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Alternative methods for estimating resource rent and depletion cost: the case of Argentina's YPF

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The quantification of the depreciation of natural capital is fundamental to the evaluation of the sustainability of economic development. Several methods for calculating the depletion cost of natural resource stocks have been proposed and used, including net price, El-Serafy's depletion cost, sustainability price, transaction value and replacement cost. Miller and Upton have also shown how resource rent can be estimated using the market value of a firm's liabilities. The relation of resource rent to depletion cost is discussed. These alternative approaches and techniques are described and critiqued. The alternative methods are used to obtain estimates for the resource rent and depletion cost of Argentina's petroleum reserves with data derived from the privatization of Argentina's state-owned oil enterprise, YPF. The results are used to argue that two methods, net price and transactions, overvalue the resource rent of petroleum reserves and to support the derivation of rent from the value of a firm's stock.

Keywords: resource rent, depletion cost, natural resource depletion, oil, Argentina, sustainable development

Introduction

Any discussion of the sustainability of economic development must deal with the issue of how to manage the stock of non-renewable natural resources. Since the extraction of any of this stock enriches the generation using it while reducing the quantity available to future generations, sustainable development requires either that no generation use the stock, or that users compensate future generations in some manner for the depletion of the stock. Methods of accounting for the depletion of the stock of natural resources are being developed by economists in response to the interest in sustainable development (see for example El-Serafy, 1989; Peskin and Lutz, 1990; Repetto *et al.*, 1989; Van Tongeren *et al.*, 1991; Von Amsberg, 1993; Hamilton, 1994; Mikesell, 1994; Stern, 1995; Young and da Motta, 1995; Crowards, 1996; Lange, 1996). The premise of their work is that future generations could be compensated for this loss if investments were made to ensure the maintenance of the flow of goods and services from the stock of productive capital, or of some more direct measure of human welfare (Hamilton, 1995; Pearce *et al.*, 1996). The particular conditions under which an investment equal to this depletion would result in development that is sustainable have been examined in the economics literature (Dasgupta and Heal, 1974; Solow, 1974, 1986; Stiglitz, 1974; Hartwick, 1978; Dasgupta and Heal, 1979; Hartwick, 1989; Pezzey, 1992; Pan, 1994; Hamilton, 1995). The question being debated among those practising natural resource accounting is how to measure the cost of depleting natural resource capital.

In theory, the price of a depletable resource includes two components: production cost, and resource rent or depletion cost (Hotelling, 1931; Dasgupta and Heal, 1979). The usual measure for resource rent has been the surplus revenue accruing to the owners of the resource after accounting for the contribution of capital and labor inputs. Various methods for obtaining an estimate of this surplus value have been developed. These are reviewed and critiqued in this paper.

The appropriateness of this measure as a means of accounting for the depletion cost is also being debated. This surplus may be composed of several distinct types of rent in addition to the resource rent.

These could include Ricardian rents due to differences in the cost of production and monopoly rents due to the exercise of market power in setting price. El-Serafy (1989) and Mikesell (1994) argue that this surplus value is composed of two values, a true income and the depletion cost. Investment based on a depletion cost measured as the entire surplus value would mean "…future generations would inherit a capital sum far greater than necessary for them to receive an after depletion revenue equal to that received by the present generation", states Mikesell. Another group (Adelman, 1990; Adelman *et al*., 1991; Adelman and Watkins, 1995, 1996; Slaper, 1996) views mineral resources not as a fixed stock, but rather as, "flows from unknown resources into a reserve inventory", (Adelman, 1990). They argue that the cost of depletion should be the costs of exploration or development of additional reserves to replace withdrawals.

The debate over accounting for depletion cost is further complicated by the discussion of how to define sustainable use of natural capital. Two criteria are offered—weak and strong sustainability. Briefly put, under the weak sustainability criterion, what matters is the maintenance of the aggregate stock of capital. This maintenance could be accomplished through investment in new capital of an amount equal to depletion cost. The particular mix of resources in the stock does not need to be maintained (Solow, 1986). Under strong sustainability, the uniqueness of certain natural resource stocks is recognized. Sustainability requires maintenance of these individual stocks or their replacement with substitutes (Pearce *et al*., 1996). Under strong sustainability, depletion cost will reflect the cost of the particular substitute.

