ESTIMATION OF RESOURCE DEPRECIATION AND SCARCITY USING THE HOTELLING RENT CONCEPT: APPLICATION TO TWO BASE METAL RESOURCES IN ZIMBABWE

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Abstract:

Convergence of views on the importance of natural resource accounting has not readily translated into agreement and clarity on how this is to be done in practice. There are at least five methods of estimating natural resource depreciation and these have yielded significantly different results. Lack of agreement also characterizes measurement and interpretation of resource scarcity and dynamics. This paper briefly outlines and critiques the five depreciation methods and argues for and applies the total Hotelling rent (THR) method to chromite and copper resources in Zimbabwe over the period 1990-2001. It is noted especially that while the THR method does not consider discovery, the dearth of exploration of the two base metals in Zimbabwe means that such discovery was insignificant over the period. A simple scarcity measure is also developed and estimated for the two metals. Results show that depletion and scarcity measures for the two minerals were negligible. While this outcome is consistent with intergenerational equity, severely limited development and production capacities had negative implications on intragenerational equity. Scarcity indices indicate that official royalty rates over the period were exorbitant. The paper recommends the stepping up of exploration and production and downward review of royalties in order to reflect objective scarcity levels.

Keywords: Hotelling rent, resource rent, natural capital depreciation, scarcity index, royalty, discovery

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Introduction:

It is agreed in literature that natural resource accounting is important if we are going to have a complete depiction of the country's asset stocks and dynamics as well as of the economic welfare or standard of living as represented by national income measures. It is the stage of implementation that is fraught with disagreements, glaring inconsistencies in terminology and assumptions, ambiguities in concept, application and interpretation. For example, Cairns (1981, p.637) implies there is a difference between the concept of royalty ("that part of the shadow price of an additional unit of the resource stock which arises because of prospective exhaustion") and that of user cost ("degradation cost"), whereby the former may be zero even though the latter could be significant. However, Farzin (1992, p.813) regards 'scarcity rent', 'user cost' and 'royalty' as interchangeable and equal to price minus marginal extraction cost (which is equal to marginal rent). Ryan et al (2001, p.13) also apparently indicate that royalty is supposed to be equal to the income component of the resource rent (and not the depletion component).

Another area of disagreement is the behaviour of the scarcity rent, price and costs over time. The three are often proposed as measures (indices) of resource scarcity. For example, Farzin (1992) notes that, while Kay and Mirrlees (1975) hold that scarcity rent grows over time with extraction approaching exhaustion, Heal (1976), Hanson (1980), and Solow and Wan (1976) conclude that it falls monotonically towards zero. Reynolds (1999) also makes findings consistent with the latter conclusion. Reynolds, while acknowledging that this trend is usually attributed to technological innovations, seeks an alternative explanation. He argues that it is neither efficient nor possible to know the full extent of the resource base, hence there is marginal exploration and discovery as extraction proceeds. This reduces exploration costs, which can result in lower prices over time, until true scarcity reveals itself towards ultimate exhaustion.

There is no agreement on the appropriate index/ measure of resource scarcity (Farzin, 1992, p.814). While (Hotelling) rent is used as a measure of resource scarcity, there are other measures proposed, including cost and price (Farzin, 1995) as indicated in the above paragraph. Logically it is expected that, ceteris paribus, price as a measure of scarcity should increase with scarcity showing restricted supply, and that cost should also increase showing that extraction is getting more dependent on low-grade marginal and more complicated deposits. Rent, being generally the difference between price and cost, would essentially be ambiguous depending on the relative trends of prices and costs. However, progression of time does not necessarily imply increasing scarcity due to technological progress (which results in increased efficiency in extraction and use, miniaturization, more effective exploration/discovery, substitution of resources by other materials in input use, recycling, et cetera).

Harris & Fraser (2002) attribute the lack of convergence on these various issues related to natural resource stocks and dynamics to the paradigmatic diversity (or holistic nature) of natural resource accounting. The field has courted the interest of economists (theoretical, applied and ecological), accountants, and natural scientists (such as biologists, biochemists, ecologists, archaeologists and geophysicists).

Objectives and significance of the study:

Estimation of depletion of minerals is one of the central issues in mineral resource accounting. Various methods of estimation have been proposed. Five main ones include the Change in Value method (CIV), User Cost or El Serafy Method (EM), the Total Hotelling Rent Method (THR) which is actually the Net Price method that uses marginal costs (Harris and Fraser, 2002; see also in Lange and Motinga, 1997, p.8), the Net Price method (average cost version) (NPac) and the appropriation method. The term 'Net Price method' is often applied directly to both THR and NPac in literature, which has created significant terminological confusion. This confusion can easily be eliminated by a differentiation of terminology that has just been done above, which effectively constitutes them as two different methods. It is agreed that THR is the theoretically correct version of the Net Price method (according to the Hotelling rent principles) (Neumayer 2000, p.3); and that NPac is only an expedient compromise between theoretical correctness and practicality (Vincent, 2000, p.21; Neumayer, 2000, p.3; Lange and Motinga, 1997, p.8).

This paper seeks to apply the THR method to estimation of the depreciation of two of the major base metal resources in Zimbabwe, chromite and copper, over the period 1990-2001, as a case study. A simple scarcity index is subsequently developed and estimated for the two metals. This study is important for several reasons. Results on depletion can be used directly to derive the income component in the resource rent and measures of sustainable income (Eco-domestic product). Estimation of depletion values can be used as a basis for determination of depletion charges (Cairns, 1981, p.635). The simple scarcity index developed can be useful in indicating the scarcity trends for the two minerals as well as the necessary depletion charges as ratios or percentages of respective metal prices. Thus, comparison with historical royalty rates would show whether or not royalty rate setting is consistent with objectively measured resource scarcity.

