9th Meeting of the Advisory Expert Group on National Accounts,
8-10 September 2014, Washington DC

Agenda item: 7.1

Methodology for the valuation of natural resources

Introduction
The valuation of natural resources is primarily intended to compare different assets using a common denominator, a comparison that cannot be made using purely physical data. Nevertheless, the measurement of remaining stocks in physical units is also essential, not only because it is the one which is most relevant when analysing the depletion of natural resources, but also because it is a necessary intermediary step for the valuation of natural resources.

The international comparability of natural resource stocks in physical units still needs further improvement. The main issue is the coexistence of different classifications to measure remaining stocks. Moving to the classification advocated by the System of Environmental-Economic Accounting 2012 Central Framework (SEEA 2012) may be difficult in practice due the level of aggregation or the focus on specific types of resources in the original classification system chosen by countries or international organisations. Efforts need to be made to convince them to choose the SEEA-CF classification as a reporting standard or to make sure that an easy conversion to the preferred classification is feasible. This point will be discussed in the first section of this paper.

Once data on physical stocks are available in an internationally comparable classification system, valuation can start. The valuation methodology will be discussed in the second section of this paper. Given that there is usually little direct information on prices of the assets underground, the SEEA 2012 suggests valuing stocks of natural resources using the net present value (NPV) method. This method relies on the assumption that the asset market is in equilibrium, implying that the market value of the asset is equal to the sum of discounted future income associated with the exploitation of the asset. As commodity prices show large swings, there is significant uncertainty about their future development. Given this volatility of commodity prices, it does not seem reasonable to assume that extracting firms take their decisions looking only at the current price or an average of recent developments in prices. From an accounting perspective, only focusing on current or recent prices can also lead to volatile stock of assets in monetary units, thus reducing the usefulness of these accounts. Here, it will be suggested to rely more heavily on dynamic optimisation models in order to compute the NPV, thus ensuring that production and price forecasts are consistent and that the ability of producers to react to changing economic conditions in the future is taken into account. In this way, at least part of the uncertainty regarding future price developments will be embedded in the NPV computations.

Guidance on documentation provided
Not relevant.

Main issues to be discussed
- *Does the AEG agree that the volatility of commodity prices is a key issue for the valuation of natural assets?*
- *Does the AEG agree that relying more heavily on modelling (dynamic optimisation) may be a reasonable way forward for the valuation of natural resources (and possibly other assets)?*

Methodology for the valuation of natural resources

I. International comparability of natural asset accounts in physical units

1.   Four main classifications are currently available to report stock volumes of natural resources (see Table 1). They result from a convergence process in reporting standards that started at the beginning of the 1990s. While CRIRSCO and SPE-PRMS focus on different types of resources, the UNFC-2009 and SEEA-2012 classifications apply to all types of resources. None of these classifications only takes geological criteria into account. Economic and technological criteria are also considered. This implies that resource stocks have to be regularly re-assessed in the light of new geological knowledge, progress in extraction technology and shifts in economic and political conditions.

Table 1: Overview of existing classifications

Abbreviation	Full Name	Subject Resource	Latest edition (first edition)
CRIRSCO,	Committee For Mineral Reserves International Reporting Standards	Minerals	2013 (2006)
SPE-PRMS	Society of Petroleum Engineers – Petroleum Resources Management System	Fossil Energy (crude oil and natural gas)	2007
UNFC-2009,	United Nations Framework Classification for Fossil Energy and Mineral Resources	Minerals and Fossil Energy	2009 (1997)
SEEA-2012	System of Environmental-Economic Accounting – Central Framework	Renewable and non-renewable natural resources and land	2012 (2003)

2.   The UNFC-2009 classification system, on which the SEEA 2012 classification is built (see Table 2), is thought as an umbrella, relevant for both fossil energy and minerals. It is based on three dimensions: the economic and social viability of the project (dimension E), the field project status and its feasibility (F), and the geological knowledge about the available quantities (G). Quantifying reserves means attributing a triplet (E,F,G) to these reserves. As an example, a mineral resource described by the triplet (1,1,1) should be understood as a resource for which extraction and sale have been confirmed to be economically viable (first 1), extraction is technically feasible (second 1) and the quantities associated to this resource can be estimated with a high level of confidence (third 1).

