Accounting for Natural Capital in Mining MFP: Comparing User Costs for Non-Renewable Resources

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Abstract

In productivity studies that account for the depletion of natural resources, a user cost of natural capital is required to construct capital service aggregates. The World Bank employed the unit rent as the user cost for valuing subsoil assets, a method also adopted by the OECD. However, Diewert and Fox (2016) have shown that the unit rent method is equal to traditional user cost if expectations formed at the beginning of the period are realised. This paper compares multifactor productivity estimates for the Australian mining sector that accounts for subsoil minerals under these two user cost of natural capital approaches. A preliminary comparison of the approaches reveals potential disadvantages of each, specifically their volatility and their tendency to become negative for at least some periods. Thus, the paper explores alternative ways of calculating the traditional user costs to avoid the prevalence of negative user costs. It also examines the residual approach to estimating the user cost of natural capital recommended by the UN System of Environmental Economic Accounting. Results show on average over 1989-90 to 2015-16, mining multifactor productivity growth including natural capital, is higher than mining multifactor productivity growth excluding natural capital by at least 0.4 percent per year.

Keywords:Productivity measurement, natural capital, industry dynamics.

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1 Introduction

The growth in a country's productivity interests economists and policymakers alike, because improvements in productivity imply that an economy can produce more output with limited (or fixed) inputs, and hence materially improve the well being of the economy. The typical production function assumed in producing multifactor productivity (MFP) measures includes labour and produced capital as input factors. MFP is considered to represent elements such as more efficient management and technological change not directly embodied in capital stocks. However, the traditional approach to measuring MFP excludes the role of natural capital, although the extraction of natural capital constitutes a considerable share of GDP in some countries.

For example, subsoil minerals[1] have played a vital role in the Australian economy, most notably over the last century. They are crucial inputs into the mining sector and are the fourth most significant non-financial asset on the national balance sheet, being around 10 percent of total non-financial assets in 2015-16. The value of the stock of subsoil minerals has tripled from a decade ago, primarily due to the result of the mining boom through the 2000s. In 2015-16, mining represented about 11 percent of Australian GDP in value-added terms (approximately $160 billion). From 1989-90 to 2015-16, the output of the mining sector in current price terms surged by 8.4 percent a year, but in real output terms its growth was more modest (3.0 percent a year).

Based on the Australian Bureau of Statistics (ABS) estimates, the decline in mining MFP in the 2000s was 31 percent. A trend of declining growth in mining MFP is not unique to Australia. According to Bradley and Sharpe (2009), over the period 1989 to 2000, Canada's annual average growth in mining MFP was 1.9 percent a year while the US recorded 0.6 percent. Over the period 2000 to 2007, the corresponding numbers were -1.1 percent a year and -1.7 percent a year respectively. Australia's mining MFP annual growth rate fell from 1.7 percent to -2.0 percent over the two periods.

Given the importance of mining to the Australian economy, and the decline in mining MFP over the 2000s, understanding the role natural capital plays in this story is an important public policy issue. Comprehensive productivity analysis, which includes all three factors (labour and produced and natural capital), provide a more accurate productivity diagnostic and thus new insights into economic growth. The omission of natural capital has been shown in studies by Loughton (2011), Zheng (2009), Topp *et al.* (2008) and Syed *et al.* (2015) to have a substantial

[1] According to the System of National Accounts 2008 (SNA 2008) (para.12.17), subsoil assets are "...those proven subsoil resources of coal, oil and natural gas, metallic minerals or non-metallic minerals that are economically exploitable given current technology and relative prices." In the Australian case, the scope is broader than proven resources since it includes proven and probable resources (ABS, 2015).

influence on the pattern of productivity growth in the mining sector. Part of the reason for this deficiency is because there remain unresolved issues in the measurement of environmental inputs in current environment accounting frameworks (UN 2014).[2] Some statistical agencies, like the ABS, were apprehensive to explicitly included mineral resources in official measures of productivity due to some of the unresolved issues (mainly around ownership principles and recognition of an asset) in the accounting frameworks.[3]

To factor in the depletion or service flows from natural capital for productivity analysis, a user cost (or 'depletion rent') is required to be coherent with the current standard methodology for constructing capital services (OECD 2001). The World Bank (2011)(2018) employed a unit resource rent as the user cost for valuing subsoil assets. Brandt *et al.* (2017) adopted this method as the user cost to construct capital aggregates for various subsoil assets. Diewert and Fox (2016) however, showed this approach to be equivalent to the traditional user cost approach only if expectations formed at the beginning of the period are realised at the end of the period. The authors thus identified some limitations of the Brandt *et al.*/World Bank method. Both approaches will be examined along with the residual approach to estimating the user cost of natural capital recommended by the UN System of Environmental-Economic Accounting.

This paper will use data from the Australian National Accounts to construct MFP estimates for the mining sector that accounts for the 27 subsoil minerals recorded on the national balance sheets. Various measures of natural capital services will also be constructed using different user cost approaches. The paper also documents how the choice of asset inflation rates and rates of return used in the traditional user costs formula can result in different capital services and MFP growth estimates for the mining sector. The comparison of the various user cost approaches reveals the potential disadvantages of each, in particular, their volatility and their tendency to become negative for at least some periods. To the best of my knowledge, a comparison of various user cost methods for natural capital in productivity analysis has not been conducted before.

Thus, the results of this paper will contribute to a better understanding of the choice of user

[2] The initial attempts to integrate environmental and natural resources into the national accounts occurred during in the 1970s and 1980s with early work in the Netherlands (Hueting 1980), France (Commission interministérielle du patrimonies nature, 1986) and Norway (Alfsen *et al.*, 1987). These developments gradually progressed, and in the 1990s, the United Nations Statistical Commission (UNSC) released the 1993 Handbook of National Accounting: Integrated Environmental and Economic Accounting (UN 1993). The System of Environmental-Economic Accounting (SEEA) is the most prominent addition to the national accounting literature on this topic in recent times (UN 2014).

[3] There are estimates of mining productivity that incorporate subsoil mineral assets in ABS (2017) cat. no. 5260.0.55.002, table 24, but these are still labelled experimental and not included in the official set of productivity estimates. The ABS (2013) notes that "to treat the services obtained by miners from mineral and energy resources consistent with the treatment for capital services requires the creation of a non-produced asset owned by miners that is separate from the resources themselves." The SEEA 2012 illustrates some examples recording depletion against the extractor, while in the national accounts it is recorded to the government sector. Thus, the ABS experimental mining productivity estimates adopt the production function approach without satisfying the ownership principle.

cost approaches for valuing natural capital. It also provides countries with different availability of data on natural capital (for example when flows of resource rents are not directly observable or perhaps when the cost of extraction is not robust enough to estimate resource rents reliably) the ability to make an informed decision on the framework suitable to the information set available for that country.

The paper is organised as follows. The next section describes the theoretical model providing the framework to account for natural capital in productivity analysis. Section 3 details the different user cost approaches for constructing a capital services index for natural capital. Section 4 presents the empirical results. The last section concludes the paper. Appendix 1 contains the sensitivity of the natural capital services index and mining MFP growth to assumptions on rates of return and asset price inflation rates in the traditional user cost framework.

2 Accounting for Natural Capital in Productivity Measurement

This section outlines a model of production inclusive of natural capital and uses the framework of Brandt *et al.* (2017). Productivity growth is commonly measured as growth in outputs relative to the growth of factor inputs. Generally, growth in outputs can be attained through either factor accumulation (supplying more inputs) or through increases in the efficiency with which the inputs transformed into outputs. In a measurement framework which includes only a subset of inputs, the term multifactor productivity (MFP) is often used.[4]

To begin, consider a production function that accounts for natural capital that is described by:

$$Y_t = A_t F(K_t, N_t, L_t) \tag{1}$$

where Y_t is the volume of output in period t; F is the production function and A_t is MFP, representing technological change which changes over time.[5] In equation (1), K_t, N_t and L_t denote the volume of produced capital, natural capital and labour input in period t, respectively. Within this framework, natural capital represents a separate input in the production process. The set of inputs is simply extended to include N, the vector of the volume of natural capital inputs, $N = (N_i, ..., N_M)$, used in production. Through the inclusion of N, the contribution of natural capital in production is isolated and treated as a distinct factor of production in the same manner as labour and produced capital.

[4]Although commonly used synonymously, the termed total factor productivity (TFP) should refer to the case where all inputs used in the production process are accounted. Hence here, following the ABS practice, we use the term MFP.

[5]A_t is also known as the Hicks-neutral (or disembodied technological change).

Brandt *et al.* (2017) justify this framework based on the reasoning that it is relatively simple to measure the direct flow of natural capital as the extracted amount of each natural asset. In contrast, the services of produced capital, such as machines and equipment, are more difficult to observe. The service flow of each type of produced asset types is assumed to be proportional to the produced capital stock. Thus, the capital services for all assets is the rate of change of the stock of different asset types weighted by their user cost shares, which aggregate up to the rate of change of the produced capital services measure, K. It is neither practicable nor desirable to combine natural capital, N, into the aggregation of produced capital services, K. Instead, N is introduced as a separate variable.

