The User Cost of Non-renewable Resources and Green Accounting

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Abstract

A fundamental problem in green accounting is the valuation of non-renewable resources. We derive and compare two alternative user cost approaches: taking unit rent as user cost, as used by the World Bank, and traditional user cost. We show that while they seem quite different, they coincide when beginning of period expectations are realized. Practical considerations lead us to recommend the traditional user cost approach. We show the implications for the calculation of net income for an economy.

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1. Unit Rent and User Cost

For productivity studies that take into account the depletion of natural resources, a user cost, or "depletion rent", of natural capital is needed in order to be consistent with the now standard methodology for constructing capital service aggregates.[1] In the context of accounting for the depletion of non-renewable resources in a productivity analysis, Brandt, Schreyer and Zipperer (2016) have proposed using the unit resource rent as the user cost, allowing the use of World Bank (2011) estimates of the unit rent for various sub-soil assets in the construction of capital aggregates.[2]

We derive their user cost expression for a resource using a simple discrete time derivation and, through a comparison with a more standard user cost approach highlighted by Schreyer and Obst (2015), point out some limitations of the "World Bank" method.

For brevity in description, but without loss of generality, we follow the example of Hotelling (1931) and consider the non-renewable resource to be a body of ore. Let V^0 and V^1 denote the *market value of an ore body* at the beginning and end of period 1. We assume that these values can be decomposed into price and quantity components where P^t is the *ex-ante expected price* of one unit of ore at the beginning of period t and S^t is the corresponding *stock* of the ore body so that we have:

$$(1)\ V^t = P^t S^t\ ; \qquad t = 0,1.$$

If expectations about the value of revenues generated by depletion during the first period and expectations about the price of ore at the end of the period are realized, and if R^1 is the *net revenue generated by selling mined ore during period 1* (we assume the revenue is realized at the end of period 1), then the following relationship between V^0, V^1 and R^1 should hold:[3]

$$(2)\ V^0 = (1+r)^{-1} R^1 + (1+r)^{-1} V^1,$$

[1] See e.g. OECD (2001). Cairns (1986; 94) credits Scott (1953) with introducing the concept of user cost to the study of natural resources.

[2] As Brandt, Schreyer and Zipperer (2016) note, implementation of the System of Environmental-Economic Accounting, agreed upon by the international community in 2012, will allow their analysis to be extended to other natural capital, in particular land, aquatic resources and freshwater.

[3] Equation (2) is a useful decomposition of the usual equation that defines the value of an ore body as the discounted cash flow that is generated by mining the ore body over time. See also Cairns (2013) and Diewert and Fox (2014) on the problems associated with accounting for sunk cost assets.

where r is the one period opportunity cost of capital for the mining firm at the beginning of period 1. That is, the value of the ore body at the beginning of the period should be equal to the (discounted to the end of the period) cash flow that accrues during the period, plus the discounted expected value of the ore body at the end of the period.

Depletion of the ore body during period 1, D^1, is defined as the difference between the starting stock of ore and the finishing stock of ore:

(3) $D^1 \equiv S^0 - S^1 \geq 0$.

Broadly following the example of Brandt, Schreyer and Zipperer, the period 1 revenue generated by mining one unit of ore is $p^1 \cdot \alpha$ where α is a positive *vector of ore final product amounts* generated by mining one unit of ore and p^1 is the corresponding period 1 market output price vector and the cost associated with mining one unit of ore is $w^1 \cdot \beta$ where β is a positive *vector of input requirements* for mining one unit of ore and w^1 is the corresponding period 1 market input price vector. The *total cash flow generated by mining D^1 units of ore during period 1* is redefined as follows:

(4) $R^1 \equiv [p^1 \cdot \alpha - w^1 \cdot \beta]D^1 = u^1 D^1$,

where $u^1 \equiv p^1 \cdot \alpha - w^1 \cdot \beta > 0$ is the unit rent, or the *World Bank/Brandt-Schreyer-Zipperer user cost of mining one unit of the ore body during period 1*.[4]