3.   Even though correspondence tables have been developed, moving to the classification advocated by the SEEA 2012 may be difficult in practice due the level of aggregation or the focus on specific types of resources in the original classification system chosen by countries or international organisations. As an example, Table 2 shows how Australia's subsoil assets are reported by the Australian Bureau of Statistics (ABS), British Petroleum (BP), the U.S. Energy Information Administration (EIA) and the U.S. Geological Survey (USGS). Obviously, none of the definitions chosen by these agencies matches the classification into three classes (A, B and C), as advocated in SEEA 2012. Moreover, there is no immediate way

Table 2: Australia's subsoil assets as measured by the ABS, BP, the EIA, the USGS and how these definitions relate to SEEA-2012 classes

Fundamental Characterization	Solid Mineral Classes	PRMS Classes	Mineral Project Development Stage	PRMS Sub-Class	UNFC E axis	UNFC F axis	UNFC G axis		
							Proved Measured	Probable Indicated	Possible Inferred
							1P/1C Low Estimate		
							2P/2C Best Estimate		
							3P/3C High Estimate		
Discovered and Commercially Recoverable	Mineral Reserves	*Reserves*	On Production	*On Production*	1	1.1	1	2	3
			Project Implementation	*Approved for Development*	1	1.2	1	2	3
			Feasibility Study	*Justified for Development*	1	1.3	1	2	3
Discovered and Not Commercially Recoverable	Mineral Resources	*Contingent Resources*	Pre-Feasibility Study	*Development Pending*	1	2.1	1	2	3
					2.1	2.1	1	2	3
			Order of Magnitude Studies	*Development Unclarified or on Hold*	2.1	2.2	1	2	3
					3.2	2.2	1	2	3
	Discovered Not Economic			*Development not Viable*	2.2	2.3	1	2	3
			Unrecoverable		3.3	4.1	1	2	3
Undiscovered	Exploration Results	*Prospective Resources*	Conceptual Studies	*Prospect*	3.2	3.1	4.1	4.2	4.3
				Lead	3.2	3.2	4.1	4.2	4.3
				Play	3.2	3.3	4.1	4.2	4.3
			Unrecoverable		3.3	4.2	4.1	4.2	4.3

Arrows to the right of the table:
- BP and EIA
- USGS
- SEEA-2012 Class A
- SEEA-2012 Class B
- SEEA-2012 Class C

Australia's Natural Resource System	Reported Categories	E axis	F axis	G axis
▮ Economically Demonstrated Resources (EDRs)	JORC Reserves and JORC Resources (measured and indicated) Development Pending			

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to move to this SEEA 2012 classification given the currently available data. This example, coming from a country that is already well advanced in the implementation of environmental-economic accounting, shows that efforts need to be done in order to convince countries and international organisations to choose the SEEA 2012 classification as a reporting standard or to make sure that an easy conversion to it is feasible.

II. Valuation of remaining stocks of natural resources

4.   The SNA and the SEEA 2012 stipulate that the valuation of natural resources should be consistent with the valuation of produced assets. For produced assets, the most common approach in the absence of observed market prices is to use the replacement value of the assets using data on investment expenditure and assumptions regarding asset lives and depreciation rates. Also in the case of natural resources other than land, there is usually little direct information on prices of the assets in the ground[1]. In this case, prices that would be observed if these natural assets were exchanged on the market need to be estimated using an alternative methodology. Consequently, the SEEA 2012 suggests valuing stocks of natural resources using the net present value (NPV) method. This method rests on the assumption that the asset market is in equilibrium, implying that the market value of the asset is equal to the sum of discounted future income associated with the exploitation of the asset. In the case of natural resources, expected income corresponds to the flow of discounted expected resource rents.