In this paper, data derived from the privatization of Argentina's state-owned oil enterprise, Yacimientos Petroliferos Fiscales, (YPF), are the basis for estimating the depletion cost for YPF's petroleum reserves using alternative techniques and definitions of depletion cost. In the next section of this paper, alternative approaches to defining and measuring depletion cost are presented. In Section 3, specific techniques derived from these approaches are individually described and critiqued. In Section 4, estimates for YPF's petroleum reserves obtained using each of these alternative estimation methods are reported. These estimates are discussed and evaluated in Section 5. Conclusions are drawn in Section 6.

Approaches to defining and measuring depletion cost

Theoretically, it should be possible to calculate the surplus value generated by a reserve of a natural resource as either (1) the present value of future net income from extractions, i.e. by projecting price, marginal extraction cost, quantity extracted and the expected lifetime, or, alternatively, (2) the market value of reserves when sold, since the sales price in a competitive market should be equal to the present value of these future rents. A current owner would not want to sell for less, and a buyer would not pay any greater amount. The sales price is also known as the transaction value.

In practice it has proved very difficult to find a value for this theoretical value of resource rent (Farrow, 1985; Landefeld and Hines, 1985; Miller and Upton, 1985a; Adelman *et al*., 1991; Adelman and Watkins, 1995; Stern, 1995; Adelman and Watkins, 1996). Calculation using the present value of future net income requires knowledge of, or assumptions about future values for price and costs. Empirical research has been plagued by the problem of separating extraction costs from price in order to estimate resource rents. While it is argued that the transaction value of reserves captures this present value, there have in fact been very few publicly recorded sales of natural resources (Adelman *et al*., 1991; Adelman and Watkins, 1995, 1996; Miller and Upton, 1985a).

Repetto *et al*. (1989) argued that the preferred methods for estimating resource rent should be those that (1) least rely upon assumptions made by the analyst and (2) make use of available data. They used the net price method, which is the difference between current price per unit and current average cost as a measure of per unit rent. Subsequently, the net price method has been used in numerous other analyses (Van Tongeren *et al*., 1991; US Department of Commerce, 1994; Young and da Motta, 1995; Crowards, 1996; Lange, 1996). This method can be justified as a measure of long-run rent if a number of important assumptions, including perfect competition, are true. It also reflects a view that the entire surplus from production should be counted as depletion cost. The Bureau of Economic Analysis (BEA) (US Department of Commerce, 1994), however, also included a return to associated fixed assets, thus dividing the surplus between physical capital and natural capital.

El-Serafy (1989) argued that the surplus for a depletable resource represents two values: (1) a true income component which can be consumed; and (2) a separate depletion cost. The depletion cost is the amount that needs to be reinvested in order to sustain the economy's ability to provide future generations with the ability to enjoy a non-declining level of consumption. In this line of thinking, the net price method overstates the true depletion cost. Von Amsberg took El-Serafy's method and applied the strong sustainability criterion to it by calling for a depletion cost sufficiently large that when invested in the production of a substitute, future generations will be able to enjoy a non-declining flow of similar services.

To the contrary of both of these, Adelman (1990) argued that resource rent is discovery value, reflecting not the scarcity of the resource but rather the costs of exploration and discovery. Mineral stocks are not viewed as a fixed, non-renewable asset, but rather as any other capital asset that can be created and consumed. Reserves constitute an inventory that can be replenished by investing in the discovery and development of additional stocks. Investors will treat this inventory as they do an inventory of any other factor of production. Expenditures on discovery that add to inventory will occur when profitable and when not profitable, any stock remaining in the Earth's crust is irrelevant. Resource rent from this perspective is the cost of replacing the inventory used up in production. This approach implicitly is using the strong sustainability criterion since it measures depletion cost according to the cost of maintaining the stock of each particular resource, as Slaper (1996) has recognized.

Studies by Miller and Upton (1985a, b) suggests an alternative that would better meet the criteria offered by Repetto *et al*. (1989) than the methods currently in use. The basis for the alternative method for estimating rent is the recognition that when a resource is privately owned, the resource rent is part of the net worth of the owner. Consider a firm in a natural resource extractive industry. The value of the firm will include both its fixed stock of physical capital (as usually recognized) and the value of all future resource rents. This implies that the rent component of the asset value of the firm can be estimated as the difference between liabilities, namely the stock value of the firm plus other liabilities, and the value of its fixed capital. Miller and Upton show how this value should approximate the surplus value attributable to the natural resource under various cost and market conditions. The information requirements are reduced to knowledge of a firm's market value, the value of its capital holdings, the value of other liabilities and the size of its reserves. This information is more readily available than transaction values, especially for firms that are publicly traded and are required to make annual reports assessing their capital value.