Following Hicks (1939) and Diewert (1974; 504) (2005; 485), the *beginning of the period user cost* for a unit of reproducible capital can be defined as the initial purchase cost of a unit of the capital stock less the discounted market value of the unit at the end of the accounting period. This beginning of the period user cost can be converted to an *end of the period user cost* by multiplying the beginning of the period user cost by one plus the interest rate; see Diewert (2005; 486). Applying this same methodology to the value of the ore body at the beginning and end of period 1 leads to the following expression for the (end of) period 1 *user cost value of the ore body*, UCV^1:

(5) $UCV^1 \equiv V^0(1+r) - V^1$

$= (1+r)[\,(1+r)^{-1} R^1 + (1+r)^{-1} V^1] - V^1$ using (2)

[4] The appendix provides the Brandt, Schreyer and Zipperer (2016) conditions under which user cost is equivalent to the unit rent of natural capital.

$= R^1$

$= u^1 D^1$ using (4)

$= u^1 [S^0 - S^1]$ using (3).

Thus we have derived a very simple justification for the World Bank/Brandt-Schreyer-Zipperer user cost for a non-renewable resource stock. Rather surprisingly, this user cost framework can be implemented for each mine where we can collect the opening and closing stocks for the ore body, S^0 and S^1, and the net revenues generated by extracting the ore during the period, R^1. Then from (5) the user cost, u^1, can be estimated as $R^1/[S^0 - S^1]$.

The mine's vectors of period 1 outputs y^1 and non-ore inputs x^1 can be defined as follows:

(6) $y^1 \equiv \alpha[S^0 - S^1]$ and the companion price vector is p^1 ;

(7) $x^1 \equiv \beta[S^0 - S^1]$ and the companion price vector is w^1.

Conversely, if y^1 and x^1 are known along with S^0 and S^1, then (6) and (7) can be used to define α and β.

It is not necessary to use the above methodology to derive the user cost of a non-renewable resource: traditional user cost techniques can be used as we will now show. We require a couple of preliminary definitions. Define the period 1 *inflation rate for the price of a unit of the ore body*, i, as follows:

(8) $1+i \equiv P^1/P^0$,

where P^0 is the beginning of the period price of ore and P^1 is the end of period price of ore. Define the period 1 *depletion rate* for the ore body, δ, as follows:

(9) $1 - \delta \equiv S^1/S^0$,

where S^0 is the beginning of the period stock of ore and S^1 is the end of period stock. Now substitute definitions (8) and (9) into definition (5) for the user cost value for the ore body:

(10) $UCV^1 \equiv V^0(1+r) - V^1$

$= P^0 S^0 (1+r) - P^1 S^1$ using (1)

$= P^0S^0(1+r) – P^0(1+i)(1–\delta)S^0$ using (8) and (9)

$= P^0[(1+r) – (1+i)(1–\delta)]S^0$

$= P^0[r – i + (1+i)\delta]S^0$,

where $P^0[r – i + (1+i)\delta]$ can be recognized as the *traditional user cost of capital* (except that δ represents a depletion rate rather than a wear and tear depreciation rate). [5]

The two expressions for the user cost value for the resource stock given by the last lines of (5) and (10) look entirely different and yet under the assumption that expectations formed at the *beginning* of period 1 are actually realized at the *end* of period 1, the two formulae are equal to each other. Dividing both these equations of user cost value by resource depletion provides another justification for using unit rents as user costs as in (5); unit rents are equal to traditional user costs if expectations are realized.