5.   NPV computations in the field of national accounts usually make a direct application of the NPV formula expressing the value of a natural resource as the discounted value of future flows of profits that can be derived from it. This requires making price and production forecasts and choosing a discount rate. We call these computations direct NPV computations. The standard NPV formula is as follows:

$$V_t = \sum_{s=0}^{+\infty} \frac{\pi_{t+s}}{(1+r)^s} = \sum_{s=0}^{+\infty} \frac{p_{t+s} \cdot q_{t+s} - C(q_{t+s})}{(1+r)^s} \qquad (1)$$

where π_{t+s}, p_{t+s} and q_{t+s} are, respectively, the nominal value of the resource rent, the output price and the extracted quantity at date *(t+s)*. $C(q_{t+s})$ corresponds to extraction costs at date *(t+s)* and *r* is the discount rate that is applied to all future income streams. For reasons of simplicity, here we assume that the discount rate remains constant over time.

6.   Considering the problem in this way, the risk is either to make inconsistent price and production forecasts, or to neglect the fact that commodity prices are uncertain in the future and that producers may be able to adapt to changing economic conditions in real time. As a simplifying assumption, the SEEA 2012 (§A5.12 and A5.13) suggests (1) using a constant rate of extraction or the most recent quantity of extraction as estimates of future production; and (2) assuming that unit resource rents follow a long-run historical trend or evolve in line with an expected general rate of inflation. However, in a world where commodity prices are highly volatile, it does not seem reasonable to assume that mining firms take their decisions looking only at the current price or its expected value in the future. Take the example of oil

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[1] The price of the asset *in the ground* has to be distinguished from the current output price charged by the extraction industry. Indeed, it is probably not feasible nor optimal to extract all the resource at one point in time. Hence, profits from extraction occurring at different points in time have to be discounted and summed up in order to derive the price of the asset in the ground.

prices. They have been characterised by large swings in the 2000s, but also in the 1970s and 1980s (see Figure 1).
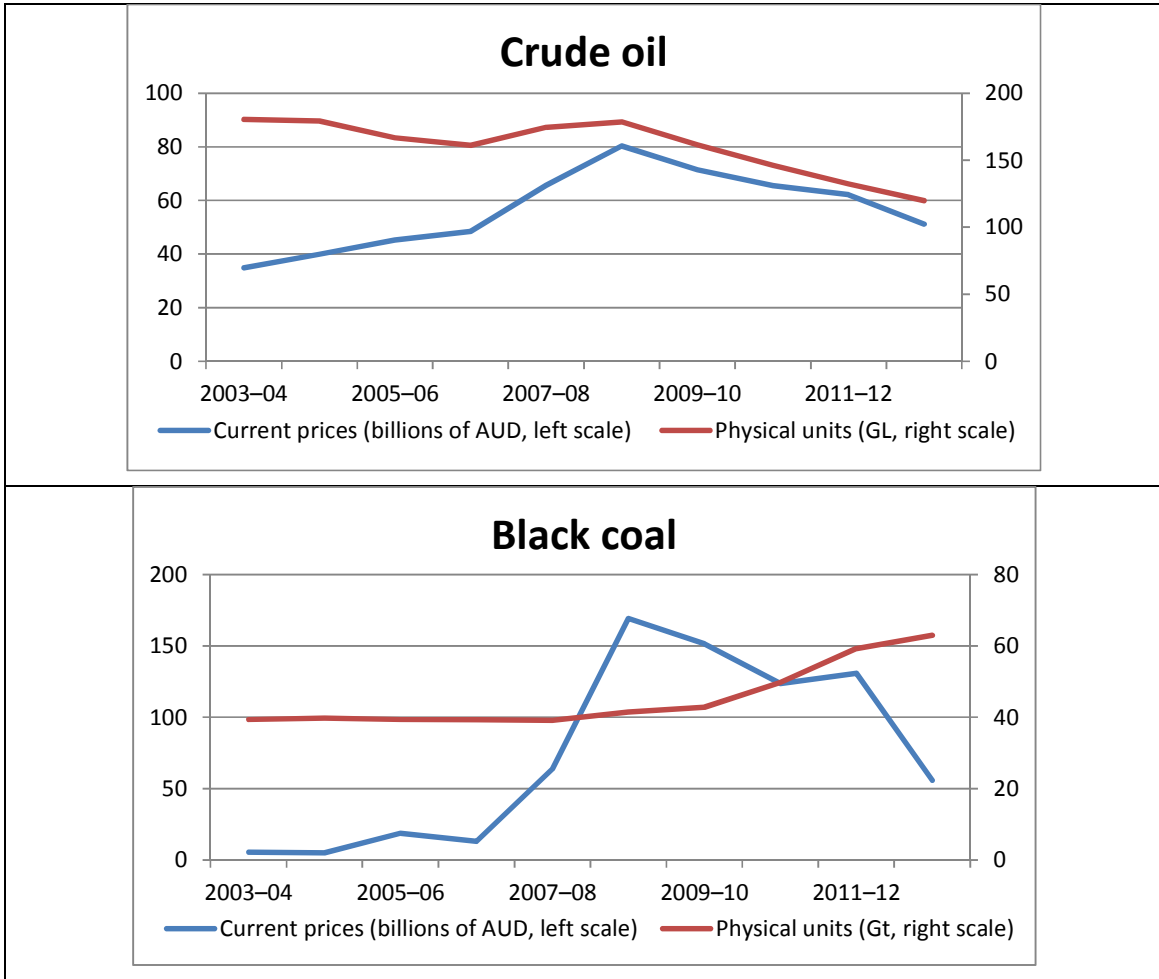
7.   From an accounting perspective, a valuation method relying exclusively on current commodity prices or their expected value in the future will lead to volatile results. One can notice, for instance in the environmental asset accounts published by the Australian Bureau of Statistics, that revaluation may be the main driver of asset accounts in monetary units (see Figure 2). This, of course, reduces the usefulness of these accounts.