The preceding discussion indicates that there are not only different methods for estimating resource rent but also different views on what this value implies for sustainable development. In the following section, different methods for estimating resource rent and depletion cost are examined in more detail. For some methods, estimates from other natural resource accounting studies are also discussed.

Alternative methods for estimating the rent of a depletable resource

Present value of future income

Theoretically, the market value, V_t, of a stock of a depletable resource, S_t, will be equal to the present discounted value of all future net benefits. The rental value of one unit of the resource at any point in time is V_t/S_t. The formulas for this technique and the others are shown in Table 1.

Use of this method requires data on current and future demand and production costs. Actual cost data is usually proprietary to the resource extracting firm or is simply unknown (Pindyck, 1978; Farrow, 1985). Analysts either have to make assumptions about or try to model present and future prices and production costs. Walls (1992) argues that the best guess about the future price expected by actual decision-makers is the current price (Walls, 1992). This method also requires the choice of a discount rate by the analyst. The life of the reserve, T, can either be assumed, (as S/q or as exponential rate of decline) or an optimal life of the reserve can be calculated using the assumptions about cost and price.

The net price method

The net price method relies upon some simplifying assumptions in order to estimate rent per unit without all the explicit assumptions needed for the present value method. Assume the present period is $t = 0$. Then the value of rent in the current period is simply the net price, which is the difference between current price and current per unit cost (Repetto *et al*., 1989).

Repetto *et al*. (1989) used this method to estimate the value of depreciation of Indonesia's oil reserves. For 1973 they found the rent to be US$2.90. This rose to US$9.06 in 1974 once OPEC began exercising more market power. For the last year of the study, 1984, the net price was US$24.30. In a study of Mexican oil reserves for 1985, Van Tongeren *et al*. (1991) found a net price of 1162 Mexican pesos.

As often applied, the net price method has not included a return to associated capital in the calculation. Thus, the entire surplus is attributed to the natural resource. The net price method used by BEA (US Department of Commerce, 1994) includes a 6% return to associated physical capital in its estimation of net price. The rationale for this rate is that it is approximately the 45-year average real rate of return to investment in corporate bonds and equities up to 1991. Contrary to usual industry accounting practices, BEA also includes all exploration and development expenditures in its measure of capital, instead of counting them as part of the cost of extraction.

Unfortunately, some of the simplifying assumptions on which the net price methods are based do not even approximately hold. One assumption is perfectly competitive markets. The sudden jump in the resource rent value after OPEC's large price increase is obviously due to the market power of the cartel. The resource rent estimate is therefore distorted by a large element of monopoly rent. On the cost side are two potential problems. One recognized problem is that the value used for c is usually average cost, when it should be marginal cost, which may be much greater than average cost. This again is primarily because of limitations on data collection. The BEA method requires the choice of a return to associated capital. Other critics have noted the potential for this method to generate negative rents if the return to capital exceeds the surplus (see Slaper, 1996).

One problem ignored in the literature is that the use of the net price method may underestimate the depletion value of the resource because of distortions

Table 1 Techniques for estimating depletion cost

Estimation technique	Depletion cost =
Present value of future income	$[\int_0^T [p_t q_t - q_t c_t] e^{-rt} dt/S$
Net price (NP) without return to K	p–c
BEA method I	((p*q − operation costs) − r(capital stock + exploration and development costs − depreciation of capital))/q
BEA method I without exploration and development costs as capital	((p*q − operation costs) − r(capital stock − depreciation of capital))/q
El-Serafy method	NP*e^{-rT}
Sustainability price	$P_s - c$
Transaction value	Transaction price/S
Replacement cost—discovery vale	NP—development cost
Replacement cost—one-half net price	NP/2
Stock market evaluation	(Debt + (stock price*shares of stock) − K)/S

p, Market price per barrel; c, average cost of production; q, quantity extracted per period of time; r, discount rate; S, stock size; K, capital; NP, net price; T, expected lifetime of reserve, P_s, sustainability price.

on the cost side of the formula. State-owned enterprises, like YPF before its recent privatization, are likely to have higher production costs than firms operating in competitive markets (Visitini, 1990). A higher cost means a lower value for the net price, and therefore an underestimation of the resource rent. The consequence is that part of the resource rents that ought to have been re-invested for sustainable development has already been spent on inefficient production in the current period.