The paper is organized as follows. The next section relates the derivation of a mathematical definition of natural capital depreciation, indicating this to be an ideal method of depreciation against which other methods are to be compared. This is followed by an outline of the EM, NP (average cost version) and the appropriation methods, and then a detailed treatment of THR, arguing why the latter is superior to the former three in Zimbabwe. A brief look at the Zimbabwe mining sector in general, and the chromite and copper sectors in particular, is followed by discussion of the methodology used in estimation of depreciation and scarcity indices for chromite and copper over a 12-year period (1990 – 2001). The last two sections present, interpret and discuss the results, which culminates in the paper's conclusions on depreciation and scarcity trends.

Definition of natural capital depreciation:

Conventional accounting measures have always included a measure for depreciation of reproducible capital. An extension of this tradition to natural resources has been based, inter alia, on the argument that natural resources (especially exhaustible ones) are a (capital) base for production of income, and one that depreciates with use (see Mlambo, 2010a). Depreciation of a natural resource[1] is defined in terms of two very important and related concepts, namely resource rent and value of a resource stock (in the case of a mineral, a mine). Resource rent in a given year is the net receipts received from the sale of the extracted mineral in that year (Ryan et al,

[1] 'Depreciation of natural capital' and 'depletion of the stock of resource' are used interchangeably (Harris & Fraser, 2002, p.165).

2001, p.7; Wikipedia, 2012). Net receipts are receipts net of all factor costs including a normal return to the entrepreneur. That is (Ryan et al, 2001, p.7):

Resource Rent ≡ Revenue from sale of minerals – cost of labour (wages and salaries) – cost of produced capital (rental) – cost of intermediate inputs/raw materials (input costs) – return to proprietor's labour (normal profit) – physical (fixed) capital consumption allowance – indirect taxes

≡ Return to owner of natural capital (for minerals in Zimbabwe, Government[2]) + resource depletion

Where natural assets belong to the private extractor, resource rents are actually supernormal profits, which would include scarcity rent (Hotelling rent), Ricardian rent and entrepreneurial rent (Wikipedia, 2012). In this case, they are not paid in practice. However, where the owner is different from the extractor, for example, government, resource rents have to be collected, and are collected partly by royalty (Ryan et al, 2001, p.7). Note that where royalties are regarded as a payment for depleting a resource, it covers depletion only and not return to the owner, which still must be collected. This has implications on setting of rates and levels in the wider mining fiscal framework.

The value of a mine (resource stock) is the total present value of resource rents associated with the exploitation and sale of the mineral (Vincent, 2000, p. 20). Thus, it is actually the net present value of a mining project (Ryan et al, 2001, p.8) with comprehensive costing. We can represent the value of a mine by (Vincent, 2000, p. 20):

$$R_t^* = \left(p_t y_t - TC_t\right) + \frac{(p_{t+1} y_{t+1} - TC_{t+1})}{1+s} + \ldots \qquad (1)$$

[2] In Zimbabwe, mineral resources are vested in (owned by) the state and are only extracted by individuals and corporates on the basis of leases. However, the income component is shared between the investor and government, with the former receiving his or her share as supernormal profits, and the government's share being that amount it collects over and above royalty.

where R_t^* is the total present value of current and future net receipts in period t, p_t is unit price of the resource in period t, y_t is the quantity of extraction in period t, TC_t is the total cost of extraction in period t and s is the discount rate.

Natural resource (natural capital) depreciation is defined as reduction in the value of a resource stock (Hartwick & Hageman, 1993). That is, depreciation in period t is change in value in period t, given by:

$$\Delta R_t^* \left(= R_{t+1}^* - R_t^* \right) = \frac{sR_{t+1}^*}{1+s} - \left(p_t y_t - TC_t \right) \qquad (2)$$

The first term on the RHS of (2) is the discounted capital gain (or loss) on the deposit associated with its holding, so that equation (2) gives net change in the value of the resource, rather than gross which ignores the capital gain (or loss). The second term is current total resource rent. Note that equation 2 is consistent with the last identity given above (from Ryan et al, 2001, p.7) which is clearly shown by transferring the last term on RHS to LHS and LHS term to right.

<u>Methods of estimating depreciation of natural capital:</u>

<u>Brief outline:</u>

Equation (2) is one way of estimating depreciation of a mineral deposit which derives directly from the definition of the value of a natural resource (mineral deposit), termed the change in value method (CIV). This method, while theoretically sound, is very difficult to apply in practice because of the need to project extraction schedules, prices and costs in future periods in the process of estimating the value of the resource stock. For minerals (which are exhaustible), one would also have to estimate the future size of deposits in order to determine the life of the resource (Hartwick and Hageman, 1993, p. 215), which implies the need to project exploration activities and discoveries. However, because the CIV method is correct from a definitional point of view, it is useful as a standard for comparison with other methods.

Four more amenable methods include the NPac (World Bank, 1997a, in Neumayer, 2000; Ryan et al, 2001), EM, the appropriation method and THR. Mathematically, in NPac, EM and THR, depreciation is respectively given by the formulae below:

NPac: $(P_t - AC_t)\, Y_t$ (3)

EM: $(P_t - AC_t) Y_t \left[\frac{1}{(1+r)^{z+1}} \right]$ (4)

THR: $\left[P_t - C'(Y_t) \right] Y_t$ (5)

The NPac simply gives depreciation as resource rent (Neumayer, 2000). The net price is given by the bracketed term in equation (3) (Ryan et al, 2001, p.9). There are a number of problems with the NPac method. The method strictly looks at figures in the current period and there is no discounting, hence is a short-term or current concept. Absence of discounting implies the possibility of mining all stock in the current period, something unlikely given that mining is capital intensive (Ryan, et al, 2001, p.9). The method results in overvaluation (Ryan, et al, 2001, p.9) apparently because it regards all net receipts as depletion, implying that there is no income from extraction and sale of minerals. Lange and Motinga (1997, p.8) explain the overvaluation by the argument that marginal cost is normally higher than average cost. The NPac method also disregards discoveries.