The estimate of MFP growth extends the ABS index-number method, which is based on Solow's (1956) growth accounting framework, whereby the growth in MFP in period t can be expressed by:

$$MFP_{t,t-1} = \frac{Y_{t,t-1}}{I_{t,t-1}} \tag{2}$$

where $Y_{t,t-1}$ is (one plus) the growth rate of a volume index of output and $I_{t,t-1}$ denotes the growth rate of a combined input volume index of different factor inputs. In this case, the factor inputs comprise produced capital, natural capital and labour. Adopting the ABS approach, the volume of output is measured as real value added using a Laspeyres index.[6]

The rates of change of different inputs have to be weighted appropriately to construct a volume index of combined inputs. Production theory tells us that under some simplifying assumptions, the weights should be factor income (or cost) shares. For every period under consideration, income (or cost) shares are recalculated and combined with the rates of change of factor inputs to obtain an index of combined inputs. Thus, the combined input index $I_{t,t-1}$ is computed as a Törnqvist index as in (3), comprising a volume index of capital input (K_t), a volume index of natural capital input (N_t) and a volume index of labour input (L_t).[7]

$$I_{t,t-1} = (K_{t,t-1})^{\bar{S}_{k,t}} (N_{t,t-1})^{\bar{S}_{n,t}} (L_{t,t-1})^{\bar{S}_{l,t}} \tag{3}$$

The corresponding average two period income (or cost) shares in period t of produced capital, natural capital and labour are $\bar{S}_{k,t}$, $\bar{S}_{n,t}$ and $\bar{S}_{l,t}$ respectively. Thus, to build an aggregate input

[6] A Laspeyres output volume index in MFP estimates is used by the ABS to maintain consistency with the output estimates published in the annual national accounts (ABS, 2015).

[7] The capital services index for produced capital is a Törnqvist index based on weighted changes in productive capital stock estimated using the perpetual inventory model. The capital services index for natural capital is also a Törnqvist index based on weighted changes in natural capital stock using user cost values. The labour input index utilises the hours worked data from the ABS Labour Force Survey, calculated as a simple elemental index.

index requires a price for capital inputs (produced and natural), where the price of capital is the user cost. The user cost estimate multiplied by the stock of capital corresponds to the cost of capital services. The total input costs at time t is thus, defined by the following:

$$X_t = w_t L_t + u_{k,t} K_t + u_{n,t} N_t \tag{4}$$

where $u_{n,t}$ denotes the user cost of using natural capital and the user cost of using produced capital is $u_{k,t}$. Labour costs are denoted by combining w_t, the wage rate and L_t, the hours worked index.

Within the extended framework with natural capital, it is not necessary to hold the typical assumption regarding returns to scale or degree of competitive of markets to derive MFP growth. In this framework, costs are considered to be more significant to account for the costs of services from natural capital. Consequently, the cost shares of other factor inputs, labour and capital, will be scaled down to reflect the increase in total cost.[8] Typically, total costs are considered equal to nominal gross value add (GVA), and the weights of factor inputs are their income shares in GVA. In the extended framework, the input costs X_t do not necessarily equal the value of nominal GVA as there are unmeasured inputs, such as the natural capital stock.

The user cost of capital as measured here is composed of two parts, the user cost of produced capital and the user cost of natural capital: $u'_{k,t} K'_t = u_{k,t} K_t + u_{n,t} N_t = X_t - w_t L_t$. Thus, the factor income shares of produced capital and labour respectively become $S_{k,t} \equiv u_{k,t} K_t / X_t$, and $S_{l,t} \equiv w_t L_t / X_t$. The factor income share of natural capital then is described as $S_{n,t} \equiv u_{n,t} N_t / X_t$. Under this approach, the input costs X_t is taken to be the sum of labour services plus capital services from natural and produced capital. The labour input is based on data from the ABS Labour Force Survey, which is a household survey providing hours worked by industry. Here, the quality unadjusted labour services index from the ABS productivity estimates (ABS 2017b) is used.

2.1 Produced Capital Input

The stock of produced capital is based on ABS estimates of productive capital stock (PKS) using the perpetual inventory method (PIM). The capital inputs are compiled at the asset type level.[9] For each asset type, there is a volume indicator of the flow of capital services and a rental

[8] In Brandt *et al.* (2017), the authors shown that the change between the growth of the traditional input index (comprising labour and capital), and the growth in N, determines whether MFP growth is adjusted upwards or downwards.

[9] The estimates of produced capital from the PIM that are used to derive MFP are based on the following 16 asset types: machinery and equipment: computers and computer peripherals; electronic and electrical machinery and communications equipment; industrial machinery and equipment; road vehicles; other transport equipment;

price that is used to weight the service flow with the service flows of other capital assets. The capital services produced by an asset over its life are assumed to be directly proportional to the productive capital stock of the asset, i.e., $PKS_t - PKS_{t-1}$ is equal to the service flow, which assumes that utilisation rates are constant. Thus, following ABS (2015), the produced capital services input is calculated as follows:

$$K_{t,t-1} = \prod_j \left(\frac{PKS_{j,t}}{PKS_{j,t-1}} \right)^{\bar{s}_{k,j,t}} \tag{5}$$

where the $\bar{s}_{k,j,t} = \left(\frac{u_{j,t} K_{j,t}}{\sum_j u_{j,t} K_{j,t}} \right)$ are shares calculated using user cost weights (u_j) of produced capital asset types.

The traditional user cost of capital in its most basic form is comprised of three components: a rate of return reflecting financing costs, depreciation of the asset, and a capital gain/loss component; see Section 3.2.2 below. Similar to the ABS, the user cost of produced capital includes a corporate income tax component, tax depreciation allowances, investment credits and indirect taxes.

3 Natural Capital Stocks, User costs and Rates of Return

This section specifies the valuation model for natural capital stocks and the three approaches to deriving a user cost for non-renewable natural capital.

3.1 Valuing subsoil minerals stock

Ideally, market prices for assets observed in markets should be used to value all assets. While such prices are available for most financial assets and newly purchased produced assets, many environmental assets are not sold in a marketplace, have not been produced (unlike buildings and equipment) and generally, there are no regularly observable prices for the value of the environmental assets or for the flows between two time periods. In the case of subsoil minerals, mines are not bought and sold on a regular basis to derive a set of acquisition prices. Further, although prices can be found to value the output from extraction, no values for the asset itself, in situ, are available.

and other equipment; non-dwelling construction; ownership transfer costs of non-dwelling construction; intellectual property products: computer software; research and development; mineral and petroleum exploration; and artistic originals (Film and TV; music; and literary); orchards, plantations and vineyards; and livestock. For a full description of the method used to derive the capital stock measures see ABS (2015).

Thus, in the deterministic case, the net present value (NPV) approach is the standard method for pricing capital (Dixit and Pindyck 1994).[10] In the instance of natural capital assets, they may be held in perpetuity and unchanging. As describe in ABS (2015), the NPV is determined as the expected economic benefits that are attributed to a natural asset. Thus, the beginning of the period V_0 is derived as follows:

$$V_0 = \sum_{t=1}^{T} \frac{R_t}{(1+r)^t} \tag{6}$$

where R_t is the resource rent in the year t; the real discount rate[11] (assumed to be a constant 7.5 percent) is denoted by r, and T is the natural resource asset life. Note that, in comparison, the discount rate, which is assumed to be the risk-free rate, applied by the ABS to the value of the produced capital stock is lower, being at 4 percent. The World Bank (2018) also used a 4 percent discount rate.[12] The asset life, denoted by T, is derived from the economic demonstrated resources (EDR)[13] divided by the rate of extraction.

The resource rent, R_t, in the year t is calculated as revenue less production cost (including a 'normal' rate of return on fixed capital) multiplied by the quantity of the resource extracted. As prices of subsoil minerals are volatile, a 5-year moving average of annual prices is used to smooth prices and reduce the volatility in estimates of revenue. An interpretation of this method is that it reflects that mining businesses would take into account longer-term prices when assessing the value of mineral deposits (ABS 2015). Further, the smooth prices result in more plausible net present values. [14]

The derivation of the NPV involves the choice of many factors (mostly on the estimation of the resource rent) like returns on natural capital, estimation of asset life, and the discount rate. The

[10] Provided the right assumptions are made about cash flow, discount rates and the life of the asset, the written-down replacement cost or the discounted value of future returns should yield the same result.

[11] The discount rate includes a premium for mining risks

[12] For coherence with the official valuation estimate of subsoil minerals asset produced by the ABS in the Australian balance sheet, the ABS valuation model is adopted.

[13] In Australia, economic demonstrated resources (EDR) include both measured and indicated resources. Measured resources are those where the volume is computed from detailed sampling so that the geological character of the deposit is well established. Indicated resources are those for which the geological nature is calculated from similar information to that used for measured resources. Subsoil assets are considered to be economical when they have a high geological assurance, and that extraction expects to be profitable at the prevailing price and technology when the assessment was undertaken

[14] Ideally, prices should be the price of the mineral as extracted from a mine site, without further processing. In practice, a range of prices reflecting various degrees of transformation through simple or more complex manufacturing processes is used to compile a resource rent. While some manufacturing processes undertaken at the mine site, such as coal washing or iron ore crushing (to produce fines for export), more elaborate processes such as metal smelting and refining are often undertaken away from the mine site. For example, commodities such as black coal are semi-processed by washing to extract non-coal material before sale. Other mineral products are commonly valued in more elaborately transformed states. Prices for metals such as copper, lead, zinc, nickel and gold are for the refined product and are usually based on London Metal Exchange prices.

extent of choice that feeds into the valuation model highlights that there still exist fundamental measurement issues with the valuation of even basic natural capital.[15] Even progressive statistical offices such as the ABS, do not record the full set of environmental assets within the SNA economic asset boundary in the national balance sheets. The environmental assets on the Australian national balance sheets are land, subsoil assets and native standing timber. Excluded are, for example, water and fish stocks due to difficulties in valuing these assets as well as a lack of available data.