The El-Serafy method

El-Serafy (1989) suggested that in natural resource accounting, the net price of depletable resources be divided into two parts. True income, Y, is the part of net revenue that could be consumed annually in perpetuity if the remainder of net revenue were invested in renewable capital. This true income flow can be found as:

$$\int_0^\infty Y_t e^{-rt} dt = \int_0^T (p_t - c_t) q_t e^{-rt} dt$$

The annual true income, Y_t, is only a fraction of the net price, NP, in each period and can be shown to be equal to Y_t = NP*$(1 - e^{-rT})$. The remaining part of the net price, NP*e^{-rT} is the depletion cost which would have to be invested in each period, t, if development is to be sustainable. The percentage of net price that constitutes depletion cost depends upon two values, the discount rate, r, and the expected life of the resource, T. With a large value for T, the portion of net price that would be counted as user cost is very small. For example, if the reserves were to be mined for 50 years, and a discount rate of 7% is applied, the value of e^{-rT} is only 0.03, i.e. only 3% of the net price is considered not to be true income. Only if the reserves will be exhausted in the near future will the user cost be equal to the net price. If T is 5 years, then user cost is 70% of net price.

Adelman *et al*. (1991) reported that for the Persian Gulf countries, the value of T estimated as S/q, i.e. the current stock divided by current production, is between 83 and 200 years. With the use of a 5% discount rate, the value of e^{-rT} is close to zero for many of these. Van Tongeren *et al*. (1991) calculated the depletion factor to be 13.8% of the net price for Mexican oil.

Because this method uses the net price as a starting point, it is subject to all the same problems as that method. Similar to the net present value method, it requires the analyst to choose a discount rate or rates and requires further assumptions about the expected lifetime of the reserve. El-Serafy also suggests using a value for T equal to S_t/q_t. This, he says, could be adjusted each year to account for changes in the producers' extraction decisions.

The sustainability price

Von Amsberg (1993) suggested a method he called the sustainability price that is based on the strong sustainability criterion. He agreed with the argument made by El-Serafy that we ought to make a distinction between true income and a depletion allowance to be invested in sustainability. Von Amsberg defined the sustainability price as the "…cost at which the services from the depleted natural capital can infinitely be provided through a sustainable substitute if for every unit of depleted natural capital the sustainable price is invested in the substitute" (p. 23). If there is no substitute for the depletable resource, no means for developing new sources of the resource and no knowledge of the resource's value in the future, Von Amsberg suggested that it not be used. In his view, no one generation has any greater claim on the income that could be generated from extraction of the resource than any other generation.

The purpose of this formulation is to calculate a price for the resource that would assure a flow of funds, which if invested in the production of the substitute, would result in a flow of benefits equal to the true income component even after the depletable resource has been exhausted. For example, suppose that a reserve of petroleum produces q_t barrels per year over the next T years at an average cost of c. A renewable substitute exists that has a price of P_u. The sustainability price, P_s, as defined by Von Amsberg, is that which satisfies:

$$\int_0^\infty q_t P_s e^{-rt} dt = \int_0^T q_t c_t e^{-rt} dt + \int_T^\infty q_t P_u e^{-rt} dt$$

The integral on the left is the present value of the future flow of income that results from P_s. The first integral on the right hand side is the present value of the costs of producing the depletable resource. The second integral is the present value of the annual costs of production using the substitute after year T. The depletion cost in this case then would be $P_s - c$.

This method adds one more choice variable to the analyst's list of decisions—what constitutes the best available renewable substitute. Von Amsberg suggested that the analyst base the decision on the available or foreseeable technology. In his analysis of a Nigerian oil reserve, he used the cost of production for hydrogen generated by solar energy, reported to be US$90 per barrel equivalent (Ogden and Williams, 1989). He chose solar hydrogen because it appears to have the best potential to be a sustainable substitute for hydrocarbons in the long run. He calculated the sustainability price for the reserve to be US$4.80 per barrel, which yields a user cost of US$0.40 a barrel. Despite the high cost of solar hydrogen, the depletion factor is small because the reserve has an estimated lifetime of 80 years.

Von Amsberg used a discount rate of 7% for this World Bank project even though the Bank was using rates of 10–12%. His justification of a lower rate was that the success of a sustainability price policy would require the investment of the depletion cost in a fund until the production from the substitute is begun, and that it is not likely that most countries would be able to find investments that would pay such high returns.