The EM method has the advantage that it is flexible with respect to extraction rates, discount rates and reserve estimates, an argument detailed in El Serafy and Lutz (1989). Accounting is a historical exercise that is different from investment appraisal – the latter seeks to reduce all future cash flows to current value by using the current discount rate only. Thus, EM by taking into account changes in discount rates over the period of the study is consistent with proper accounting practice. The method incorporates discoveries through changes in life expectancies premised on changes in either production rates or reserves or both.

In the appropriation approach, economic rent is derived from observed government revenue from fees, taxes and royalties. However, Ryan et al (2001, p.9) argues that this may result in a poor reflection of true economic rent since the rates set by government are also meant to address government objectives, for example, regional development, industrial development and encouragement of exploration.

From the above outline, it is clear that the NPac and the EM methods give different results, since the latter is a downward adjustment of the former by the factor given in square brackets in equation (4). Young (1995) applies both methods in estimating depletion of minerals in Brazil over the period 1970 – 1988, and he finds the results between the two methods to differ significantly. Common and Sanyal (1998) also finds that the various methods of estimating natural resource depreciation yield significantly different results in Australia and concludes that "robust measurement of natural resource depreciation is unlikely, and that results appertaining to such should be treated skeptically" (from abstract).

Total Hotelling rent approach:

This approach is based on the concept of Hotelling rent (see Vincent, 1997). Hartwick and Hageman (1993, p. 215) define Hotelling rent as "…rent that exists on the marginal ton of an exhaustible resource… a measure of the intertemporal scarcity of the exhaustible resource". The concept is that, as the resource becomes more and more scarce extraction will be pegged at lower levels than would equate marginal revenue to marginal costs so that the marginal unit earns profit or rent purely attributable to scarcity. Thus, the greater the scarcity, the greater the marginal rent.[3] This rent (that is, marginal rent) earned due to scarcity is Hotelling rent, and may also be termed scarcity rent (see Wikipedia, 2012). Increasing Hotelling rent over time would mean that the known reserves of the concerned mineral are getting scarcer and there is need to undertake exploration to ensure that supply is maintained in the long-term. Of the three main rent

[3] However, it does not follow that the greater the scarcity the greater the total Hotelling rent. Scarcity implies that there may be reduced levels of extraction which would in turn reduce the amount of THR per given level of marginal rent. The net relationship between scarcity and THR then seems to depend on rate of increase of marginal rent relative to the rate of decrease of extraction levels. Thus, while marginal rent could be regarded as an index of scarcity, THR cannot.

concepts (scarcity rent, Ricardian rent and entrepreneurial rent), scarcity rent is appropriate to estimation of resource depreciation and scarcity.

Equation (7) tells us that depreciation of a non-renewable natural resource (LHS) is the product of marginal rent and the change in the stock of the resource (Vincent, 1997, p.22). The approach assumes optimal extraction (no open access – complete or partial) and that there are no exogenous shocks on price and total costs, under which conditions capital gains (or losses) disappear and average costs (in the CIV method above) are replaceable by marginal costs (Vincent, 2000, p. 21).

$$\frac{dK_n}{dt} = -\left[p_t - C'(y_t)\right]y_t \tag{7}$$

where $C'(y_t)$ is the marginal extraction cost in period t (all factor costs including a normal return to capital) (Bartelmus et al, 1993, p. 116), y_t is the amount of the resource extracted in period t and p_t is the respective price of the resource. The expression $p_t - C'(y_t)$ is the marginal rent.

Marginal extraction costs are normally difficult to obtain in practice. To avoid this difficulty one approach is to estimate the total Hotelling rent from the total resource rent, given by $[p_t - AC_t]Y_t$, by using the fact that the ratio of the total Hotelling rent to total resource rent is equal to the ratio of the marginal rent to average rent (Vincent, 1997. The rest of this subsection is based on this reference). Let:

$$C(Y_t) = aY_t^b, \qquad C'(Y_t) = MC = \theta Y_t^\eta, \qquad AC = \frac{MC}{\eta + 1} \tag{8}$$

where MC = marginal cost, AC = average cost, a and b are constants, θ = ab and η = b-1. The MC function is an isoelastic function since its elasticity, given by η, is a constant.

Denoting total Hotelling rent by H_t and the total resource rent by R_t, and using equation (8):

$$\frac{H_t}{R_t} = \frac{p_t - C'(Y_t)}{p_t - C'(Y_t)/(\eta+1)} \tag{9}$$

By the terminal time transversality condition, marginal cost (MC) equals average cost (AC) at the point of stock exhaustion, assuming optimal extraction (on transversality condition see in Conrad & Clark, 1987). With η>0 (or in particular $\eta \neq 0,-1$), marginal cost equals average cost only if $Y_t = 0$. The implication of this is that marginal rent at terminal time is equal to price.

Discounting terminal time marginal rent to the current period, assuming for simplicity, constant price and optimal extraction (so that the present values of marginal rents are equalized through time), by the transversality condition marginal rent at terminal time would be given by:

$$\begin{aligned} p &= \left[p - C'(Y_t)\right](1+\sigma)^{T-t} \\ \therefore C'(Y_t) &= p\left[1-(1+\sigma)^{t-T}\right] \end{aligned} \tag{10}$$

In equation (9), multiplying both the numerator and the denominator in the RHS by η+1, substituting MC from (10) and simplifying we get:

$$\frac{H_t}{R_t} = \frac{\eta+1}{\eta(1+\sigma)^{T-t}+1} = \frac{\eta+1}{1+\eta(1+\sigma)^{x_t/Y_t-1}} \tag{11}$$

where the far RHS approximates T-t by $(x_t/Y_t) - 1$, with x_t as the remaining stock of the resource in year t (that is, current year)[4]. Equation (11) can then be used to calculate total Hotelling rent as the product of the total resource rent and the expression on the far RHS.

<u>Brief critique of the THR method:</u>

[4] We subtract 1 because in the terminal period there is no extraction. Extraction lasts until T-1 and in T the resource is in its terminal state exploitation of which is economically not feasible.

