about 0.69 to get the real value in euros at the time of our calculations (2007).

7. Fund management costs

The central Dutch government specifies a strict treasury framework for water councils. These statutory risk norms leave the treasuries only marginal room for investment management. Instruments allowed roughly include (repackaged) low risk loans. Trade costs for these can be kept low. If a possible lump sum is invested in low risk loans, the yearly costs may be 0.5% or a little more, but gross returns to bonds may also go up by about 0.5%. However, if government bonds are used, the yearly costs may be as low as 0.1%. These costs are therefore relatively small in comparison to the amounts to be redeemed by the NAM. Of course additional risks of mismanagement of their investments may also be faced by the water councils and these aren't taken into account here.

8. Concluding remarks

The water councils' cost of capital is the risk free rate, but it is not for the NAM, causing a conflict of interest. The buy off term of a settlement arrangement must be very long, as soil decline is irreversible. The effects of a term limitation are large. As low interest rates have more weight with long terms, a discount rate of 3% is quite high and it seems fair to use an average amount calculated from values based on historical interest rates. This implies an overall real interest rate to about 2%. Rephrased it implies that the water councils may need an additional amount for the risk of discounting at a real interest rate of 3%, while the investment returns might be smaller than 3%. Wage, energy, steel and concrete costs of water works have gone up and if these trends are reflected in sector price indices substantial value effects arise. The costs of managing an eventual lump sum are limited for the water councils.

The operational costs increase has not fallen. Yet we advise not to include the insecure 1% mark-up. The long term nominal interest rate has decreased from 3% to below 1.5%. We feel that cash flows for soil decline projects may be discounted at 2%. It is strange to limit an arrangement term between the water councils and the NAM to an arbitrary 75 years as the decline of the soil will be eternal. Investment costs of the lump sum can be neglected with a settlement.

We feel to have given an adequate update of the long term value of soil decline caused by gas exploration. The reasoning does not differ materially from the EWA report of 1998, though our 2007 proposals show the large impact of averaging interest rates or reducing average discount rates. Our contribution to the literature is twofold. First we showed that negotiations may be difficult to close, if the parties at the negotiation table use different discount rates. Second, the difference in results between averaging discount rates and averaging discounted amounts is generally neglected in the literature on calculating present values. Our results show that this may result in highly divergent outcomes.

JEL Classification Code: G31

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OPTIMAL EXERCISE OF THE OPTION TO MINE

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Abstract
When a mining project is considered as a set of real options to extract the underlying commodity resource, the actual act of extraction entails giving up the time value of the exercised options. This sacrifice may be worthwhile if it leads to sufficient cash flow to assuage financiers' information asymmetry concerns about the true value of the commodity resource. I present a model framework that incorporates these contrary influences on the decision to mine, which then provides indication for the optimal extraction rate.

1. Introduction

When a mining project is considered as a set of real options to extract the underlying commodity resource, the actual act of extraction entails giving up the time value of the exercised options. This sacrifice may be worthwhile if it leads to sufficient cash flow to assuage financiers' information asymmetry concerns about the true value of the commodity resource. I present a model framework that incorporates these contrary influences on the decision to mine, which then provides indication for the optimal extraction rate.

2. Incentive to exercise the option to mine

One perspective of a mining operation is that the operator has the option to extract each unit of the underlying commodity resource. Ostensibly each option to extract has infinite life (assuming property rights are sustainable for perpetuity). It is well known that an American-style option should not be exercised early unless the dividend yield or convenience yield of the underlying asset or commodity is sufficiently large to outweigh the option's time value[1]. Such early exercise tends to be optimal when the dividend / convenience yield is greater than the risk-free interest rate. Thus the high convenience yields of consumption commodities justify early exercise of options to extract. However this argument does not apply to store-of-value commodities with low convenience yields.

A second imperative for early exercise of options to extract is information asymmetry between mine operators and financiers. Geologist claims about the quality of a resource become credible via the proof of extraction, which provides confidence to creditors and shareholders. This may translate into a market value benefit that exceeds the foregone time value due to early exercise. Agreeing to and honoring a schedule of debt or dividend payments is a credible signal of the value of a resource, but this requires operating cash flows, which motivates the exercise of options to extract. In this vein, Grundy and Raaballe (2005) demonstrate that standard option pricing arguments and assumptions (including no convenience yield and sustainable property rights) imply that we should not expect to observe operating gold mines[2]; they then demonstrate that asymmetric information about gold mine reserves is a necessary and sufficient condition for the existence of operating gold mines.

[1] The convenience yield of a commodity indicates the relative degree to which physical possession of the commodity is not substitutable with a contract entitling future possession. It is their nature that store-of-value commodities have low or negligible convenience yields, and consumption commodities have comparatively high convenience yields. For example, Casassus and Collin-Dufresne (2005) estimated long-term average annual convenience yields for silver, gold, copper and crude oil of about 0%, 1%, 6% and 11% respectively for the period 1990 to 2003.

[2] It is an interesting philosophical quandary as to whether one should prefer to keep one's store of gold unseen in a bank vault under trust of a bank manager, or unseen under the ground on the word of a geologist.

3. Optimal exercise of the option to mine

Mining operations entail the periodic payment of extraction costs in exchange for production revenues. The revenues are a function of the variable price of an underlying commodity such as gold. The costs will also be a function of variable factors including labor prices and, most particularly, energy prices. Consequently, a miner can be considered to have multiple options to exchange a unit of extraction costs for a unit of production commodity. That is, a miner with a time-zero resource of Q_0 units of production commodity has Q_0 real options to exchange[3]. In theory, early exercise of these options to exchange will not be desirable unless the convenience yield of the production commodity is sufficiently high, or if required to satisfy external demands for cash flow imposed to alleviate information asymmetry.