Transaction value

Since, theoretically, the market value of a stock of resources is equal to the present discounted value of future earnings, the sales price of a resource stock should provide a value of these earnings. Miller and Upton contended that this would be the ideal method for valuing reserves, but this method has been hampered by a lack of publicly available data. Recently however, Adelman and Watkins (1995, 1996) have been able to obtain transaction data for petroleum reserves in Canada and the USA. In their 1995 article, they found a value of US$5.37 per barrel from 34 sales of oil reserves in Alberta during 1989–91. In their 1996 paper, they report values around US$4.00 per barrel from 122 sales of reserves in the USA in 1993.

There are numerous problems in using values derived from the sale of reserves as estimates of the depletion cost of other reserves. These are reflected in the fact that the price paid per barrel of reserves varies. This is because no two properties are exactly the same. The assets being sold often include other, non-resource assets. The cost of extraction, the cost of transport and the percentage of known to potential reserves can all vary greatly from one site to another. For all these reasons, the transaction value of reserves has not, in practice, been a good source of estimates of resource rents even in a market as large as the USA.

Replacement cost method

A different perspective on the meaning of resource rent and its calculation is offered in Adelman (1990, 1995); Adelman *et al*. (1991) and Slaper (1996). They argued that only a portion of the reserves actually existing will ever be used because some reserves will be too costly to exploit. Therefore, only a fraction of the physically existing resource is of economic importance. The stocks of a resource should be considered to be an existing inventory, which can be increased through exploration and development. Investment in these activities is thus equivalent to investment in the inventory of any other capital asset. The resource rent then is equal to the "discovery value", i.e. the marginal cost of finding another unit to replace it (Adelman, 1990; Slaper, 1996). In this case, the market price per unit of the resource, $p = c +$ marginal replacement cost.

If finding cost data were available, then they could serve as a value for depletion cost. However, there is usually a long lag time between the expenditure on exploration and estimation of what reserves, if any, were found. Thus, exploration costs in any one year are not related to the quantity found that year. Adelman (1990) offered two alternatives. One is to subtract development cost per barrel from the net price. Development cost is more commonly reported in annual financial reports. The second is to use one-half of the net price. In his development cost model for the value of a reserve, Adelman (1990) showed that if the current rate of extraction for the reserve is equal to the rate of interest, then the per barrel value of *in situ* developed reserves is one-half the net price. This serves as another proxy for replacement cost. Using data on wellhead prices and estimates of costs prepared by a private firm, Adelman *et al*. (1991) found that *in situ* value in the period 1946–84 varied around one-half the net price. They report that this finding is in accord with an informal rule in the petroleum industry in the USA that the *in situ* value is about one-third of the wellhead price or one-half of the price minus production costs.

The stock value method

This method is based on the recognition that the resource rent is part of the net worth of the private owner(s). The assets of a private firm in a resource extracting industry include the value of its capital goods, and the net present value of the stream of future rents, V_t. In equilibrium, the total value of a firm's assets will be equal to the value of its total liabilities. Liabilities include short and long-term debt, as well as the value of all outstanding shares of stock, which is the market price per share multiplied by the number of shares.

The use of this method reduces the demand for information and explicit assumptions. Stock prices can be found in financial newspapers. The values for capital goods, debt and reserves can be found in a firm's annual report if the stock is publicly traded. Miller and Upton (1985a) found a good fit between the value derived from this method and estimates of net price for 39 US oil producers.

Estimates for YPF's petroleum reserves

The results of using the alternative methods for estimating the depletion cost for YPF's petroleum reserves are presented below and summarized in Table 2. The data were obtained from the YPF Prospectus, YPF annual reports for 1993, 1995 and 1996 and the Secretaria de Energia of Argentina (Secretaria de Energia, 1994; Yacimientos Petroliferos Fiscales, 1995). Unless otherwise noted, all values are in 1993 Argentine pesos. The Argentine currency in 1993 was the peso, and is represented by the $ symbol. Prices were adjusted using the Wholesale Domestic Price Index for Argentina. In 1993, the Argentine peso was fixed at a value of US$1 by law, so that the values could also be read as equal to 1993 US dollars. Values in US dollars herein are represented as US$.

Present value of future income

The 1993 YPF annual report (Yacimientos Petroliferos Fiscales, 1993) includes an estimate for the present value of future flows of income net of production costs based on the expectation of the continuation of then current costs and price. This estimate was made following the standards of the Financial Accounting Standards Board. It applies a 10% discount rate to future income. The value reported is $4247 million. The report includes the disclaimer that this should not be considered as the fair market value of the reserves; rather, that this value will depend upon the actual rate of extraction, changes in costs and prices and other factors.