The THR method has been criticized for ignoring the capital gains element of the change in value as shown in the change in value method. It is clear that the Hotelling rent gives the returns in the accounting period only (Bartelmus et al, 1993, p. 18). Vincent (2000, p. 21) argues that this method is correct only under the strong assumptions that it makes, noting that the reality is that these assumptions are violated in most countries.

The method would share the criticism leveled against the NPac method by El Serafy (1989) and Nuemayer (2000) (in Harris and Fraser, 2002, p.166) for counting all net receipts from resource extraction as depreciation/capital consumption, as though there was no resource in the first place, implying zero net income (Hartwick 1990, in Harris and Fraser 2002, p.166). However, the author notes that such conclusion would apply directly to NPac where the extraction is valued at the unit profit rather than the THR in which the marginal rent is used. As long as there is a positive difference between AC and MC (that is, as long as the AC is falling), there is positive net Hotelling rent over and above the value-added and vice-versa. This can be easily viewed by drawing standard cost curves for a single firm.

Bartelmus et al (1993, p. 18) point out that the advantage of the THR method is that, in looking at returns in the accounting period only: “the valuation of resource depletion is very close to common accounting practice for withdrawals from stocks of produced commodities….(it) can be seen as an application of stock accounting to an exhaustible resource (which)…is more of an inventory than a fixed asset”.

In comparison with the method that the World Bank used in calculating resource rents in 103 countries in their report World Bank (1997a, in Neumayer, 2000), which is actually NPac, the THR does not just directly substitute the MC by the AC. Doing that would depart from the assumption of optimal resource pricing based on MC (Nuemayer, 2000, p.266) which underlies optimal programmes upon which the whole concept is based, thereby directly creating conceptual inconsistencies. However, this does not by itself create merit for the assumption, which is in fact often violated in practice.

This study argues that the THR approach is the most appropriate measure of mineral resource depreciation in Zimbabwe over the period 1990 - 2001. This argument is backed by the lack of significant exploration and discoveries in the mining sector over that period. Harris and Fraser (2002, p.165) point out without elaborating that, there is no consensus on how discoveries should be treated, with authors such as Levin (1991) and Butterfield (1992) (both in Harris and Fraser, 2002, p.165) apparently suggesting their incorporation into "satellite accounts to record resource stocks as 'inventories' to be brought into the productive sphere" (Harris and Fraser, 2002, p.165). In Cairns (1981, p.644) it is noted that the assumption of no discovery, and difficulty of getting appropriate data as companies jealously guard it, are limitations of his depletion study. Cairns also notes that exploration to delineate reserves for several years would not be an efficient practice and hence is not practiced.

This study argues that a direct substitution of MC by AC, which leads to overstatement of depreciation (Hartwick, 1990 in Harris and Fraser, 2002)) and negates the basis underpinning the method (Hotelling rule)(Harris and Fraser, 2002, p.165), is not inevitable as shown in Vincent (1997) summarized above.

Mining sector in Zimbabwe:

General background:

As many as forty different types of minerals are found in Zimbabwe (Chamber of Mines of Zimbabwe, 2012). The ten major minerals mined in the 1990s, in terms of production value, included gold, asbestos, nickel, coal, copper, chrome, tin, iron, silver and cobalt (Government of Zimbabwe, a). More than 6,000 mineral deposits were known in Zimbabwe from ancient workings, and little exploration outside rediscovering these workings has occurred (Mugumbate, 2010). This left a huge amount of undiscovered deposits unexplored, implying tremendous exploration scope still exists. Mining of many minerals in the country, especially chromite, has also remained small-scale, by small miners who have neither desire nor the capacity to undertake major exploration, even around their deposits. It is believed that most of these small mines are actually sites of expansive deposits waiting to be explored.

Historically, politics has played a major role at various stages in the development of the country (Valliers, 1993; Mugumbate, 2010). Sanctions which were imposed on Zimbabwe by Britain and the Commonwealth Countries (1965) and later the United Nations (1968), and were generally respected by foreign firms, significantly affected exploration in the country. This happened at a time when new exploration methods were being developed and successfully applied elsewhere. Because of sanctions, it was not possible to import this new technology and geoscientific expertise or transfer them through FDI. Later the advent of intense guerrilla war increased insecurity, which compounded the risky situation naturally associated with exploration.

However, a significant exploration drive was recorded after independence when political stability returned, which resulted in several new deposits being discovered as well as re-discovery of old workings (Mugumbate, 2010). This trend, however, remained constricted by the smallness of operations, as well as the complacence from the general belief of abundance. From the late 1990s political and economic difficulties came into play as the economy entered into a recession that was to last at least a decade. Hawkins (2009) reports that after 1997, except in the platinum and diamond sectors, exploration and new capacity investments have been minimal (in Mlambo, 2011, p.65). Therefore, it has generally remained true throughout the period after independence that Zimbabwe is "a mining country awaiting discovery" (Valliers, 1993, p.2). In the words of a senior officer of the Zimbabwe Geological Survey in 2010, "Zimbabwe is many years behind other countries with similar geology in terms of exploration…." (Mugumbate, 2010).

While the mining sector is characterized by little exploration as shown in the above section, generous assumptions about abundance have been thrown around by many authors (Valliers, 1993; Ministry of Mines and Mining Development, 2011), betraying dangerous naivety. At least one author has indicated that Zimbabwe is not a typical minerally rich economy as compared to other countries like Botswana, Zambia and DRC (Hawkins, 2009, p.1). However, the country has remained highly dependent on mining besides agriculture. The dependency of the Zimbabwean economy on the mining sector in the 1990s and early 2000s is demonstrated statistically. On average the sector contributed 4.5% of Gross Domestic Product (GDP) in the 1990s, 4.5% of employment in the same period, 10.2% of Gross National Investment from 1992 to 1997, and about 40-45% of foreign exchange earnings (in the 2000s) (Government of Zimbabwe a & d, in Mlambo, 2010a, p.243).