2. Discussion

We favour the use of (10) over (5) for two reasons. First, (5) is only valid if expectations about R^1 and V^1 formed at the beginning of the period turn out to be realized at the end of the period. It is extremely unlikely that this assumption will hold and so if V^0, V^1 and R^1 are estimated using *ex post* data (so V^0 is an estimated market value for the ore body at the beginning of the period and R^1 and V^1 are market values estimated at the end of the period) and r is exogenous, equation (2) is unlikely to hold. It will often not hold, even as a first approximation. On the other hand, the *ex-ante* version of formula (10) (the last line) does not require equation (2) to hold. But implementing (10) means that expected values for δ and i have to be formed and of course, there will be difficulties in deciding how to estimate these parameters in an unambiguous manner. However, the same difficulties are present when implementing the usual formula for the user cost of reproducible capital.

Second, (5) provides a valid formula for the user cost of the nonrenewable resource stock but it cannot be decomposed into the sum of waiting services[6] (rP^0S^0), revaluation ($– iP^0S^0$) and depletion terms ($[1+i]\delta P^0S^0 = \delta P^1S^0$), whereas formula (10) can be decomposed into this sum of terms. It is useful to be able to make this decomposition if we want to measure net output or

[5] Schreyer and Obst (2014) have the first two lines of (10), noting that the second line has the form of a standard expression for the user cost of capital.

[6] See Rymes (1968) (1983) on the concept of waiting services.

income, as may be desired in green accounting contexts. Three alternative income measures are given in Table 1, along with the corresponding user cost value for each.

Gross Income, or Gross Domestic Product (GDP) in the aggregate national context, is measured by Value Added. Income A results from the subtraction of the value of environmental depletion from Value Added to get a measure of net income. That is, income net of the value of natural resources exhausted in producing consumption goods; this accounts for the fact that national wealth has been diminished through economic activity impacting on environmental resources. Such an adjustment is consistent with the recommended approach of the UN System of Environmental-Economic Accounting (UN 2014, p. xii).

Table 1: Alternative Income Concepts

Income Concept	Net Income Definition	User Cost Value
Gross Income (GDP)	Value Added	$(rP^0 - iP^0 + \delta P^1)S^0$
Income A	Value Added - $\delta P^1 S^0$	$(rP^0 - iP^0)S^0$
Income B	Value Added - $\delta P^1 S^0 + iP^0 S^0$	$(rP^0)S^0$

An alternative is to also subtract the revaluation term from Value Added. This results in Income B in Table 1. This takes into account that a revaluation of the environmental resource can impact on wealth, due to e.g. increased information on resource degradation or exogenous shocks such as a fall in demand for ore. That is, by holding the environmental asset a financial cost is incurred and the fall in value should be reflected in the (net) income earned for the period. This view is consistent with the real financial maintenance of capital concept advocated by Hayek (1941). Income A, in contrast, is consistent with the maintenance of physical capital concept of Pigou (1941).

In the usual case of a produced asset, the asset-specific inflation rate, i, will normally be negative due to, for example, foreseen obsolescence, so Gross Income > Income A > Income B. For a natural resource asset, scarcity and macroeconomic conditions driving international demand may cause i to be positive so that Income B may become larger than Gross Income. Alternatively, technological advances and degradation of the resource may cause i to fall in a similar manner to produced capital. Hayek (1941) argued that Income A would overstate income in any period due to not accounting for (foreseen, produced-asset) obsolescence, and this argument appears to have merit in the natural resources context as well as the produced asset context.

References

Brandt, N., P. Schreyer and V. Zipperer (2016), "Productivity Measurement with Natural Capital," forthcoming, *Review of Income & Wealth*: available under http://www.oecd-ilibrary.org/economics/oecd-economics-department-working-papers_18151973

Cairns, R.D. (1986), "More on Depletion in the Nickel Industry," *Journal of Environmental Economics and Management* 13, 93-98.

Cairns, R. D. (2009), "Green Accounting for Black Gold," *The Energy Journal* 30, 113-139.

Cairns, R.D. (2013), "The Fundamental Problem of Accounting", *Canadian Journal of Economics* 46, 634-655.

Diewert, W.E. (1974), "Intertemporal Consumer Theory and the Demand for Durables", *Econometrica* 42, 497-516.