At the end of 1993 YPF has 2530 million BPE, (barrels of petroleum equivalent) of proved reserves. The value per barrel using the annual report estimate of future income flows is $1.68. As will be shown below, this is net of royalties paid to provincial governments equal to $0.91 per BPE. The real resource rent should include this value which is treated as a cost of production by the firm. Thus, the total rent per BPE is $2.59.

Net price method

For the net price method, the cost per unit of production and a price per barrel are needed. For price, the price of West Texas Intermediate Crude (WTI) at the end of 1993 of $14 is used. It should be noted

Table 2 Estimates of the rent or depletion cost per barrel

Method of estimation	Rent estimate $ per BPE	% of net price ($6.40)
Present value of future income	2.59	40
Net price—no return to *K*	6.40	100
Net price—BEA method I	5.51	86
Net price—BEA method I, without exploration and development costs in *K*	5.76	90
El-Serafy method	2.40	37.5
Sustainability price method	30.92	483
Transaction value-developed, producing reserves	5.17	81
Transaction value-developed, abandoned reserves	2.17	34
Replacement cost – discovery value	3.00	47
Replacement cost – one-half net price	3.20	20
Stock market evaluation rent	2.35	37

that the average price of WTI crude during the year was US$18.44 and that the price fell significantly at the end of the year. To the extent that the market price decline is the result of failing monopoly power and therefore reduces the monopoly rent component of net price, the use of the year-end value helps provide a better value of the actual resource rent.

The cost of production was estimated from data in the 1993 YPF annual report (Yacimientos Petroliferos Fiscales, 1993). Expenditures on production and the costs of depreciation of equipment are given as $1113 and $445 million, respectively, for a total of $1558 million. Given a production of 1840 million BPE by YPF in 1993, the average cost for the firm per BPE was $8.49. This value included private costs of production as well as royalties paid by YPF. The royalty rate is 12% of cost. The royalty can thus be calculated to be $0.91 and the private cost of production is $7.58. If YPF had paid other taxes during the year, these too should be subtracted from costs, however the firm was exempted from income taxes in 1993. It should be noted that this method masks large differences in costs of production across the country. Production in the southern regions has been reported in the past to be much less costly than in the north (Visitini, 1990). Using a price of $14.00 and a cost of $7.60, (rounding up), the net price method gives an estimated resource rent of $6.40 per BPE at the end of 1993.

Using BEA's net price method I for estimating rent per unit (US Department of Commerce, 1994), the value per BPE in 1993 was $4.60. Adding the $0.91 royalty in, the net price is $5.51. If E and D costs are not included as part of the net stock of capital, the net price per BPE rises to $4.85 before adding the royalty, and $5.76 with the royalty.

The El-Serafy method

The application of the El-Serafy method requires a value for the expected useful life of the reserve, *T*. This is estimated as the ratio of reserves to current production, S_t/q_t. In the case of YPF in 1993, this value is equal to 14 years. The analyst must also choose a discount rate. Von Amsberg justified a discount rate of 0.07 in his study of petroleum reserves in Nigeria. Given the new openness of the Argentine economy to foreign investment and the increasing capital inflows, it seems appropriate to follow von Amsberg and use a discount rate of 7%.

The depletion cost according to the El-Serafy method then is $1/e^{07*14}$ or 37.5% of net price, yielding $2.40 per BPE. For comparison purposes, Figure 1 presents the depletion cost for three discount rates, 3, 7 and 12% for values of *T* from 0 to 50.

The sustainability price

The calculation of von Amsberg's sustainability price requires the identification of an alternative resource that does not depend upon an exhaustible supply. The