Lack of exploration, heavy bias towards primary production and statistically proven dependency on minerals unambiguously raises the question of economic sustainability. The question of sustainability in a resource sector automatically translates into resource accounting.

Zimbabwe chromite and copper Sectors:

In Zimbabwe, chromite ore is found in the Great Dyke and the greenstone belts, with the former hosting approximately 10 billion tones (Ministry of Mines and Mining Development, 2011, p.17). More than 80% of the metallurgical quality chromite resources in the world are found in Zimbabwe. In terms of tones, that is 560mt out of 650mt (Valliers, 1993, p.69). Greenstone belt deposits are located in Shurugwi, Mashava, Belingwe greenstone belts, and the Limpopo Mobile Belt (Ministry of Mines and Mining Development, 2011, p.17). Valliers (1993, p.70) believes that the Great Dyke resources cannot be exhausted, though benefiting from them has been limited by the difficulty of using mechanized mining on their thinly-layered ores.

Zimbabwe is a significant producer of chromite in the world, ranking 5th in 1991 (Valliers, 1993, p.69). Two main producers are ZIMASCO and Zimalloys. ZIMASCO is currently owned 86.3% and 13.7% by Sinosteel Corporation and China-Africa Development respectively (Zimasco Pvt Ltd, 2012) while Zimalloys is owned 88% by Benscore Investment, a local company (Herald Business Reporter, 2012). Both have each a refinery, and together extract 84% of all chrome ore, with the remainder coming from many co-operatives and small individual producers most of which are tributors of the two main producers (Valliers, 1993). Main geographical sources/areas of production for ZIMASCO include Shurugwi, Mutorashanga and Lalapanzi with ferrochrome production at a 7-furnace refinery in Kwekwe. Zimalloys produces along the Great Dyke and in Mberengwa , with its foundry in Gweru. World chrome production has been affected by depressed prices, which, in Zimbabwe have been coupled with increases in production costs (of alloys) due to escalating electricity and rail transport costs.

There are a number of known copper provinces with Deweras Sediments, Umkondo Sediments and Piriwiri Sediments being major (Mugandani & Masiya, 2011). Deposits of copper number about 70, and most of them are located in the northern part of the country (Vallieres, 1993). Most of these deposits are small and believed to be low-grade. Mhangura Copper Mine, one of the major copper mines in the country owned by the Zimbabwe Mining Development Corporation (ZMDC) shut down in 2001 (Financial Gazette, 2011). The collapse was due to unrelenting financial and operational problems as well as the depleted ore reserves at the mine (Mbendi Information Services, 1995-2012). Generally, in the country known reserves of copper have been depleting, which trend has not been helped by low expenditure levels dedicated to copper exploration. Exploration mainly targets known occurrences (Mlambo, 2010b, p.7), meaning that huge potential for exploration exists (Mbendi Information Services, 1995-2012). Lomagundi Mining and Smelting and Sanyati Copper mine are also closed (Voice of America, 2012). Production is currently from small to medium scale mines in the north-west of Zimbabwe (Mbendi Information Services, 1995-2012) and as by-product from gold and nickel mines (African Weibo Zimbabwe, 2012).

Methodology and data:

Estimation of depreciation:

This study applies the THR method to depreciation of minerals in Zimbabwe for the following main reasons: (a) it is theoretically correct, being consistent with the fundamental principle of natural resources (the Hotelling rule) (see Mupimbila, 1998); (b) unlike the NPac which regards all resource rent to be depreciation, this method, like the EM, ensures that there is a split between true income and resource depletion; (c) while the method does not take into account resource discovery, it is noted that in Zimbabwe the dearth of exploration means that such discovery has been insignificant. This case study applies the THR method to estimate the depreciation of two of the major base minerals mined in Zimbabwe, namely chromite and copper. According to the Central Statistical Office publications, the two minerals were among the ten major minerals mined in the 1990s. Table 1 shows the time-series estimated reserves, production data, computed life expectancies and prices for the two minerals over the period 1990-2001.

Table 1: Mineral Reserve, Production (gross weight for chromite, mineral content for copper) and Prices for Chromite and Copper (1990-2001)

	Chromite					Copper, Average Ore Grade = 1.01%				
Year	**Reserves, t**	**Prod., t**	**LE, Yrs**	**Price, US$/t, /1**	**Price, Z$/t**	**Reserves, t**	**Prod., t**	**LE, Yrs**	**Price, US$/t, /2**	**Price, Z$/t**
1990	614,416,043	573,000	1,071	72	27.31	3,535,000	15,000	235	2,715.21	1,029.88
1991	613,843,043	564,000	1,087	71	358.63	3,520,000	14,000	250	2,410.31	12,174.72
1992	613,279,043	522,000	1,174	70	383.71	3,506,000	10,000	350	2,368.20	12,981.30
1993	612,757,043	252,000	2,431	65	450.78	3,496,000	9,000	387	2,018.55	13,998.64
1994	612,505,043	517,000	1,184	69	578.71	3,487,000	9,000	386	2,448.23	20,533.55
1995	611,988,043	707,000	865	80	744.87	3,478,000	9,000	385	3,049.65	28,394.99
1996	611,281,043	697,000	876	93	1,008.02	3,469,000	10,000	346	2,403.92	26,055.82
1997	610,584,043	670,000	910	74	1,377.00	3,459,000	9,000	383	2,357.18	43,862.64
1998	609,914,043	605,000	1,007	74	2,765.32	3,450,000	4,000	862	1,733.71	64,787.47
1999	609,309,043	641,000	950	63	2,400.91	3,446,000	5,000	688	1,673.53	63,777.61
2000	608,668,043	668,043	910	63	2,727.27	3,441,000	2,104	1,634	1,943.59	84,138.14
2001	608,000,000	780,150	778	63	3,461.54	3,438,896	2,057	1,671	1,694.25	93,090.76