The 27 minerals identified on the national balance sheet are from the Australia's Identified Mineral Resources (AIMR) by Geoscience Australia. Namely: antimony, bauxite, black coal, brown coal, cadmium, cobalt, copper, diamonds, gold, iron ore, lead, lithium, magnesite, minerals sands (ilmenite, rutile and zircon, nickel), petroleum products (crude oil, condensate, natural gas and LPG), platinum, rare earths, silver, tin, uranium and zinc.

3.2 User cost of natural capital

3.2.1 Unit rents approach

For ease of exposition and without loss of generality, let us consider an ore body, following the example of Hotelling (1931). Let V_0 and V_1 denoting the market price of an ore body at the beginning and end of period 1. Also, let P_t denotes the price of one unit of ore at the beginning of period t and S_t is the corresponding stock of the ore body (i.e. units of ore in the ore body) so that for periods $t = 0, 1$, $V_t = P_t S_t$. We see that these V_t values consist of price and quantity components.

If we let R_1 denote the net revenue (sales less extraction costs) during period 1 and assume that expectations about the value of revenues generated by the ore extracted during the first period and expectations about the price at the end of the period are realised then the following relationship should hold:[16]

$$V_0 = (1 + r)^{-1} R_1 + (1 + r)^{-1} V_1 \tag{7}$$

It should be noted that equation (7) is another way of expressing (6) to obtain V_0. Following Brandt *et al.* (2017), the total cash flow, R_1, generated by mining D_1 units of ore during period

[15] In economic theory, treating natural resources as capital goes back over 200 years to classical economists such as Faustmann and Ricardo (Gaffney 2008), with the modern treatment pioneered by Hotelling (1931). Since the 1970s, work by Weitzman (1976), Hartwick (1990), Heal (1998), Arrow *et al.* (2004), Nordhaus (2006) and Arrow *et al.* (2012). Despite this strong theoretical support, the progress by national statistical agencies in measuring quantities of natural stocks and the value of natural capital is still in its infancy and generally, disconnected from valuation approaches for other assets (Schreyer and Obst, 2015).

[16] If the problems associated with including sunk cost assets are ignored (see Diewert and Fox, 2016)

1 is defined as $(p_1 \cdot \alpha - w_1 \cdot \beta)D_1 = u_1 D_1$ where α is a positive vector of ore final products, p_1 is the period 1 market output price vector, 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. Thus $u_1 \equiv p_1 \cdot \alpha - w_1 \cdot \beta > 0$ is the 'unit rent user cost' of mining one unit of the ore body during period 1. Then, following Hicks (1939) and Diewert (1975), the end of period user cost value, UCV_1, could then be expressed as in equation (8).

$$UCV_1 \equiv V_0(1+r) - V_1 = R_1 = u_1 D_1 = u_1(S_0 - S_1) \tag{8}$$

Brandt *et al.* (2017) directly estimated the resource rent of natural capital using average extraction costs across countries.[17] In this case, the net revenues from the physical extraction of a subsoil asset are the unit user cost of the natural capital for each period. As a result, the unit resource rent reflects purely the value of a subsoil mineral resource arising from the quality of deposits and scarcity. Similar studies have used the Brandt *et al.* (2017) method due to the lack of better available data. In this method, the unit rent, which is the market price net of extraction costs, is taken as the user cost of capital based on the assumption of inter-temporarily optimal depletion of natural capital.

3.2.2 Traditional user cost of capital

Diewert and Fox (2016) derived the user cost of natural capital using a simple discrete time derivation, which presented an alternative to the unit rents methodology. They showed that only when the assumption that expectations formed at the beginning of the period are realised at the end of the period, the traditional user cost of capital is equal to the unit rents approached as expressed in equation (8). To illustrate, from equation (8), the user cost, u_1, can be derived as $\frac{R_1}{S_0 - S_1}$. Then let the period 1 expected inflation rate for the price of a unit of ore body is defined as $1 + i \equiv \frac{P_1}{P_0}$ and the period 1 depletion rate as $\delta \equiv 1 - \frac{S_1}{S_0}$. By substituting these definitions in (8), yields the following user cost value in (9) where $P_0[r - i + (1+i)\delta]$ is the traditional user cost of capital, except δ is the depletion rate rather than the usual 'wear and tear' depreciation rate.

$$UCV_1 \equiv P_0 S_0(1+r) - P_1 S_1 = P_0 S_0(1+r) - P_0(1+i)(1-\delta)S_0 = P_0[r - i + (1+i)\delta]S_0 \tag{9}$$

Consider the last equation in (9). Upon noting that capital gains, τ, is represented by $P_0 S_0 \Delta i$,

[17] The marginal extraction costs would be the relevant measure for unit rents however these are not readily available. Hence, the user cost of natural capital equals the marginal resource rent, i.e. the market price net of marginal extraction cost. The measure of unit rents approximates marginal with average extraction costs.

equation (9) can be rewritten as $P_0[r + \delta - \Delta i]S_0$.

Thus, the unit rent approach is only valid if expectations about V_1 and R_1 formed at the beginning of the period are realised at the end of the period. One would expect that it is improbable that this assumption will hold, because investment decisions are based on an expected rate of return on assets covering some years, and should not be influenced by one-off events in a particular year. As Diewert (2001) observes the assumption that "anticipated price changes are equal to actual ex-post price changes is very unsatisfactory since it is unlikely that producers could anticipate all of the random noise that seems to be inherent in series of actual ex-post asset price changes" (p. 72). As the traditional user cost approach does not require this assumption to hold, it would suggest that the traditional user cost approach is a more reasonable way of valuing non-renewable natural capital for productivity.

Another benefit of the traditional user cost approach to estimate natural capital services is that it follows the same method typically used for the estimates of produced capital services. It presents a nice symmetry in the sense that it demonstrates that under certain assumptions, the measurement of natural capital can be done in the same manner as for produced capital. However, the traditional user cost approach in this context exhibits the same challenges as those faced when determining the user cost of produced capital, that is how to form the expected values for δ and i. There are difficulties in deciding how to estimate these parameters in an unambiguous manner and the user cost estimates may be sensitive to the choice of model, even becoming negative.

The choice of asset prices is another component of the user cost that is subjective. Generally, the ex-post constant quality asset specific price changes are used in estimating holding gains, but in some cases, this has led to negative rental prices due to volatile fluctuations in subsoil minerals. As well, there is the problem of market bubbles in commodity prices during mining booms. The use of the CPI was the solution to market bubbles suggested by the OECD (2009) with the idea that a general measure of inflation helps keep real purchasing power neutral. This solution may be equally applicable to mineral resources given speculative bubbles during the mining boom make the ex-post user cost model impractical.[18] However, the assumption that mining businesses base their expectations of holding gains on movements in the CPI is largely unsupported in literature.

The ABS applies a combination of endogenous (ex-post) and exogenous (ex-ante) rates of return in their official productivity estimates. They use the endogenous rate but set an exogenous 'floor' to this rate, which is at 4 percent plus the Consumer Price Index (CPI) (ABS 2015). This

[18] There would be some assets, such as computers, where expectations of price change would likely be different to the general level of inflation, and different asset prices may be required.

approach prevents the nominal rate of return from becoming negative when income is low in certain years (hence avoiding the occurrence of many negative user costs) while preserving the industry-specific rates of return that come from solving the nominal rate of return endogenously.[19] In the case where a 'pure' endogenous rate of return is used (with no floor), the income share of capital inputs is attributed to income (or cost) of produced capital, and hence, there is no allowance of the income share to attribute to unmeasured inputs.

Thus, to provide a share of the income to natural capital, the rates of return of produced capital need to be exogenous to the mining sector. One interpretation that fits this framework is that the difference between the calculated capital services and capital income, defined in the national accounts as gross operating surplus (GOS), that may be attributed to returns to other assets such as natural capital or intangibles. These missing assets would contribute to GOS used to derive endogenous rates of return. Another factor to consider is that GOS is an ex-post measure of the return to capital. To the extent that expected and realised returns differ, inconsistencies in average rates of return will exist. Here, the exogenous rate of return selected is the Reserve Bank of Australia (RBA) cash rate. In choosing the exogenous rate of return, several factors were taken into account. First, using an exogenous rate of return may lead to volatility in the user costs, and, sometimes, negative user costs. Second, deriving a variable rate from financial market data that corresponds with longer-run expectations is difficult, because short-run financial market fluctuations may not necessarily reflect long-run expectations. The RBA cash rate compared to the RBA business loan rate proved to be less volatile over the long run.