Diewert, W.E. (2005), "Issues in the Measurement of Capital Services, Depreciation, Asset Price Changes and Interest Rates", pp. 479-542 in *Measuring Capital in the New Economy*, C. Corrado, J. Haltiwanger and D. Sichel (eds.), Chicago: University of Chicago Press.

Diewert, W.E. and K.J. Fox (2014), "Sunk Costs and the Measurement of Commercial Property Depreciation", UNSW School of Economics Discussion Paper 2014-28. Forthcoming, *Canadian Journal of Economics*.

Hayek, F.A. von (1941), "Maintaining Capital Intact: A Reply", *Economica* 8, 276-280.

Hicks, J.R. (1939), *Value and Capital*, Oxford: The Clarendon Press.

Hotelling, H. (1931), "The Economics of Exhaustible Resources," *Journal of Political Economy* 39(2), 137-175.

OECD (2001), *Measuring Capital: Measurement of capital stocks, consumption of fixed capital and capital services*, OECD, Paris.

Pigou, A.C. (1941), "Maintaining Capital Intact", *Economica* 8, 271-275.

Rymes, T.K. (1968), "Professor Read and the Measurement of Total Factor Productivity", *The Canadian Journal of Economics* 1, 359-367.

Rymes, T.K. (1983), "More on the Measurement of Total Factor Productivity", *The Review of Income and Wealth* 29 (September), 297-316.

Schreyer, P. and C. Obst (2015), "Towards Complete Balance Sheets in the National Accounts — The case of subsoil assets," OECD Green Growth Papers 2015/02.

Scott, A. D. (1953), "Notes on user cost", *Economic Journal* 63, 364-383.

UN/EU/FAO/OECD/World Bank (2014), *System of Environmental-Economic Accounting: Experimental Ecosystem Accounting*, United Nations, New York.

World Bank (2011), *The Changing Wealth of Nations: Measuring Sustainable Development in the New Millennium*, The World Bank, Washington, USA.

Appendix

For ease of reference, this appendix provides the derivation of the result that user cost equals unit rent, following the method of Brandt, Schreyer and Zipperer (2016). The objective function for the optimal extraction of the subsoil asset stock S(t) over a lifetime T, depleted by quantity D(t) in period t can be expressed as follows:

(A1) $$\max_{D(a)} V(t) = \int_t^{T-t} R(a, D(a), S(a)) e^{-r(a-t)} da ,$$

given $\dot{S} = -D(t)$, and where r is a nominal rate of interest.

From (A1), it can be seen that V(t) is the net present value of resource rents, R(t, D(t)). Resource rents are the revenues from extraction less costs C(·) (which include a normal rate of return), so that we have R(t, D(t)) = P(t)D(t)–C(D(t),t), where P is the market price for the resource.

Assuming that resource rents do not depend on the remaining stock of subsoil assets, the present value Hamiltonian for the optimization problem is then as follows:

(A2) $$H(D(t), \lambda(t)) = R(t, D(t)) - \lambda(t) D(t) ,$$

where λ(t) is the shadow cost of depleting one unit of resource stock.

The first order condition for static efficient is then as follows:

(A3) $$\frac{\partial H(\cdot)}{\partial D} = \frac{\partial R(\cdot)}{\partial D} - \lambda(t) = 0 .$$

As λ(t) is the change of in the present value of resource rents R with a change in depletion D, it can be interpreted as the user cost of the resource. For unit extraction costs c(t) that are independent of the level of extraction, resource rents become R(t,D(t)) = P(t)D(t) – c(t)D(t). Denoting $\lambda^*(t)$ as the solution to the first order condition (A3), we then have:

(A4) $$\lambda^*(t) = \frac{\partial R(\cdot)}{\partial D} = P(t) - c(t) = \frac{R(\cdot)}{D} ,$$

which states that the user cost of the natural capital equals its unit rent.