Figure 1: Nominal and real oil prices (U.S. dollars per barrel)

Annual Imported Crude Oil Price
dollars per barrel

EIA Short-Term Energy Outlook, August 2014
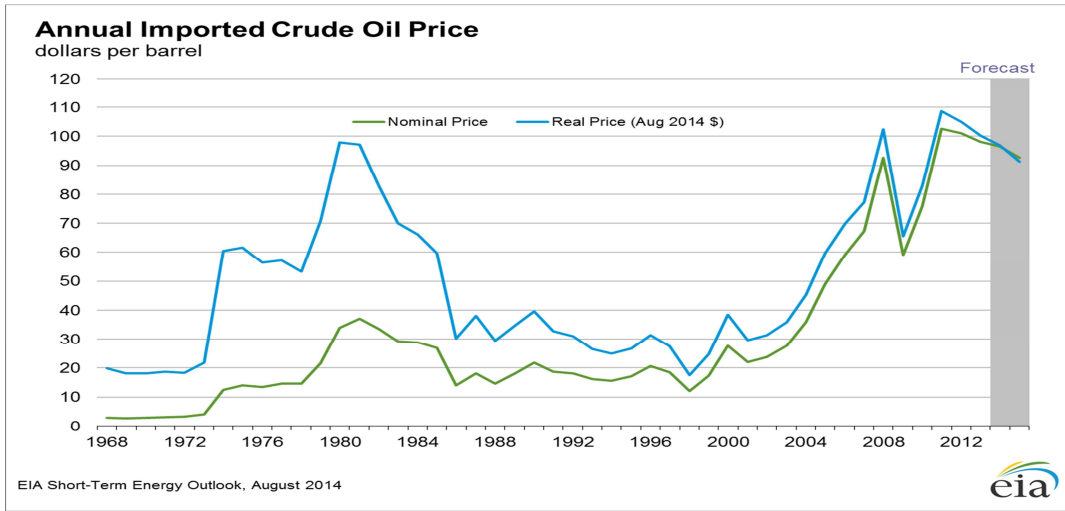
Source: U.S. Energy Information Administration, August 2014 Short-Term Energy Outlook
http://www.eia.gov/forecasts/aeo/index.cfm