Sources: Original reserve figures are obtained from the Mlambo (2007). These figures (not adjusted for ore grade) are 350 million tons for copper (1990) and 608 million tons for chromite (2001). Production figures are from Mobbs (1994, 1999, 2004). Sources of prices: Amey (2001), Amey (2004),Edelstein (2000), Edelstein (2004), Papp (2002). Original prices from sources are in US$, and are converted to Zimbabwe Dollar equivalent by the exchange rates obtained from Reserve Bank of Zimbabwe (1999)(for 1990-1999), and World Factbook (2002) (for 2000-2001)./1 - Ore value, dollars per metric ton, gross weight. 2002-2005 chromium prices are unit values of average annual imports into USA. 1999-2000 prices are year end prices for chromite (not specified gross or ore). 2001 price is just assumed to be equal to 2000 price./2 - Converted from cents per pound by multiplying by 22.0462

The elasticities of the marginal cost of extraction (emce) for the two minerals are approximated by average elasticities of cost with respect to output computed over the period 1969-1995 in Chifamba (2003), which are respectively 0.350 and -0.228 for chromite and copper. These are assumed to be constant over time so that they are applied directly throughout the study period. Formula (14) is used for extrapolation of average cost figures from those reported by the Ministry of Mines and Mining Development. This simple proportional adjustment to extrapolate values of a variable is common in economic literature (see Mlambo, 2010a, p.249). Note that in this particular extrapolation the Producer Price Index (PPI) for metals is used as a proxy for cost indices which are not available. Table 2 shows the average cost estimates, the PPI, and the average money market rates of interest (used for estimation of a discount rate proxy).

$$AC_t = AC_{t-1}\left(\frac{PPI_t}{PPI_{t-1}}\right) \tag{14}$$

The discount rate is supposed to indicate the time preference for income by the owner (how much they prefer income today than in the future) and the "Draft SEEA recommends that the corporate bond rate for resource companies be used" (Ryan, et al, 2001, p.13). However, Ryan et al notes that the large business borrowing rate has been used in Australia since mining company bonds in Australia are limited. In this paper, the discount rate, which is equal to 29.45%, is estimated by the average of the principal money market rates of interest over the period 1990-2001. The market rates represent the opportunity costs of investing funds into financing productive activities since the funds can alternatively be invested in the money market. Its assumed constancy over time means that society's time preference (between the current and future generations) remains the same over time. It is safer to assume that in every generation people are equally concerned with their posterity as their predecessors were about them. Environmental movements which are being witnessed now do not necessarily mean that the current generation is more altruistic in an intergenerational sense, but that there are new environmental concerns that need to be addressed, which were not there in the past.

Table 2: Average Costs (AC), PPI and Interest Rates ®

	Chromite	**Copper**	**PPI**	**®**
Year	**AC, Z$/t**	**AC, Z$/t**		
1990	267.67	4,917.63	100.0	10.50
1991	404.99	7,440.37	151.3	21.90
1992	580.58	10,666.34	216.9	28.14
1993	680.15	12,495.70	254.1	22.75
1994	799.80	14,693.88	298.8	22.97
1995	703.78	7,175.38	331.7	25.30
1996	783.98	10,973.02	369.5	17.94
1997	2,274.34	23,110.29	401.6	27.49
1998	1,650.48	32,495.97	564.7	33.64
1999	2,643.75	57,792.99	1,004.3	59.12
2000	4,014.19	87,751.20	1,524.9	50.18
2001	5,464.66	119,458.79	2,075.9	33.47

Source: Original figures for cost/tonne milled for the two metals and grade forcopper which are used to compute chromite average costs (1994,1995, 1997, 1998, 1999) and copper average costs (1994, 1995, 1996, 1997) are from Government of Zimbabwe (1995, 1997, 1999). Average costs for the rest of the years are estimated by formula (equation) 14. Average costs are estimated by average milling costs. PPI denotes producer price indices for metallic products, which are obtained from Government of Zimbabwe (2001). The PPI figure for 2001 is an average for the half year up to June 2001. Interest rates are from CSO Compendium of Statistics 2000 and several CSO QDS (referenced together as Government of Zimbabwe, a). The computation of the averages for 2000 and 2001 ignores zero rates or rates for which figures were not available, and the 2000 rates used are for December.

Regarding reserves, two simplifying assumptions are made: (a) the average grade of reserves is constant over time; (b) profitability and technological changes over time have not significantly affected the definition of reserves, so that change in reserves where there is little discovery (exploration) is accounted for by changes in production only. Average grades are obtained by the following process: (i) From the Government of Zimbabwe (1995, 1997 and 1999) we get for each reporting mine for each of the three years (1995, 1997, 1999) the various grades for proven, probable and possible reserves; (ii) The grades for the mineral are averaged (inclusive of the three reserve categories) for each year and the overall average is then computed for the three years. For chromite we do not adjust reserves for grades because the production figures are reported gross (ore) and the prices are for gross weight.

Assumption (a) on reserves means that we can obtain some reference reserve estimate (mineral content for copper) by multiplying the original reserve estimate by the grade. Assumption (b) means that the rent estimates made in this study are for a scenario in which reserve definition is fixed over time. Thus, for each mineral we generate reserve estimates for the rest of the years by adding production figures (for years preceding the year for which the original estimate is available) and subtracting production figures (for years after the original estimate). By this method, we complete the time-series for reserves in Table 1. It is assumed that reserve figures are as at the beginning of each year.

A simple scarcity index (ratio):

An index of scarcity must necessarily be relative rather than absolute. It can be calculated as the ratio of THR to total revenue (gross) or just marginal rent to price. Denoting the scarcity index by φ:

$$\varphi = \frac{H_t}{p_t y_t} = \frac{p_t - C'(y_t)}{p_t} \tag{15}$$

This paper's reasoning for a relative measure is that as the resource becomes scarcer an increasing component of price should constitute marginal rent (attributable to scarcity) rather than Ricardian or entrepreneurial rent as the latter two must necessarily diminish. That is, the importance of differences in sites and advertising diminish as the resource becomes scarcer.