3.2.3 Residual Value Method

The SEEA (UN 2014) provides three alternate methods to estimating resource rent.[20] It states, "...resource rent and the net return to environmental assets can be derived from the national accounts framework through a focus on the operating surplus of extracting enterprises. In this context, the operating surplus earned by an enterprise is considered to comprise a return for the investment in produced assets and return on the environmental assets used in production" (para. 5.117).

[19] An advantage of this approach is that the exogenous floor retains the long-term ex-ante nature of investment decision-making and enables higher rates of return to manifest where there are missing assets. A disadvantage of this approach is that it is not symmetric (i.e. it imposes a floor to the rate of return, but does not impose a corresponding 'ceiling').

[20] The three main approaches to estimating resource rent described in the SEEA (2014, para 5.121 - 5.131) comprise the residual value method, the appropriate method and the access price method. As the country's institutional arrangements profoundly influence both the appropriation and access price method, the residual approach is the recommended way for estimating resource rent.

Under the residual value approach, the approach recommended by SEEA, the resource rent is estimated by taking the produced capital services from gross operating surplus (GOS) after any adjustment for taxes and subsidies. One could do this by splitting GOS into returns on produced capital and returns on natural capital. This approach has been discussed in Coremberg (2004), OCED (2009) and subsequently applied by Adams and Wang (2016) to the Canadian estimates of productivity of the mining and oil and gas sector. In comparing the unit rent and the residual value approaches, one could consider the unit rent method as a direct measure of the resource rent, while the residual approach is an indirect measure which could be applied when the resource rent could not be directly derived. Thus, similar to the unit rent method, the user cost of produced capital is estimated using an exogenous rate of return to the mining sector. In this case, as resource rent is derived residually using the GOS as obtained in the national accounts, the income share of labour does not change. This method merely partitions an amount of GOS, which in traditional measures of MFP is allocated entirely to produced capital, to natural capital.[21]

3.2.4 Rates of Return

In the literature, there are various methods for selecting the cost of capital that has been suggested; however, they can be categorised into two groups. Those that choose exogenous estimates and those that choose endogenously derived rates of return which will make the value of inputs used during the period (including capital services) equal to the value of outputs produced during the same period.

Most commonly, exogenous rates of return that are selected are government bond interest rates. Using an exogenous rate may lead to a difference between the calculated capital rent and capital income. Capital income differs from capital rent as capital income is the sum of gross operating surplus (GOS) and the proportion of return on the owner's capital in mixed gross income. The exogenous approach could be considered an ex-ante approach to calculating the rate of return because it is the expected return on an investment decision. The ex-ante approach could give rise to negative rental prices when there are significant changes in capital gains and losses. For estimating capital services indexes, because rental prices are used to form weights, negative weights will cause problems in creating an aggregate index.

[21] One difficulty that is worth noting in estimating resource rents using this method is that the measure of GOS for the mining sector as captured by the Australian national accounts will include some downstream processing, refinement and other value-added activity undertaken by this sector. Allocating a firm's GOS to pure extraction or harvesting activity of a single mineral resource is not always straightforward. Additional complexity is that in certain circumstances, multiple mineral resources may be extracted at the same time.

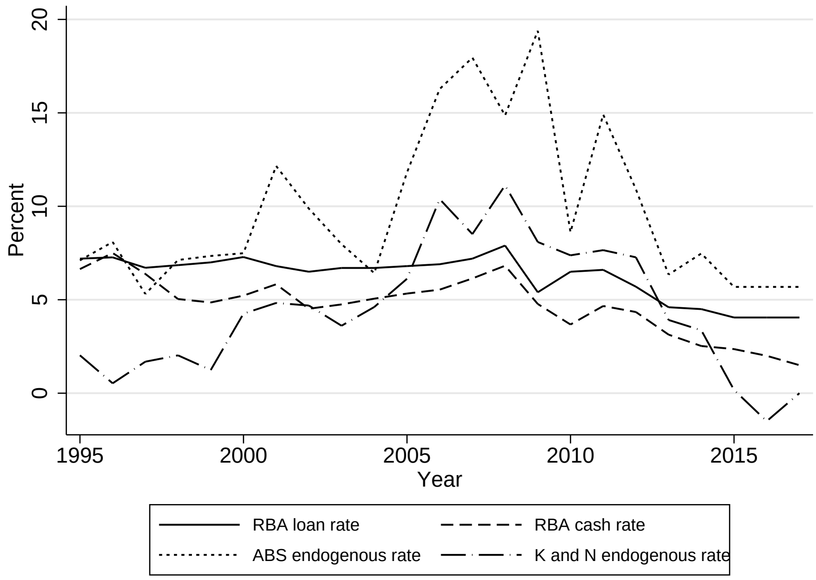
The second way of calculating rates of return is by using an endogenous rate of return which is represented by the internal rate of return for the industry. Using an endogenous rate of return to calculate user costs of capital imposes some implicit assumptions, namely that the underlying production function exhibits constant returns to scale, that markets are competitive and that the expected return is the same as the realised return (OECD 2001). The endogenous rate is thereby equating all non-labour income to capital services (produced and natural) and solving for the rate of return (Hall and Jorgenson 1967). An endogenous approach is an ex-post rate of return as it takes rates of return after the results of the investment decision are known. An issue with using an endogenous rate of return is that when capital income is small, the associated internal rate of return will also be small.

There are criticisms about the endogenous approach to determining the nominal rate of return. Firstly, this approach assumes that all of the GOS (after deducting labour income) is attributable to the observed capital in the scope of the productivity analysis. Schreyer (2004) observes that "there are many good reasons to argue that such assets [intangibles] account for at least part of GOS." While this may appear a minor point, it puts in question an assumption routinely made by analysts of productivity and growth, namely that GOS exactly represents the remuneration of the fixed assets recognised in the System of National Accounts (SNA), or the value of these services of these assets. Thus, capital assets that could be included are natural resources. Further, if an endogenous rate is computed based on only fixed assets currently measured in the national accounts, "but if there are other, unmeasured assets that provide capital services, the resulting rate may be liable to bias." (OECD 2009, p. 68)

Figure 1 shows the various rates of return over the period 1995-96 to 2015-16. It is noticeable from the figure that the average exogenous and endogenous rates of return can differ quite substantially over time.[22] A consequence of using an endogenously-determined rate of return can be that industry rates of return can appear economically implausible. As with the endogenous approach, there are some practical issues associated with using an ex-ante or exogenous rate of return. The choice about what the exogenous rate of return should be is difficult. Most importantly, regardless of which rate of return was applied, there can be economically meaningless

[22] The endogenous approach assumes that there is perfect competition and that capital and rental markets are clearing such that the marginal cost of the assets is equal to their marginal product and revenue. Schreyer (2004) provides examples where mark-ups (i.e. the extent to that an endogenous rate of return would exceed an exogenous rate) could exist. It is assumed that in the long run, mark-ups would be positive since a negative term over an extended period would imply sustained losses, which is economically implausible. Cases that could lead to positive mark-ups include where output markets are not sufficiently competitive, so that monopoly rents exist; under Schumpeterian growth patterns where mark-ups constitute the incentives for entrepreneurial activity; within industries where long gestation periods of investment are prevalent and where there is time-varying capacity utilisation. These cases are very prevalent in the mining sector, where usually significant capital investment occurs before full capacity utilisation is possible.

Figure 1: Rates of Return



Source: RBA loan rate and cash rate are from Reserve Bank of Australia, Statistical Table F5 Indicator Lending Rates, http://www.rba.gov.au/statistics/tables/ and author's estimates. The 'K and N endogenous rate' refers to the endogenous rates of return that includes both produced and natural capital derived by the author from unpublished ABS national accounts data.

negative user costs due to the expected nominal return plus depreciation being lower than the expected nominal asset inflation rate in some years.

Economic theory suggests that rental prices should be positive over the long term.[23] Thus, following the ABS method to resolve this issue, any negative user costs are set to a tiny positive number (0.001). By adjusting the negative rental prices in this way, the capital stock weights for that asset return to positive values and consequently, it changes the weights of the remaining assets.[24]

[23] The user cost of capital is used to weight together with the respective volumes of capital services provided by the stocks of capital extant within each industry. It can be interpreted as the marginal cost of the capital services being provided and hence, negative user costs are economically implausible. As the user cost weights represent the underlying production function, we would not expect these weights to display significant fluctuations in short to medium term. In the absence of fundamental changes to the production function, the asset capital services weight would be expected to remain relatively stable over the short to medium term.

[24] Another approach suggested by Oulton (2007) is where an ex-post, endogenous rate is initially computed, and then the ex-ante rate is selected as the trend of the ex-post rate of return. This method avoids the problem of choosing an exogenous rate of return while preserving the ex-ante nature of the calculation (OECD 2009). An advantage of a hybrid approach is that it allows for an empirically derived industry-specific rate of return which could reflect (among other things): missing assets from the capital services model (such as land, research and development, and other intellectual property assets).

3.2.5 Choice of user cost models

The formula for the traditional user cost was obtained by Christensen and Jorgenson (1969) for the geometric model of depreciation. It plays a fundamental role in the Diewert and Fox (2018) user cost of natural capital approach. There are two variants of the user cost formula. An ex-post version that uses the actual beginning and end of period constant quality asset prices and an ex-ante version, that uses the actual beginning of period constant quality asset price, and an anticipated price for the asset at the end of the period.