For sake of simplicity, assume net cash flow from mining production goes into a bank account that serves as satisfactory collateral for cumulated cash flow demands. Further assume the absence of market and operational frictions such as taxes and transaction costs, and shut-down, start-up or production rate variation costs. Then the value of the mining operation in discrete time can be represented as:

$$V_t = (Q_{t-\Delta t} - X_{t-\Delta t}\Delta t)\; c_t \; d_t + \sum_{\tau=\Delta t}^{t} \left[p_\tau - f(s_\tau) \right] X_{\tau-\Delta t}\, \Delta t \; e^{r(t-\tau)}$$

where: t is time measured in discrete steps of Δt; $Q_{t-\Delta t}$ is the quantity of commodity resource at the start of the just-completed production period; $X_{t-\Delta t}$ is the commodity extraction rate at the start of the just-completed production period (therefore $Q_{t-\Delta t} - X_{t-\Delta t}\Delta t$ is the remaining quantity of commodity resource at the start of the just-*started* production period); c_t is the unexercised value of the option to mine a unit of the commodity resource (conceptualized as an option to exchange, which will be a function of the usual variables and parameters); d_t is an information asymmetry discount factor, representing market concerns about the "true" quantity of the commodity resource which is known with certainty only by the mine operators; $p_t - f(s_t)$ is the exercised value of the option to mine a unit of the commodity resource, where p_t is the spot commodity price, and $f(s_t)$ is the unit extraction cost presented as a notional function of the oil price, s_t; r is the interest rate; and the summation operator, $\sum$, is applied in steps of Δt.

Ignoring practical operational limits, the notional limits on $X_{t-\Delta t}$ are:

$$0 \le X_{t-\Delta t} \le \frac{Q_{t-\Delta t}}{\Delta t}.$$

Thus, once the remaining commodity resource has fallen to zero, the extraction rate must also be zero, and the mining operation ceases.

Suppose the information asymmetry discount factor is a function of the relative extraction rate as follows:

$$d_t = \left(\frac{X_{t-\Delta t}\Delta t}{Q_{t-\Delta t}} \right)^{\gamma}, \quad 0 \le \frac{X_{t-\Delta t}\Delta t}{Q_{t-\Delta t}} \le 1$$

where $\gamma \ge 0$ is the information asymmetry parameter. The implication is that the higher the relative extraction rate, the lower the information asymmetry, and the closer to unity will be the discount factor. A sensible value for γ would arguably be close to zero.

We are now able to determine the strategy for $X_{t-\Delta t}$ that maximizes V_t:

$$\frac{dV_t}{dX_{t-\Delta t}} = \gamma \left(\frac{X_{t-\Delta t}\Delta t}{Q_{t-\Delta t}} \right)^{\gamma-1} \Delta t \; c_t - (1+\gamma) \left(\frac{X_{t-\Delta t}\Delta t}{Q_{t-\Delta t}} \right)^{\gamma} \Delta t \; c_t + \left[p_t - f(s_t) \right] \Delta t$$

Noting that $d^2V_t / dX_{t-\Delta t}^2 < 0$ for $0 < \gamma \le 1$, the optimal value of $X_{t-\Delta t}$ solves:

$$\gamma \left(\frac{X_{t-\Delta t}\Delta t}{Q_{t-\Delta t}} \right)^{\gamma-1} - (1+\gamma) \left(\frac{X_{t-\Delta t}\Delta t}{Q_{t-\Delta t}} \right)^{\gamma} + \frac{\left[p_t - f(s_t) \right]}{c_t} = 0$$

, $0 \le \frac{X_{t-\Delta t}\Delta t}{Q_{t-\Delta t}} \le 1$.

For example, assuming the ratio of the exercised to unexercised value of the option to mine ($[p_t - f(s_t)] / c_t$) is 0.8, and γ is 0.01, then the optimal relative extraction rate ($X_{t-\Delta t}\Delta t / Q_{t-\Delta t}$) is 5.37%. The optimal value

[3] Margrabe (1978) provides an analytical valuation solution for an option to exchange assuming early exercise is not allowed or never desirable.

of $X_{t-\Delta t}\Delta t / Q_{t-\Delta t}$ increases with increasing $[p_t - f(s_t)]/c_t$ and γ.

For $\gamma = 0$ (i.e. zero information asymmetry), the optimal extraction rate is an all or nothing decision (i.e. $X_{t-\Delta t}\Delta t / Q_{t-\Delta t}$ is equal to 100% or 0%) respectively associated with whether $[p_t - f(s_t)]/c_t$ is greater than one or less than one. A high convenience yield can lead to $[p_t - f(s_t)]/c_t$ being greater than one.

Note that, because $X_{t-\Delta t}\Delta t / Q_{t-\Delta t}$ is a start-of-period choice but $[p_t - f(s_t)]/c_t$ is an end-of-period observation, the extraction decision must be based on end-of-period expectations.

4. Conclusion

When a mining project is considered as a set of real options to extract the underlying commodity resource, the actual act of extraction entails giving up the time value of the exercised options. The severity of this sacrifice is inversely related to the ratio of the exercised to unexercised value of the option to mine each unit of commodity resource ($[p_t - f(s_t)]/c_t$ in my notation). This sacrifice may be worthwhile if it leads to sufficient cash flow to assuage financiers' information asymmetry concerns about the true value of the commodity resource. I present a model framework that incorporates these contrary influences on the decision to mine, which then provides indication for the optimal extraction rate.

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