Results and interpretation:

Results of rent and scarcity ratio computations for chromite and copper in Zimbabwe:

Tables 3 and 4 show, in columns 2-6, all the data that enter into the computation of the resource rent (second last column) and finally the total Hotelling rent (last column) for the two minerals respectively. Figures 1 and 2 graphically present the trends of resource rents (CRR and CuRR) and total Hotelling rents (CHR and CuHR) for the two minerals respectively. Table 5 presents results on the scarcity indices for the two minerals.

Resource rents (blue line) for chromite were mostly negative throughout the period, while those for copper were mostly positive and significant. However, the total Hotelling rents for both minerals were negligible throughout the twelve-year period, as conspicuously demonstrated by the coincidence of the red lines with the time axes. Some of the negligible results on the total Hotelling rent are negative. Regarding negative results in asset evaluation Ryan et al (2001, p.13) says:

> Where costs exceed prices the economic rent will be negative, and the NPV of the asset will be set to zero in the balance sheet … Even though extraction may still be taking place (in anticipation of future profitability),

there cannot be any depletion in an economic sense when the asset derives no resource rent, as the asset will not have any value.

Table 5 shows that throughout the period of study scarcity ratios for both minerals were negligible and in most cases also negative. This follows directly from the negligible THR. This is an overwhelming indication that production during the period and in long periods to come will not make the resource significantly scarce unless the levels of production are extremely increased.

Table 3: Chromite Results

Year	Price, Z$/t	Prod., t	LE-1, Years	AC, Z$/t	emce+1	Discount rate+1	Rt, Z$	Ht, Z$
1990	27.31	573,000.00	1,070.28	267.67	1.35	1.29	-137,726,900.40	-2.3089E-110
1991	358.63	564,000.00	1,086.37	404.99	1.35	1.29	-26,145,710.64	-7.2754E-113
1992	383.71	522,000.00	1,172.86	580.58	1.35	1.29	-102,767,555.06	-7.788E-122
1993	450.78	252,000.00	2,429.58	680.15	1.35	1.29	-57,802,803.61	-4.5936E-261
1994	578.71	517,000.00	1,182.73	799.80	1.35	1.29	-114,303,581.70	-7.0248E-123
1995	744.87	707,000.00	863.61	703.78	1.35	1.29	29,052,044.00	3.48968E-88
1996	1,008.02	697,000.00	875.02	783.98	1.35	1.29	156,153,133.79	1.0278E-88
1997	1,377.00	670,000.00	909.32	2,274.34	1.35	1.29	-601,218,202.00	-6.3668E-92
1998	2,765.32	605,000.00	1,006.12	1,650.48	1.35	1.29	674,478,684.00	1.4075E-102
1999	2,400.91	641,000.00	948.56	2,643.75	1.35	1.29	-155,659,734.90	-7.5414E-97
2000	2,727.27	668,043.00	909.12	4,014.19	1.35	1.29	-859,720,131.24	-9.5761E-92
2001	3,461.54	780,150.00	777.34	5,464.66	1.35	1.29	-1,562,735,063.41	-6.52595E-77

Table 4: Copper Results

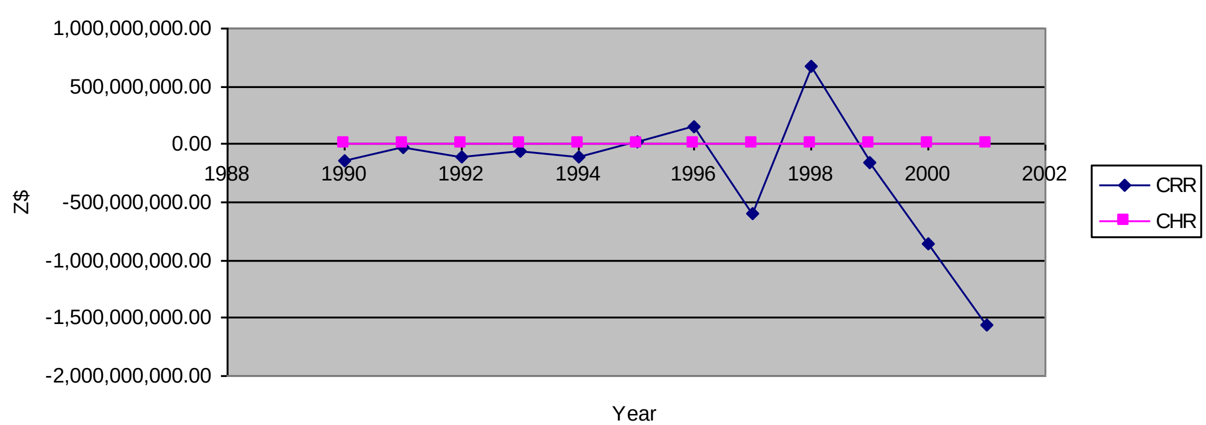
Year	Price, Z$/t	Prod., t	LE-1, Years	AC, Z$/t	emce+1	Discount rate+1	Rt, Z$	Ht, Z$
1990	1,029.88	15,000.00	233.67	4,917.63	0.77	1.29	-58,316,270.58	2.84671E-18
1991	12,174.72	14,000.00	249.43	7,440.37	0.77	1.29	66,280,860.02	-5.84571E-20
1992	12,981.30	10,000.00	348.60	10,666.34	0.77	1.29	23,149,630.68	-2.20117E-31
1993	13,998.64	9,000.00	386.44	12,495.70	0.77	1.29	13,526,510.33	-8.39632E-36
1994	20,533.55	9,000.00	385.44	14,693.88	0.77	1.29	52,557,066.99	-4.20847E-35
1995	28,394.99	9,000.00	384.44	7,175.38	0.77	1.29	190,976,526.56	-1.97271E-34
1996	26,055.82	10,000.00	344.90	10,973.02	0.77	1.29	150,828,029.95	-3.67937E-30
1997	43,862.64	9,000.00	382.33	23,110.29	0.77	1.29	186,771,110.85	-3.30263E-34
1998	64,787.47	4,000.00	860.50	32,495.97	0.77	1.29	129,166,024.33	-3.00874E-87