Jorgenson (1995) has endorsed the use of ex-post inflation rates implying that producers can perfectly anticipate future asset prices. On the other hand, Diewert (1980) (2005) and Hill and Hill (2003) endorsed the ex-ante version for most purposes, since these ex-ante user costs will tend to be smoother than their ex-post counterparts and they will generally be closer to a rental or leasing price for the asset.

As discussed in the previous section, there are also issues surrounding the choice for the financing (opportunity) cost of capital (produced or natural) in the user cost formula. Given the possible choices of the models, this study selected four traditional user cost of capital models for comparison against the resource rent and the residual method. Initially, sixteen models were tested for the sensitivity of choice of asset prices and the financing cost of capital on capital services aggregates and the resulting rates of MFP growth. These models are shown in Table A1 in the Appendix, together with the results of the sensitivity analysis.

The four models presented in the main text are as follows:

1. "Exogenous", due to the use exogenous estimates for the financing cost of capital.

2. "Jorgenson", due to the use of ex-post inflation rates in a user cost formula, which has been advocated by Dale Jorgenson (1995) and his coworkers.

3. "Diewert and Fox", as this model makes use of predicted asset inflation rates in the user cost formula as advocated by Diewert and Fox (2018) to smoothed user costs. They suggest a straightforward geometric moving average method for forming these predicted asset inflation rates.

4. "No capital gains", as this model follows MacGibbon (2013) where capital gains, τ, are excluded from the user cost of capital formula. The author found that this method provides more plausible asset-weights which display markedly less volatility.

4 Results

This section presents estimates of capital services growth and MFP growth that includes natural capital for the Australian mining sector. First are the estimates of the changes in the stock for a selection of subsoil mineral resources. The volume growth estimates of subsoil mineral stock are then aggregated across different types of resources to derive an aggregate index for the total natural capital stock. Lastly, it discusses the contribution of the natural capital to output growth and its effect on MFP growth in the mining sector and the market sector.

4.1 Natural Capital Stock and Natural Capital Services

Australia has a comprehensive set of data on subsoil minerals compared to most countries. In what follow, these data are used to explore the user cost patterns of selected subsoil minerals under the various user cost models. The first column of plots in Figure 2 presents the changes in the estimated value of subsoil mineral reserves with price and the resource rent from the extraction of iron ore, black coal and crude oil between 1989-90 to 2015-16.

Since the early 2000s, a structural shift has occurred in the Australian mining sector as prices for essential subsoil minerals resource exports rose significantly in line with a rise in demand in emerging economies. The higher resource prices created substantial rents for companies with existing mines (Grafton 2012). In response, the value of subsoil minerals resources rose until 2011, increasing fourfold compared to 1989-90. The rise in the value of subsoil minerals might not be intuitive since extraction depletes these stocks. However, subsoil minerals have only become productive assets and are included in the balance sheet when they are economically proven and probable, that is, discovered and profitable to extract at a given price and available technology. The result for Australia is similar to that globally. The World Bank (2018) found that the value of natural capital assets doubled in the decade between 1995 and 2014. The majority of the growth was in non-renewable assets (308 percent), mostly because of changes in both volume and prices.

The patterns of the resource rent and the subsoil minerals stock are quite close to each other. Both stayed low and stagnant before 2005-06 and then grew sharply after that. Over the whole period, the implicit price of the subsoil mineral resources has increased by over five times, especially during the periods from 2005-06 to 2012-13. During this period of steady price increases, discoveries also increased by around three times. Interestingly, depletion of subsoil minerals reserve remained relatively constant, except the period from 2010-11 and 2013-14. The resource rent is mostly positive; however, it does go negative in some periods for some types of subsoil minerals. Net depletion (discoveries - extraction) was positive in most years.

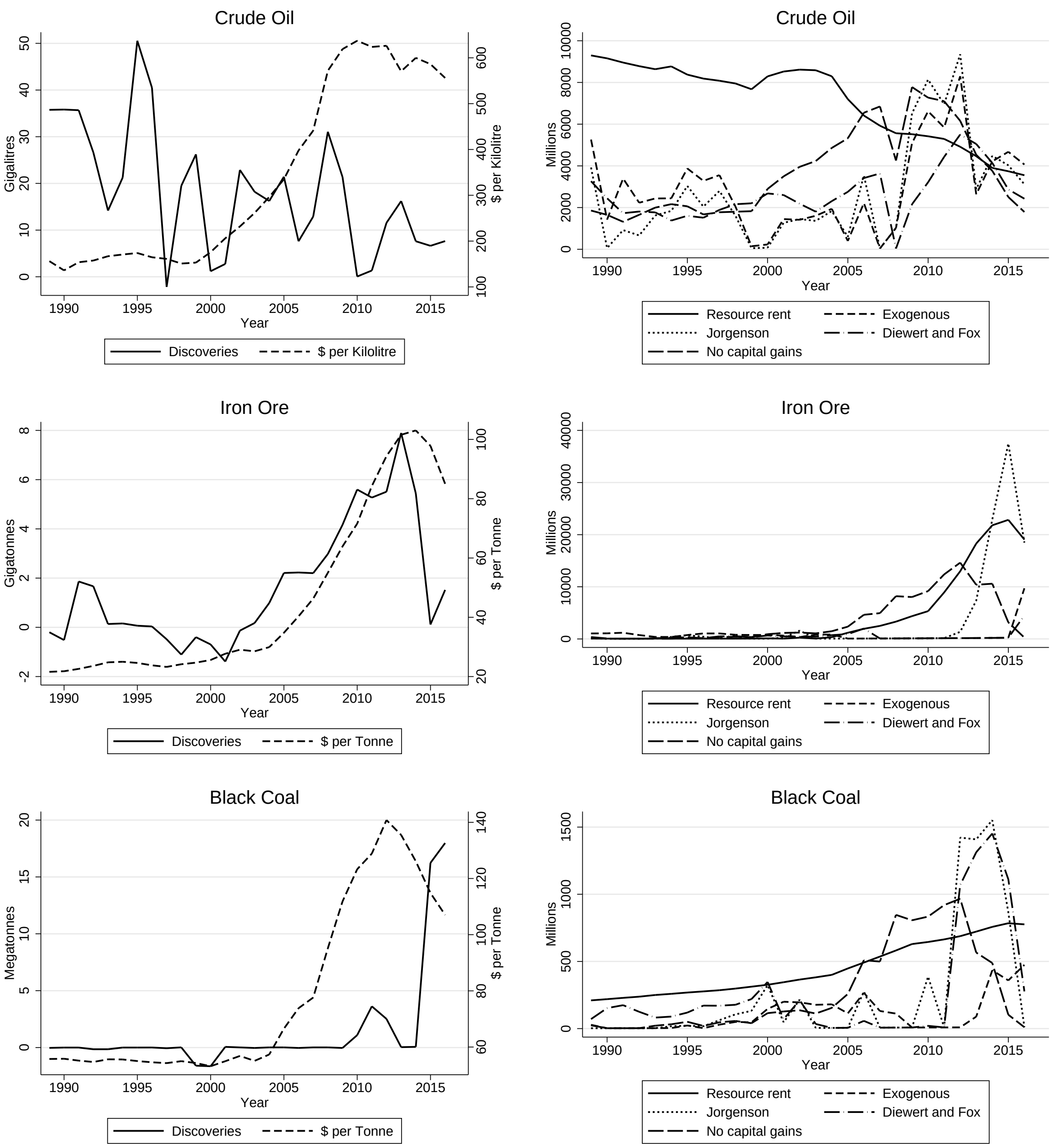


Figure 2: Trends in Australian Subsoil Minerals Resources, 1989-99 to 2015-16

Source: Author's calculation using ABS data.
The figures on the right hand side compares the users cost of selected subsoil minerals under the resource rent approach and four traditional user cost approach models. The residual method is not included because its natural capital services is not estimated for each subsoil mineral.

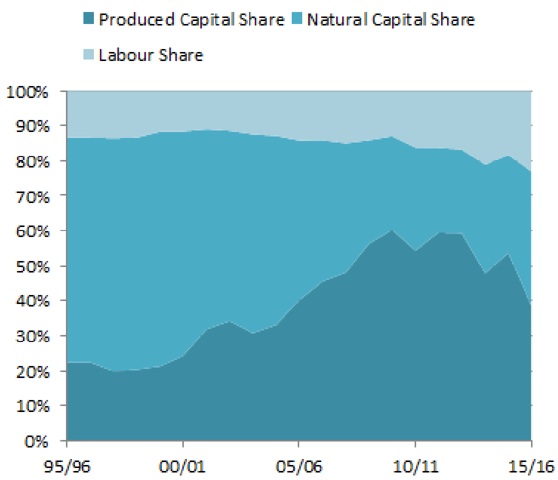
In determining the best user costs of natural capital that result from the models tested, the question arises about how to choose which user costs provide the 'best' natural capital services weights? This question is not simple to answer, as the user cost of capital is an implicitly derived approximation to something that is (at least in general) not observable. Any assessment of the fitness for the user cost series will lead to a combination of assessments against a range of criteria such as conceptual coherency combined with an evaluation of a variety of observable characteristics. Parameters that can be used to assess (but not necessarily determine) the quality of the user costs include: the user costs themselves and the industry nominal rates of return, together with the asset capital services weights that result.