Figure 2: Australian crude oil and black coal reserves, physical and monetary units

Crude oil

Current prices (billions of AUD, left scale) — Physical units (GL, right scale)

Black coal

Current prices (billions of AUD, left scale) — Physical units (Gt, right scale)

Source: Australian Bureau of Statistics, 2014 Australian Environmental-Economic Accounts
http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/4655.02014?OpenDocument

8.   It seems more logical to take the uncertainty about future prices, i.e. the whole price distribution, into account when computing the NPV. Let us take an example assuming that production and price forecasts are not made independently from each other. In other words, when they choose their output level, producers are assumed to maximize their intertemporal profit subject to specific costs and production constraints and given an exogenous commodity price process. Furthermore, assume that current prices are below extraction costs and that expected prices at future dates are equal to current prices[2]. Does it imply that the net present value of the resource is equal to zero? If the price developments are highly volatile, this is probably not the case. Indeed, high volatility means that in some events, with a strictly positive probability, future prices will be higher than extraction costs, in which case it will be profitable to extract the resource[3]. Note that considering the full distribution of prices can

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[2] Computing the expectation of future prices in such a way is fully legitimate if (log-) commodity prices follow a random walk without drift, which is sometimes believed to be the case for natural resources.

[3] Another concrete example, taken from economic history and quoted by Pindyck (Irreversibility, Uncertainty and Investment, *Journal of Economic Literature, Vol. XXIX, pp. 1110-1148*, 1991), further justifies the interest in price volatility. Pindyck recalls that oil prices fell during the mid-1980s but that the perceived uncertainty over future oil prices rose at the same time. "In response, oil companies paid more than ever for offshore leases and other oil-bearing lands, even though their development expenditures fell and they produced less."

only increase the NPV because production is bounded from below by zero. Due to this non-linearity, the expected NPV is different from the NPV computed at the expected price level.

9.   Here, we come back to the standard NPV formula (1) in order to introduce additional ingredients to take uncertainty into account. It will be more convenient to consider the continuous-time analogue of formula (1) in the following:

$$V_t = \int_0^{+\infty} \pi_{t+s} e^{-rs} ds = \int_t^{+\infty} \pi_s e^{-r(s-t)} ds \qquad (2)$$

Leibniz' differentiation rule implies that:

$$\frac{dV_t}{dt} = -\pi_t + rV_t \qquad (3)$$

Formula (3) shows that the net present value V_t can be obtained, in any case, as the solution of a differential equation. This equation simply says that, in equilibrium, the normal return to the (natural) asset (rV_t) is equal to the sum of the resource rent (π_t) and the increase in the value of the asset between date t and date $(t+dt)$, which is a standard result in capital theory (see OECD 2009). The particular solution of this equation depends on the shape of the resource rent (profit) function π_t.

10.   Now we introduce uncertainty in the model. In order to keep things simple, we consider that uncertainty is only related to future resource prices and that the model is stationary. In this case, the resource rent function may be written more explicitly as $\pi(p_t)$. This is justified when, for instance, extracted quantities are given or chosen, so that the resource rent is maximised at each date given observed prices at that date. Given the presence of uncertainty, we now focus on the expected NPV and we condition on resource prices observed at date t. Hence, V_t becomes $V(p_t)$ and it is defined by the following equation:

$$V(p_t) = E\left[\int_t^{+\infty} \pi(p_s) e^{-r(s-t)} ds \mid p_t\right] \qquad (4)$$