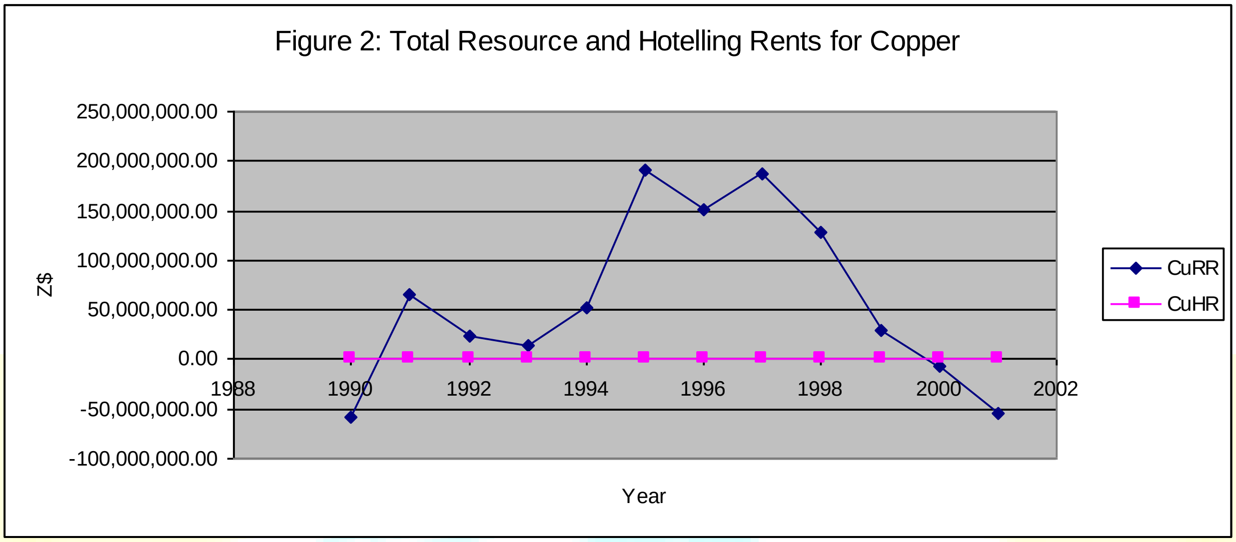
1999	63,777.61	5,000.00	687.20	57,792.99	0.77	1.29	29,923,124.25	-1.01962E-68
2000	84,138.14	2,104.00	1,633.46	87,751.20	0.77	1.29	-7,601,873.27	5.8499E-174
2001	93,090.76	2,057.00	1,669.80	119,458.79	0.77	1.29	-54,239,039.48	3.9913E-177

Table 5: Scarcity indices

Year	Chromite	Copper
1990	-1.4755E-117	1.843E-25
1991	-3.597E-121	-3.43E-28
1992	-3.8883E-130	-1.696E-39
1993	-4.0439E-269	-6.664E-44
1994	-2.3479E-131	-2.277E-43
1995	6.6265E-97	-7.719E-43
1996	1.46288E-97	-1.412E-38
1997	-6.901E-101	-8.366E-43
1998	8.413E-112	-1.161E-95
1999	-4.9002E-106	-3.197E-77
2000	-5.256E-101	3.3E-182
2001	-2.41655E-86	2.08E-185

Figure 1: Total Resource and Hotelling Rents for Chromite





These results on rents and scarcity index are apparently linked to the following factors:

a) Known reserves of the two minerals are large;

b) The level of production of the two minerals has generally remained low, with that of copper generally declining almost monotonically over the period. This was generally accounted for by declining world market prices, beginning at US$72/t for chrome down to US$63/t, while that for copper began at over US$2,700/t and ended at below US$1,700/t. This was compounded by increasing average costs of production, which are to some extent mirrored by the PPI for metals and the rate of interest as a cost of capital. Profitability conditions in the chromite sector became so bad they threatened the main producing mine in Shurugwi; and

c) The rates of extraction relative to the known reserves of both minerals were very low, resulting in large life expectancies throughout the period. Life expectancies for chromite ranged between 778 and 2,431 years, while for copper they ranged between 235 and 1,671 years.

Conclusion:

It is concluded that production of the two minerals over the 12-year period did not result in any noticeable depreciation of the respective resource bases, which presents a prima facie case for accepting that resource exploitation, from the environmental perspective was sustainable.

However, considering a wider definition of sustainability to include the economic and social perspectives (intra-generational), it is noted that very low rents indicated limited economic benefits from resources on which the economy is dependent. Thus, production capacities in these sectors were severely and adversely limited. While at these capacities the resources will 'never be exhausted' (Cairns, 1981, p.643) especially considering that huge exploration scopes exist, which will definitely preserve the resources, it would mean these resources are not beneficial to the country. Results on scarcity index imply that the appropriate royalties (exhaustion rents) would be zero (Cairns, 1983, p.643). Thus, at official rates of 2% for both minerals (in the 1990s) (Government of Zimbabwe, b) royalties exacted from these mineral sub-sectors were not justified.

It is therefore, recommended that in order for the country to benefit from these resources, measures should be put in place to step up both exploration and production capacities, especially by attracting Foreign Direct Investment (FDI) in the subsectors through various fiscal and monetary incentives. The study readily indicates that significant reduction of royalty in the two sub-sectors (even down to zero) is possible without threatening sustainability since essentially there is zero depletion and zero scarcity. The current depletion charges are clearly exorbitant and a disincentive to investment. Given that discovery over the period has been assumed to be zero, not because of over-exploitation, but restricted exploration, expanded exploration programmes would actually further indicate that indeed worries about possible scarcity in the two sectors have no basis. Measures also need to be put in place to encourage reinvestments (ploughing back into the sectors), such as reinvestment tax credits, and to support small miners who constitute the bulk of miners, especially in the chromite sector.

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