The study shows that for many subsoil minerals, Jorgenson user costs can be negative at times and quite volatile which means that they are not suitable in many contexts. Diewert and Fox predicted user costs are much less volatile, however still negative at times. Somewhat surprisingly, there was little difference in the resulting tread measures of mining MFP growth, even though there are substantial differences in the two sets of user costs. Diewert and Fox (2016b) also found this result in their study on what can occur to user costs when ex-post asset inflation rates are used in the user cost formula, for two major sectors of the US economy. They found that the predicted and Jorgenson user costs can give rise to rates of capital services and Total Factor Productivity growth that are very close to each other. Regardless of which model, none completely resolve the issue of negative rental prices for some subsoil minerals resource in some periods. Interestingly, while there are observed differences in growth rates for capital services, none changed the underlying growth patterns. The model that excluded capital gains produced the most smoothed user costs.

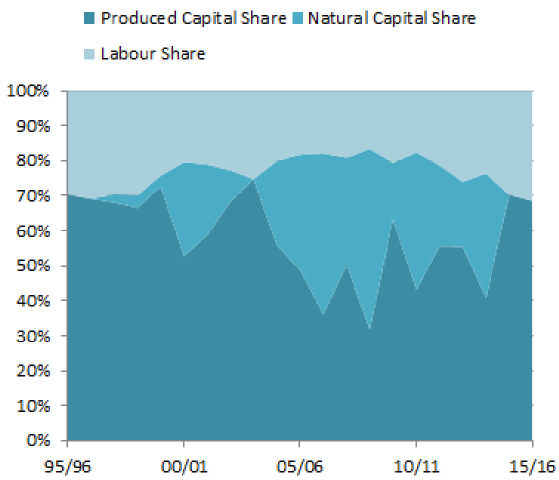
4.2 Factor Cost shares

Figure 3 reports results from estimating the cost shares using the different user cost approaches. The user cost approach applied has influenced the cost shares allocated to produced capital, natural capital and labour. Some substantial differences in the detail of the pattern of the allocation between produced and natural capital are most noticeable between the residual method and the resource rent approach. Note that the natural capital share in the residual method often sits at zero, due to GOS being exhausted in that period fully by produced capital. Interestingly, the cost shares of the factor inputs of the different traditional user costs methods maintain a similar profile.

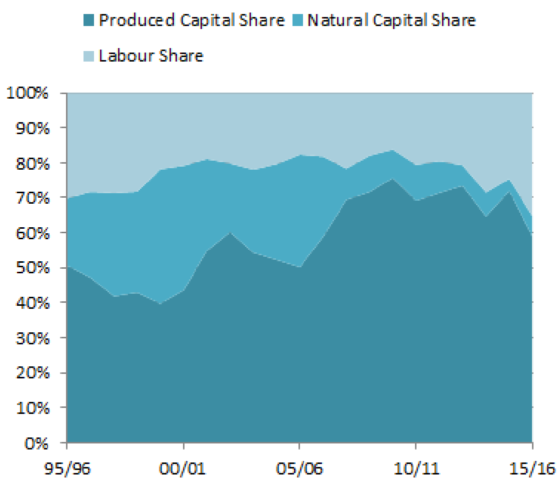
Figure 3: Capital Shares



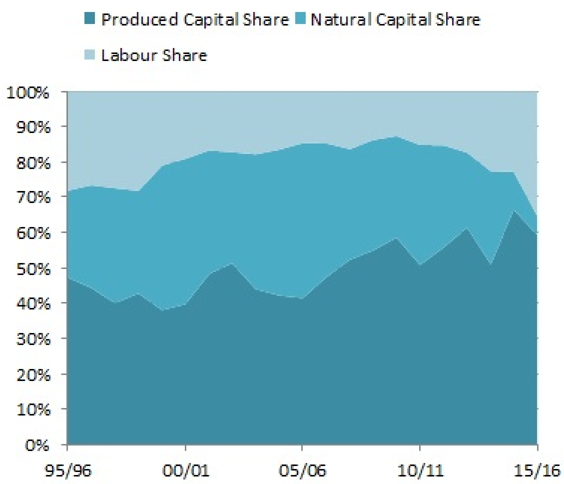
(a) Resource Rent



(b) Residual Method



(c) Diewert and Fox



(d) No Capital Gains

The price index for capital services from subsoil minerals is volatile, particularly for from the 2000s onward. These subsoil minerals rental prices have significant implications for the cost share of subsoil minerals including some negative values for at least some periods.[25]

4.3 Mining Capital Services and Multifactor Productivity

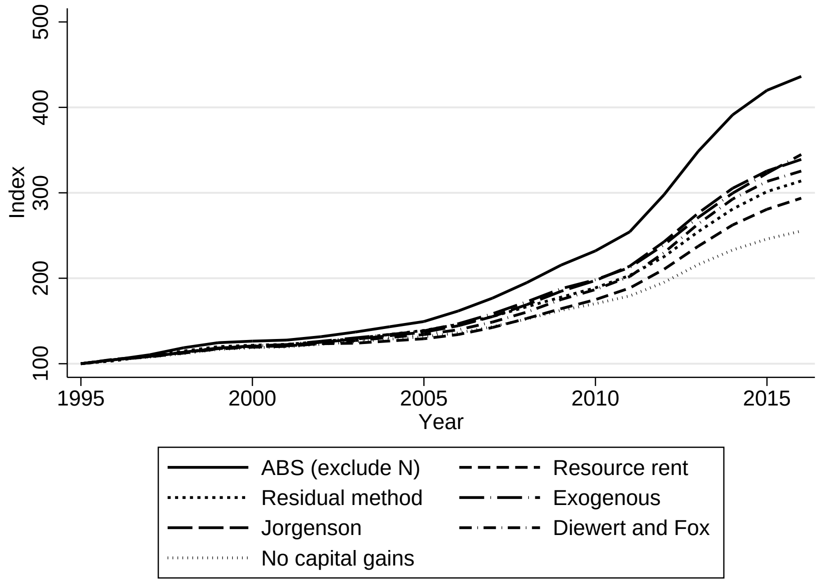
Drivers of MFP are typically things that generate more significant efficiency in input use, such as capacity utilisation, technological change, economies of scale, and changes in the quality of inputs (BREE 2013). Productivity in the Australian mining sector is analysed annually by the ABS. The most recent estimates published by the ABS (2017b) suggest that MFP in the mining sector has declined significantly in past years. As the mining sector makes up around 8 percent of gross value added of the market sector, the decline in mining MFP contributed substantially to a slowdown in productivity growth for the market sector as a whole.

The characteristics of the mining sector mean that traditional measures of productivity warrant careful interpretation. As mining activity is heavily reliant on the availability and quality of the natural capital stock, ignoring the role of natural capital may bias estimates of productivity. For example, when ore grades decline as deposits depletes more inputs are needed to produce a unit of saleable output causing the measured productivity of mining falls. Panel (a) of Figure 4 charts the latest ABS capital services index and the adjusted capital services index that accounted for natural capital. The upward trend in the capital services indexes that include natural capital is very noticeable.

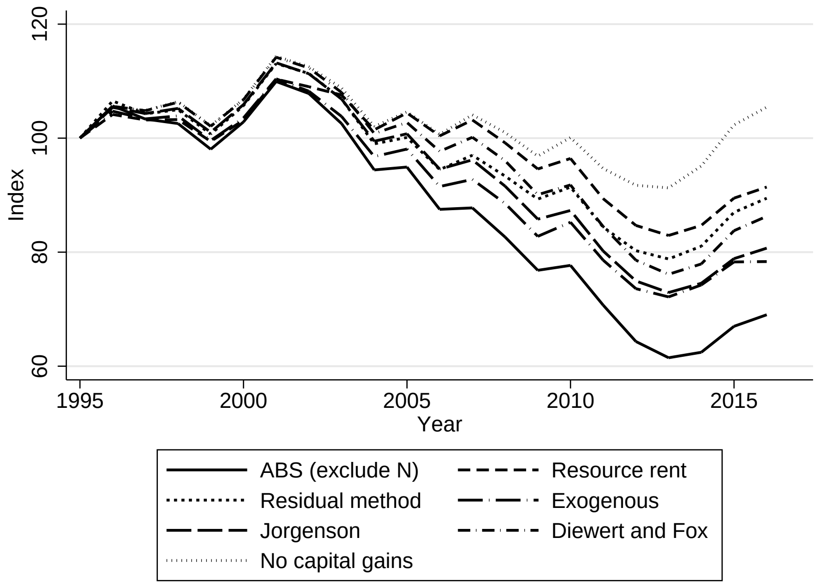
Panel (b) of Figure 4 plots the various mining MFP estimates that includes natural capital against the ABS unadjusted mining MFP estimate. It can be seen that the change to MFP that includes natural capital is positive. Australia experienced a substantial increase in minerals production mainly to iron ore, oil and gas production. Contrary to what one might reasonably assume, it is not the case that MFP growth is an overestimated of productivity growth during a mining resources boom. During the resource boom in Australia, we observed not only natural capital growth but other factor inputs too. Often, a resource boom comes hand in hand with an investment boom, originating from the mining industry, but will spill over into other sectors of the economy. As can seen, even though subsoil minerals grow very fast during the resource boom, other inputs grow even faster, and MFP that includes natural capital of the mining sector is adjusted upwards. From 2004-05 onward, the growth contribution of natural capital was

[25] Alston (2018) made a similar observation regarding the United States Department of Agriculture - Economic Research Service (USDA-ERS) price index for services from land. He noted the volatility of the index was remarkable. The land rental price fluctuations have significant (and perhaps implausible) implications for both the predicted and observed cost share of land.