It is now possible to show that $V(p_t)$ is the solution of the following differential equation, which is similar to (3):

$$\frac{E[dV(p_t)]}{dt} = -\pi(p_t) + rV(p_t) \qquad (5)$$

Specifying a stochastic process for resource prices, i.e. making explicit how they depend on time, allows going further. We now assume that the evolution of resource prices is partly deterministic (i.e. predictable) and partly stochastic (i.e. unpredictable). This is the case, for instance, when the evolution of resource prices is specified in the following way[4]:

$$dp_t = \mu \cdot dt + \sigma\sqrt{dt} \cdot dz_t \qquad (6)$$

where dz_t are independently distributed Gaussian increments with mean 0 and variance 1. With this specification, resource prices p_t have a variance equal to $\sigma^2 t$ around a linear

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[4] In technical terms, this is called a Brownian motion with drift. Of course, more general price processes could be considered, for instance a geometric Brownian motion where $\frac{dp_t}{p_t}$ and not dp_t is equal to $\mu \cdot dt + \sigma\sqrt{dt} \cdot dz$, thus ensuring that prices never become negative. Parameters μ and σ could also depend on time or on p_t. The reasoning would be the same but the eventual (partial) differential equation characterising $V(p_t)$ would be more complicated to solve.

deterministic trend μt. Making use of the differentiation rule for functions of stochastic variables (Itô's lemma):

$$\frac{E[dV(p_t)]}{dt} = V'(p_t)\mu + \frac{1}{2}V''(p_t)\sigma^2 \qquad (7)$$

the differential equation (5) in $V(p_t)$ can be rewritten more explicitly as:

$$\frac{1}{2}V''(p_t)\sigma^2 + V'(p_t)\mu - rV(p_t) = -\pi(p_t) \qquad (8)$$

Notice that when prices are assumed to remain constant over time ($\mu = \sigma = 0$), this equation simply says that the NPV of the resource can be computed as $\frac{\pi(p_t)}{r}$, a result that can also be derived using equation (1) in the simple case of constant prices over time. More generally, the solution of equation (8) depends on the shape of the resource rent (profit) function $\pi(p_t)$.

11. Brennan and Schwartz (1985)[5] offer an interesting example of how these techniques may be used to value stocks of natural resources. In their model, a mining firm chooses output given quadratic extraction costs and an exogenous stochastic price process. Current output (q) is constrained to lie between 0 and $\bar{q}$. The resource stock is assumed to be infinite. This assumption allows linking the mine value (v) to the current commodity price (s) analytically[6]. Two price levels have a particular importance in this model: s^* is the price below which current production is chosen to be 0 and $\bar{s}$ is the price above which the mine produces at full capacity. The result may be shown graphically (see Figure 3). One can already notice that the mine value is strictly positive even when the current resource price falls below s^*, i.e. when current production is equal to zero because prices are too low to ensure a positive profit. This would not be the case if the mining firm were required to perpetually produce at full capacity, in which case the value function of the mine would correspond to the dotted line. This would not be the case, either, for any valuation assuming that current rents remain constant in the future[7].

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[5] Evaluating Natural Resource Investments, *Journal of Business, Vol. 58, No. 2, pp. 135-157*. We are referring to the model developed in the appendix of their paper.

[6] Without this assumption, the mine value could still be computed. But with an additional state variable in the model (e.g. the remaining resource stock), we would have to solve partial rather than ordinary differential equations and this would require numerical techniques.

[7] This model can be further refined in order to explain other economic historical facts. Indeed, Brennan and Schwartz (1985) show how sunk costs of opening and closing a mine can explain the hysteresis often observed in extractive resource industries. During periods of low prices, firms may continue to operate unprofitable mines that had been opened when prices were high. This is exactly what happened to many copper mines built during the 1970s when copper prices were high: they were kept open during the mid-1980s when copper prices had fallen to their lowest levels in real terms since the Great Depression. Conversely at other times, firms may fail to reopen seemingly profitable mines that have been closed when prices were low.