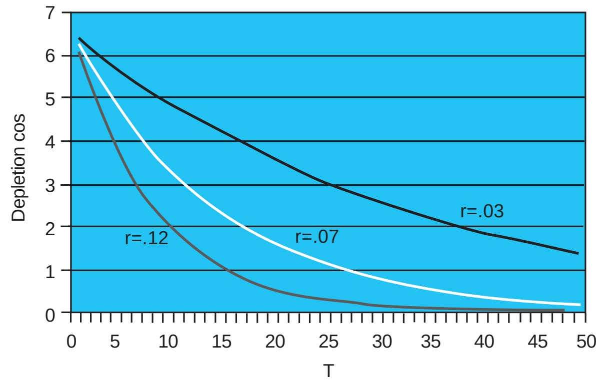

Figure 1 Depletion costs using the El-Serafy method

alternative used by von Amsberg in his analysis of a Nigerian reserve was hydrogen-produced from photovoltaic cells at a reported cost of $90 per BPE. In Argentina solar hydrogen may well be an appropriate alternative, although there is a great potential to produce it using wind-powered turbines instead of solar cells. There is currently one privately financed wind power project being developed in the south. Without any cost data yet available, the $90 cost figure is used here. Certainly this would be the highest possible cost for wind power-produced hydrogen, given the alternative of the solar cells. At a discount rate of 7%, the depletion cost would be $30.92 and the sustainability price would be $38.52. At a 12% discount rate, the depletion cost would be $15.35 and the sustainability price would be $22.95. While these sustainability prices are much higher than recent world prices, they are within the range of nominal world oil prices over the past two decades.

Transaction value

Before privatization, all hydrocarbon reserves were also state property. The plan for privatizing YPF also called for the sale of some reserves rather than their retention by YPF. YPF sold the right to production from previously developed reserves located in the central areas of production. The price per barrel for each of the sales is reported in Table 3. The transactions were all in US$. The overall sales price was $4.26 per barrel. The standard deviation of the prices is 2.14. Because the provincial government will collect part of the rent in royalties, the average royalty of $0.91 should be added into this private user cost, for a value of $5.17.

YPF also sold reserves that had been inactive for 5 years and had low levels of production in a series of auctions in 1990 and 1991. A total of 192 million BPE of proved reserves, along with 212 million BPE of unproved reserves were included. Their sale generated $417 million (unadjusted). The average value for the sum of proved and unproved reserves was $1.03 per BPE in nominal prices. The sales value per barrel of proved reserves only, which constitute 48% of the

Table 3 Sales of reserves

Area	Reserves	Offer	Price per barrel
	'000 barrels	Mill US$	
Puesto Hernandez	90726	292	3.22
Vizcacheras	55627	167.5	3.01
El Huemel	44753	223	4.98
El Tordilo	47533	181.4	3.82
Tierra del Fuego	27678	195.8	7.07
Santa Cruz I	10307	72.8	7.06
Santa Cruz II	10232	90.8	8.87
Total	286858	1223.3	4.26

Source: Visitini (1992).

total, (i.e. assuming no value for unproved reserves) was $2.17. As would be expected, the value was substantially lower than for the centrally located developed, producing areas.

Replacement cost method

In its 1995 annual report, YPF reported development costs for 1993. In 1993 pesos, the development cost per BPE was $3.40. The depletion cost, as measured by the net price minus development cost, referred to by Adelman as a proxy for "discovery value", is $3.00. Using the argument put forward by Adelman *et al*., that the resource rent can be estimated as one-half of price net of production costs and taxes when the inverse of T is equal to the discount rate, the rent is $6.40/2 = $3.20. Note that in the case of YPF in 1993, 1/T = 0.07, the discount rate used and justified above.

The stock value method

The stock value method is used to estimate the resource rent of the reserves belonging to YPF as at the end of 1993. The value of a share of YPF stock in the Buenos Aires stock market was $25.90. There were 353 million shares of stock held by private investors, the federal government, some provincial governments and YPF employees. The market evaluation of YPF is thus $9142.7 million. The difference between non-reserve assets and liabilities, as reported by YPF was $5510 in 1993. Subtracting this value from the stock market evaluation of the firm leaves reserves valued at $3633 million. With 2530 BPE of reserves, the value is $1.44 per BPE. Adding in the $0.91 royalty, the rent per BPE is estimated to be $2.35.

Discussion of estimates

The results of depletion cost derived using alternative techniques are shown in Table 2. Table 2 also shows how each estimate compares with the estimate derived from the commonly used net price method. Following the argument of Repetto *et al*. (1989), the preferred methods for estimating resource rent should be those that (1) least rely upon assumptions made by the analyst, and (2) that make use of available data.

The sustainability price method, which yields the highest depletion estimate, relies upon a very significant assumption of the analyst—the choice of a renewable substitute. Even in the case of Argentina, where current reserves are not as substantial a multiple of annual production as in Nigeria or the Gulf states, the sustainability price based on the generation of hydrogen is lower, in current prices, than historic highs that were reached in the decade following the rise of OPEC's market power. Nonetheless, this value lies well beyond the other estimated values. Therefore, it will be treated as an outlier, and will be excluded from further analysis.