Figure 4: Mining Capital Services and Multifactor Productivity



(a) Mining Capital Services



(b) Mining MFP

Table 1: Mining MFP Growth Decomposition

Average Growth Rates in Percent						
Resource Rent						
Period	Output Growth	Produced Capital	Natural Capital	Labour Input	MFP Growth	Adjust. Effect*
1989/90 - 1995/96	5.40	1.94	1.29	-0.07	2.25	-1.47
1996/97 - 2000/01	3.50	1.77	0.79	-0.04	0.95	0.06
2001/02 - 2005-06	1.04	2.28	0.01	1.66	-2.92	1.48
2006/07 - 2010/11	4.89	4.03	0.55	1.91	-1.60	2.49
2011/12 - 2015/16	7.84	4.83	1.39	0.29	1.39	1.70
1989/90 - 2015/16	4.60	2.89	0.84	0.69	0.18	0.68
Residual Method						
Period	Output Growth	Produced Capital	Natural Capital	Labour Input	MFP Growth	Adjust. Effect
1989/90 - 1995/96	5.40	1.82	1.40	-0.12	2.23	-1.50
1996/97 - 2000/01	3.50	1.55	0.84	-0.04	1.02	0.13
2001/02 - 2005-06	1.04	2.66	0.39	1.95	-3.93	0.48
2006/07 - 2010/11	4.89	4.95	0.01	2.31	-2.55	1.54
2011/12 - 2015/16	7.84	4.57	1.55	0.33	1.60	1.91
1989/90 - 2015/16	4.60	3.02	0.88	0.81	-0.14	0.36
Traditional User Costs - Exogenous						
Period	Output Growth	Produced Capital	Natural Capital	Labour Input	MFP Growth	Adjust. Effect
1989/90 - 1995/96	5.40	1.31	1.52	-0.47	2.90	-0.82
1996/97 - 2000/01	3.50	1.32	0.77	-0.07	1.34	0.46
2001/02 - 2005-06	1.04	2.57	0.42	1.91	-3.85	0.56
2006/07 - 2010/11	4.89	5.39	0.08	1.60	-2.36	1.73
2011/12 - 2015/16	7.84	5.20	1.53	0.21	1.10	1.41
1989/90 - 2015/16	4.60	3.02	0.91	0.56	0.05	0.56
Traditional User Costs - Jorgenson						
Period	Output Growth	Produced Capital	Natural Capital	Labour Input	MFP Growth	Adjust. Effect
1989/90 - 1995/96	5.40	1.27	1.83	-0.33	2.50	-1.23
1996/97 - 2000/01	3.50	1.53	0.55	-0.06	1.48	0.60
2001/02 - 2005-06	1.04	2.37	0.18	1.79	-3.29	1.11
2006/07 - 2010/11	4.89	4.97	-0.27	1.56	-1.28	2.81
2011/12 - 2015/16	7.84	7.06	-0.01	0.23	0.70	1.01
1989/90 - 2015/16	4.60	3.28	0.56	0.57	0.20	0.71

Table 1: Mining MFP Growth Decomposition

Average Growth Rates in Percent						
Traditional User Costs - Diewert and Fox						
Period	Output Growth	Produced Capital	Natural Capital	Labour Input	MFP Growth	Adjust. Effect
1989/90 - 1995/96	5.40	1.94	1.29	-0.07	2.25	-1.47
1996/97 - 2000/01	3.50	1.77	0.79	-0.04	0.95	0.06
2001/02 - 2005-06	1.04	2.28	0.01	1.66	-2.92	1.48
2006/07 - 2010/11	4.89	4.03	0.55	1.91	-1.60	2.49
2011/12 - 2015/16	7.84	4.83	1.39	0.29	1.39	1.70
1989/90 - 2015/16	4.60	2.89	0.84	0.69	0.18	0.68
Traditional User Costs - No Capital Gains						
Period	Output Growth	Produced Capital	Natural Capital	Labour Input	MFP Growth	Adjust. Effect
1989/90 - 1995/96	5.40	1.34	1.88	-0.29	2.52	-1.20
1996/97 - 2000/01	3.50	1.39	0.72	-0.06	1.46	0.58
2001/02 - 2005-06	1.04	2.03	-0.10	1.51	-2.42	1.98
2006/07 - 2010/11	4.89	4.24	0.63	1.32	-1.25	2.84
2011/12 - 2015/16	7.84	5.74	0.76	0.12	1.31	1.63
1989/90 - 2015/16	4.60	2.83	0.86	0.46	0.49	0.99

* Ajust. Effect indicates to the percentage points in growth difference between the mining sector MFP adjusted for natural capital compared to ABS MFP measure.

relatively significant in Australia. After that it stagnant, as commodity prices started to fall.

Table 1 compares the estimates of MFP growth for the mining sector with and without natural capital. This growth accounting technique examines how much of an observed rate of change of an industry's output can be explained by the rate of change of combined inputs. Thus, the growth accounting approach evaluates MFP growth as a residual, and the impact of adding natural capital, as an input into production on MFP growth, relies on the relative growth of produced and natural capital.

In this framework, adding natural capital has no impact on output (value-added) growth. However, the income share is scaled down and, thus, the contribution of labour and produced capital inputs to productivity. Growth accounting with natural capital is also useful in the study of the changing contribution of natural capital in times of resource abundance and scarcity. It raises MFP growth when the natural capital growth is slower than that for produced capital and vice versa.

Looking at the averages over selected periods, the inclusion of natural resources as a factor of production increases the estimated rate of MFP growth in all periods except from 1998-90 to 1995-96 for all the different user cost of natural capital approaches. In general, the inclusion of natural resources results in moderate increases in the measured growth rate of MFP for the mining sector. On average over 1989-90 to 2015-16, the growth rate of natural capital was between 0.5 percent to 0.9 percent, while the growth rate of produced capital was between 2.9 percent to 3.3 percent. The contribution of natural capital input to the value-added industry growth is higher under the resource rent (1.8 percent) compared to the residual method (0.9 percent) and the traditional user cost method (0.6 to 0.9 percent). The result is not surprising as the income share of natural capital under the resource rents method (as shown in figure 3) is the largest compared to the other user costs approaches. The result is that MFP growth excluding natural capital over the 27 years, is significantly lower than the MFP growth including natural resource by at least 0.4 percent lower per year.

5 Conclusion

This paper uses privileged access to Australian data to compare methods for modelling natural capital as a capital input into the production process. It provides a better understanding of the contribution of natural capital to economic growth and the impact of adding natural capital on productivity measurement. This paper examines different user cost approaches to account for capital services that include natural capital into traditional measures of productivity growth. It shows that different user cost approaches impact on the natural capital MFP profile. While, in theory, all of the different user cost of capital methods can generate the same estimates, it is the case that the choice of the method more profoundly influenced the outcome of the traditional user cost method. In contrast, the choice of method for calculating a resource rent, whether via the unit rents approach or using the residual approach, the major influencing factor is the choice of the exogenous rate used in the user cost of produced capital. The exogenous rate, very much, determines the cost factor share attributed to produced capital and natural capital.

The results suggest a significant contribution of natural capital to the real value-added economic growth in the Australian mining industry. The inclusion of natural capital generated substantial productivity gains for the mining sector. However, the impact of adding natural capital does change over time. For the mining sector, in general, except the period 1998-90 to 1995-96, natural capital growth positively and significantly contributed to MFP growth. Overall, natural capital is adding at least 0.4 percent growth on average to annual productivity growth between 1989-90 to 2015-16. The results establish that natural capital considerably contributed to the productivity performance in the mining sector.

The size and direction of the adjustment to productivity growth largely depends on the rate of change of natural capital relative to the rate of change or produced capital and labour. We see that failing to account for natural capital has led to an underestimation of productivity during the mining boom when produced capital is growing even faster than the natural capital. However, recognising natural resources as a factor of production does not explain the entire decline in MFP as other factors such as lags associated with investment in new infrastructure will likely have also contributed to the decline.

The results presented here confirm that overall the preferred option is the Diewert and Fox user cost approach and the most influencing adjustment to the traditional mining MFP is to include subsoil minerals. That is, whether subsoil minerals resources are included or not in the productivity of the mining sector matters. It probably does not get enough attention from national statistical agencies, most likely because accounting for the contribution of natural capital to economic growth is associated with significant uncertainties like lack appropriate data, difficulties in setting the price and accounting for quality change. Work remains to be done to resolve the debate over how best to measure the price and quantity of natural capital. However, it is hoped that this paper significantly advanced understanding through demonstrating the importance of accounting for natural capital, and settling on the empirical implications of different user cost choices.