Figure 3: NPV of a mine as a function of the current resource price (Brennan and Schwartz 1985)
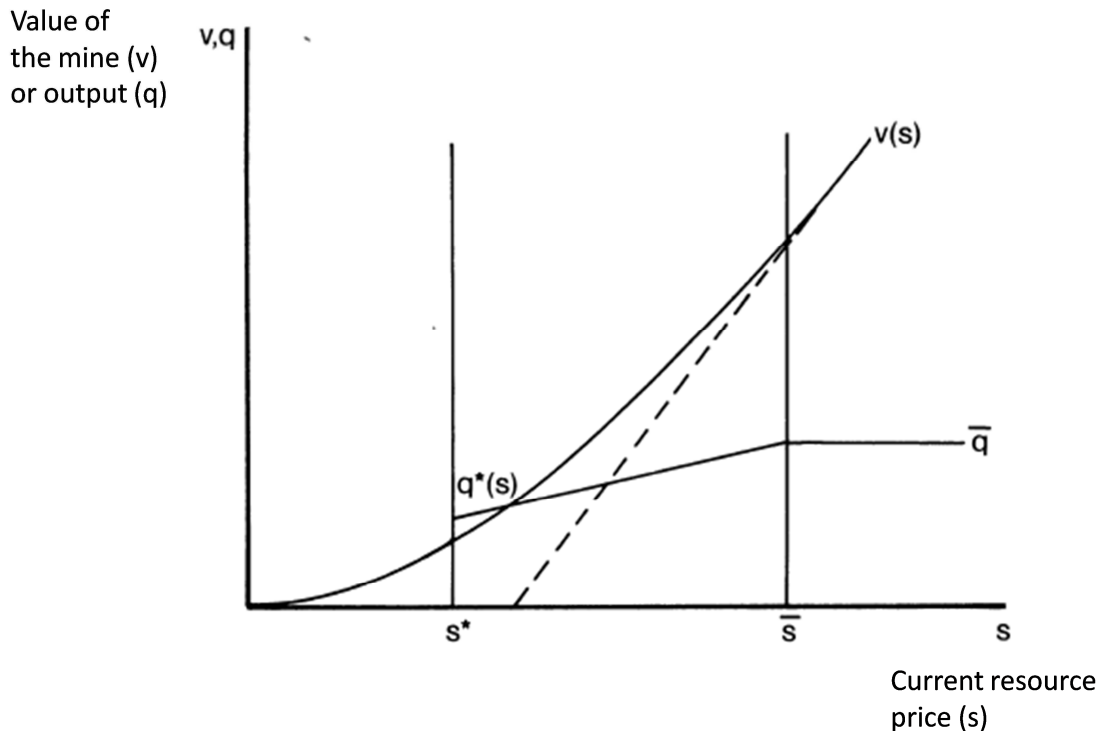
12.   Admittedly, relying on a dynamic optimisation framework in order to compute NPVs involves critical modelling assumptions. But it is a necessary step if one wants to consider that mining firms do not only consider expected future prices and are able to adapt to changing economic conditions in the future. Note that these assumptions also need to be made, even implicitly, when one relies on direct NPV computations. Two of these modelling assumptions can be mentioned:
- Specifying the right stochastic process for commodity prices. It is a hotly debated issue in the finance literature and choices made at this stage can partly drive final results.
- Specifying how extraction costs depend on current production or remaining reserves. It is a difficult task given the current scarcity of data on extraction costs. An econometric analysis on the subject would require reliable and informative data. But this is one more reason, if needed, justifying why statisticians working in the field of environmental accounting, and national accounts alike, should consider the improvement of data quality on extraction costs as a priority.

In any case, this methodology should not be discarded for its mathematical complexity. Providing convincing unit rent and production forecasts and choosing a relevant discount rate is also problematic when one wants to directly compute the NPV of a natural resource stock without explicitly relying on dynamic optimisation. In this context, results from dynamic optimisation can certainly be considered as a useful comparison, not only for valuing natural resources but also for other assets whose valuation relies on NPV-estimates.

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III. Main issues for discussion within the AEG

13.   *The AEG is invited to discuss the following topics:*
       - Does the AEG agree that the volatility of commodity prices is a key issue for the valuation of natural assets?
       - Does it agree that relying more heavily on modelling (dynamic optimisation) may be a reasonable way forward for the valuation of natural resources (and possibly other assets)?