The remaining estimates obtained range from $2.17 to $6.40. The average of these prices is $3.85 and the standard deviation is 1.57. The highest of these remaining values are the estimates derived from the alternative versions of the net price method. All three are more than one standard deviation away from the mean. The argument advanced earlier in this paper, that the current net price is likely to provide a high estimate for depletion cost, is demonstrated with this data. The next largest value, $5.17, derives from the sales price of the centrally located reserves. This value also probably overestimates the depletion cost attributable to proved reserves because, as is usually the case, it includes payment for physical capital as well as the option to exploit yet unproved reserves. The sale of non-producing reserves brought only $2.17 per barrel. It is interesting to note that the difference in price between the two transaction values is $3.00. This is also the "discovery value" which, according to Adelman (1990), should be equal to the marginal cost of adding an additional barrel of oil through any type of investment. Bringing these areas into production might be considered an example of investment in replacement. The other proxy for replacement cost, the one-half net price estimate, is $3.20. This was derived using the assumption that the discount rate to use is $1/T$. In contrast to the findings of Adelman *et al*., in neither case is the replacement cost equal to the in situ value of developed reserves as indicated by the transactions value.

The El-Serafy method yields an estimate of $2.40. It relies upon the choice of a discount rate and a prediction of the estimated life expectancy of the reserve. As expected, it is relatively low when there are more than a few years worth of reserves remaining. The present value of future net income method used by YPF gives a value of $2.59 per BPE. This method explicitly relies on the assumptions of no changes in current costs, prices or extraction rates, while the El-Serafy and sustainable price methods do so implicitly.

The one method that does not require numerable assumptions on the part of the analyst is the use of the stock value of a mineral extracting firm. The depletion cost estimate based on YPF's balance sheet and stock value at the end of 1993 was $2.35. The stock value that arises from the trading floor reflects the suppositions and expectations of all traders. The analyst need neither presume no changes in important variables nor try to model the formation of expectations. While economists and others may be seeking estimates of resource rent and depletion cost to use in analysis of sustainable development, the owners of a potentially immortal corporation are directly and personally involved in a process of assessing the sustainability of their firm.

Interestingly in this case, the estimate obtained using the stock valuation technique is in close proximity to three of the other estimates (less than 1 standard deviation away), but substantially less than (2.5 standard deviations away from) the $6.40 net price estimate. It is closest to the value reported by YPF itself using standard accounting practices for calculating net present value. It is also close to the estimate derived using El-Serafy's method, which indicates that the stock market might also be making the distinction he advocates. Since this estimate depends upon the discount rate and reserve lifespan chosen by the analyst, it is difficult to determine whether this is purely coincidental or whether it results because the stock market participants share the same perspective on these variables as the analyst. The replacement cost, estimated either as net price minus development costs, or as the difference in transaction value between producing and non-producing reserves is also within one standard deviation of the stock market estimate. This lends support to the Adelman hypothesis that the market value of a barrel in the ground is based on its cost of replacement. Those who differ with him with respect to his definition of natural resource stocks as flows rather than fixed stocks may not, however, be willing to accept replacement cost as a long-term indicator of depletion cost.

Conclusions

This comparison of the alternative methods for estimating resource rent and depletion cost indicates that the estimates derived are consistent with the prediction of theory that net price method, which seems to be finding favor with analysts, will overestimate true depletion cost. A policy of sustainability based on this value for rent would subject the generations that use the resource to the problem cited by Mikesell (1994). They would be overinvesting on behalf of future generations, and depriving themselves of any net income from the resource being depleted. Future analysis of policies aimed at promoting sustainable development should be wary of using simple net price as the value of depletion cost.

The depletion cost as obtained from the sustainability price is much higher, but does provide an indication of the potential expense of a policy that reflects a risk-averse attitude towards the depletion of non-renewable resources. In light of oil prices over the past two decades, a gradual move towards sustainable development pricing does not seem too unreasonable a prospect, even for the re-emerging Argentine economy.

By its nature, any estimated value of resource rent reflects assumptions about discount rates, future prices and costs, extraction rates, reserves and even the definition of natural resources. Absent the existence of perfectly functioning future markets, any value for resource rent that depends upon values taken from current markets will be imperfect and probably unstable. The pertinent question is who should make the assumptions. The advantage of the stock valuation method is that it does not require the analyst to make all these assumptions. The potential for the use of the stock value method is growing with the privatization of state-owned energy and mineral enterprises in many of the newly emerging economies and the economies in transition, and the trading of their stock in world markets.

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