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Appendix 1 Sensitivity Analysis of User Cost Models

The question about the formulation of the user cost of capital, which is used to provide the underlying asset weights within a series of capital services indexes, is a conceptually interesting one. Table A1 presents the 16 models that were used to assessed the sensitivity of the traditional user cost formula to the different choice of parameters. It examines the effects of using an exogenous versus an endogenous rate of return as well as the impact of smoothing of the inflation rate or dropping the capital gains term altogether on user cost of natural capital. The results of the sensitivity analysis are shown in Table A2.

The sensitivity analysis shows that the input variables for determining the factors of the user costs make a difference to productivity. Interestingly, the difference in whether the capital gains term is included or excluded is the most significant, producing the most robust MFP growth on average over the period from 1989-90 to 2015-16. The results showed that a reduction in a considerable number of negative rental prices for individual subsoil asset compared to the other methods and confirmed an observation made in MacGibbon (2013) that the exclusion of capital gains from the user cost of capital could provide more plausible asset-weights which display markedly less volatility.

Another tentative conclusion is that endogenous method for the computation of user costs produces a more substantial number of negative rental prices than the other methods. Also that the difference between the gross operating surplus for market producers as taken from the national accounts and the gross operating surplus as implied by the ex-ante method yields a picture as would be expected: differences change sign and oscillate around a long-run value close to zero. This agrees with the idea that the difference between ex-ante and ex-post values is a surprise term. The number of negative prices by smoothing prices over a five year period.

The differences between the 16 user costs models are relatively large for the mining sector, nearly one percentage point in average annual growth rates over the entire period. These results provide useful information indicating how the selection of rates of return and a price deflator can offer more reasonable user costs for natural capital. The choice of traditional user cost model could also imply materially different views at the individual subsoil asset on the time pattern of productivity change.

Table A1: Traditional User Cost Models

	Natural Capital			Produced Capital
Model	r_N	i_N	π_N	r_K
1	RBA business loan rate	Price deflater	Yes	RBA cash rate
2	RBA business loan rate	Exponential smoothing***	Yes	RBA cash rate
3	RBA business loan rate	Geometric smoothing****	Yes	RBA cash rate
4	RBA business loan rate	Price deflater	No	RBA cash rate
5	RBA cash rate	Price deflater	Yes	RBA cash rate
6	RBA cash rate	Exponential smoothing	Yes	RBA cash rate
7	RBA cash rate	Geometric smoothing	Yes	RBA cash rate
8	RBA cash rate	Price deflater	No	RBA cash rate
9	ABS Endogenous rate*	Price deflater	Yes	RBA cash rate
10	ABS Endogenous rate	Exponential smoothing	Yes	RBA cash rate
11	ABS Endogenous rate	Geometric smoothing	Yes	RBA cash rate
12	ABS Endogenous rate	Price deflater	No	RBA cash rate
13	K and N Endo. rate**	Price deflater	Yes	K and N Endo. rate
14	K and N Endo. rate	Exponential smoothing	Yes	K and N Endo. rate
15	K and N Endo. rate	Geometric smoothing	Yes	K and N Endo. rate
16	K and N Endo. rate	Price deflater	No	K and N Endo. rate

*This rate refers to the ABS endogenously derived rates of return for produced capital.

** Refers to the endogenous rates of return including both produced and natural capital.

*** Exponential smoothing over 5 periods using dampening factor of 0.9.

**** Based on Diewert and Fox (2016a, p20) method.

Source: Estimates of Industry Multifactor Productivity (ABS cat. no. 5260.0.55.002), Australian System of National Accounts (ABS cat. no. 5204.0), and RBA Statistical Table F5 Indicator Lending Rates.

Table A2: Traditional User Cost Models

Average Growth Rates in Percent					
Period	ABS	Model 1	Model 1	Model 3	Model 4
1989/90 - 1995/96	3.7	2.1	2.0	2.1	2.0
1996/97 - 2000/01	0.9	1.0	1.1	1.1	1.1
2001/02 - 2005-06	-4.4	-3.8	-3.4	-3.3	-2.5
2006/07 - 2010/11	-4.1	-2.4	-2.2	-1.3	-1.3
2011/12 - 2015/16	-0.3	1.7	0.9	1.1	1.7
1989/90 - 2015/16	-0.5	-0.1	-0.2	0.1	0.3
Period		Model 5	Model 6	Model 7	Model 8
1989/90 - 1995/96		2.2	2.0	2.2	2.1
1996/97 - 2000/01		1.0	1.1	1.1	1.1
2001/02 - 2005-06		-3.9	-3.5	-3.4	-2.6
2006/07 - 2010/11		-2.6	-2.2	-1.5	-1.5
2011/12 - 2015/16		1.6	0.8	1.0	1.6
1989/90 - 2015/16		-0.1	-0.2	0.0	0.3
Period		Model 9	Model 10	Model 11	Model 12
1989/90 - 1995/96		2.3	2.0	2.2	2.1
1996/97 - 2000/01		1.1	1.1	1.1	1.1
2001/02 - 2005-06		-3.6	-3.2	-3.1	-2.2
2006/07 - 2010/11		-1.2	-1.1	-0.3	-0.5
2011/12 - 2015/16		1.9	1.5	1.8	2.2
1989/90 - 2015/16		0.3	0.2	0.5	0.6
Period		Model 13	Model 14	Model 15	Model 16
1989/90 - 1995/96		2.9	2.2	2.5	2.5
1996/97 - 2000/01		1.3	1.5	1.5	1.5
2001/02 - 2005-06		-3.8	-3.4	-3.3	-2.4
2006/07 - 2010/11		-2.4	-2.0	-1.3	-1.2
2011/12 - 2015/16		1.1	0.4	0.7	1.3
1989/90 - 2015/16		0.1	-0.1	0.2	0.5

Appendix 2 Data sources

To estimate productivity measures in the Australian mining sector, relevant data on subsoil minerals, output, capital and labour inputs were from the following sources:

- ABS cat. no. 5260.0.55.002, Estimates of Industry Productivity;
- ABS cat. no. 5204.0, Australian System of National Accounts;
- ABS cat. no. 6291.0.55.003, Labour Force, Australia, Detailed Quarterly;
- BREE, Australian Energy Statistics;
- Geoscience Australia, Oil and Gas Resources of Australia; and
- Geoscience Australia, Australia's Identified Mineral Resources.

The industry-level data on value-added, labour and produced capital inputs come from the ABS productivity database. The labour volume series used for the ABS official multifactor productivity estimates are adjusted for labour quality. This adjustment is to account for the quality of the aggregate series for different skill levels. For simplicity and to facilitate comparison with other countries productivity statistics, the unadjusted labour volume series is used.

Appendix 3 Endogenous Rates of Return

The user cost of capital could be observed as a market rental price for the asset. Given that capital rental markets are almost non-existent, the user cost is approximated by an implicit rental that owners of capital are inferred to be charging themselves. The user cost for produced capital for industry i of asset j in period t used by the ABS is as follows:

$$u_{ijt} = T_{ijt}(i_{it}P_{ij(t-1)} + \delta_{jt}P_{ijt} - \tau_{ijt}) + x_{it}P_{ij(t-1)} \tag{C1}$$

where T_{ijt} is the income tax parameter of asset j, i_{it} is the nominal rate of return, $P_{ij(t-1)}$ is the price of capital asset j at the beginning of the period, δ_{jt} is the economic depreciation rate of asset j, P_{ijt} is the price of capital asset j at the end of the period, τ_{ijt} is the capital gain effect due to the revaluation of asset j and x_{it} is the average non-income tax rate on production. The nominal rate of return in equation (C1) represents the rate of return which is expected within an industry. An endogenous rate of return is derived for all assets in each industry i, by equating the entire gross operating surplus, GOS_{it}, to equal the rental price multiplied by the real productive capital stock, K_{ijt}. That is:

$$GOS_{it} = \sum_j u_{ijt} K_{ijt} \tag{C2}$$

By substituting (C1) in (C2) and rearrange to solve for the rate of return gives:

$$i_{it} = \frac{GOS_{it} - \sum_j K_{ijt}(T_{ijt}(\delta_{jt} P_{ijt} - \tau_{ijt}) + x_{it} P_{ij(t-1)})}{\sum_j K_{ijt} T_{ijt} P_{ij(t-1)}} \tag{C3}$$

To derive an endogenous rate of return that accounts for natural capital, we now assume that the capital services that exactly exhaust GOS include both produced and natural capital. This is shown in equation (C4):

$$i^*_{it} = \frac{GOS_{it} - \sum_j K_{ijt}(T_{ijt}(\delta_{jt} P_{ijt} - \tau_{ijt}) + x_{it} P_{ij(t-1)}) - \sum_m N_{mt}(\delta^N_{mt} P^N_{mt} - \tau^N_{mt})}{\sum_j K_{ijt} T_{ijt} P_{ij(t-1)} + \sum_m N_{mt} P^N_{m(t-1)}} \tag{C4}$$

where N_{mt} is the natural capital stock of asset m in period t. This approach has a degree of intuitive appeal as the all capital assets observed is utilised to generate capital income and treats user cost of capital as the marginal revenue.