



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

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Economic Measurement Group Workshop  
Sydney, 1 December 2017

## Motivation

- Traditional measures of productivity growth do not account for natural capital
- Only labour and produced capital are considered as inputs
- Australia's productivity performance deteriorated in the 2000s relative to the 1990s
- A proportion of the slowdown in Australia's productivity performance is attributable to the mining industry
- Including natural capital can give a better understanding of its role in productivity and economic growth

## Summary

- This study considers including non-renewable natural resources, ie. subsoil minerals, in a productivity analysis of the Mining industry
- Builds on the recent work of World Bank (2011), ABS (2013), Brandt, Schreyer and Zipperer (2017) and Diewert and Fox (2016)
- Compares two alternative user cost approaches:
  - unit rent as user cost (World Bank, 2011 and Brandt, Schreyer and Zipperer, 2017)
  - traditional user cost (Diewert and Fox, 2016)
- No study has yet implemented the Diewert and Fox derivation of user cost for natural capital.
- Assess the differences in the mining industry multifactor productivity that includes natural capital (MFP+N) using the two approaches
- Test the sensitivity of the results to assumptions made in calculating the traditional user cost

## Framework for accounting for subsoil resources

- To include the contribution of subsoil resources in production, they are treated as a distinct factor of production in the same way as labour and produced capital.
- A Hicksian neutral production function including natural capital,  $N$ , then can be written as:

$$Y = A f(K, N, L, t)$$

- where the output ( $Y$ ) is value-added based and is a function of:
  - total inputs - labour ( $L$ ), produced capital ( $K$ ) and natural capital ( $N$ ); and
  - productivity ( $A$ )
- Logarithmically differentiating the production function yields

$$\frac{\dot{Y}}{Y} = \frac{\dot{A}}{A} + \left( \frac{\partial Y}{\partial K} \frac{K}{Y} \right) \frac{\dot{K}}{K} + \left( \frac{\partial Y}{\partial N} \frac{N}{Y} \right) \frac{\dot{N}}{N} + \left( \frac{\partial Y}{\partial L} \frac{L}{Y} \right) \frac{\dot{L}}{L}$$

where  $\frac{\partial Y}{\partial K} \frac{K}{Y}$ ,  $\frac{\partial Y}{\partial N} \frac{N}{Y}$  and  $\frac{\partial Y}{\partial L} \frac{L}{Y}$  denote the elasticities of output with respect to produced capital natural capital and labour, respectively

## Framework for accounting for subsoil resources

- These elasticities are not observable, but can be derived by imposing the optimization conditions:
  - constant returns to scale
  - each factor is paid its marginal product
- Given output price ( $P^Y$ ) and factor input prices ( $C^M$ ) the output elasticities can be measured by:

$$P^Y \frac{\partial Y}{\partial M} = C^M \Rightarrow \frac{\partial Y}{\partial M} \frac{M}{Y} = \frac{C^M M}{P^Y Y} \equiv S_M \quad \text{for } M = K, N, L$$

- Given equations (3), the output elasticities can be replaced with the corresponding factor shares and (2) can be expressed as:

$$\frac{\dot{Y}}{Y} = \frac{\dot{A}}{A} + S_K \frac{\dot{K}}{K} + S_N \frac{\dot{N}}{N} + S_L \frac{\dot{L}}{L}$$

## Framework for accounting for subsoil resources

- Under constant returns to scale, income and expenditure can be equated to:

$$P^Y Y = \sum_M C^M M = wH + u_K P^K K + u_N P^N N \quad (4)$$

where

- labour cost = hours worked ( $H$ ) x nominal wage rate ( $w$ )
  - cost of produced capital = nominal stock value ( $P^K K$ ) x user cost of produced capital ( $u_K$ )
  - cost of natural capital = nominal stock value ( $P^N N$ ) x user cost of natural capital ( $u_N$ )
- Since  $S_K + S_N + S_L = 1$  the factor shares can be expressed by:

$$S_K \equiv u_K P^K K / P^Y Y$$

$$S_N \equiv u_N P^N N / P^Y Y$$

$$S_L \equiv w H / P^Y Y$$

## Framework for accounting for subsoil resources

- The discrete approximation of the growth accounting formula can be derived and with rearrangement we show that MFP can be directly measured by:

$$\ln\left(\frac{A_t}{A_{t-1}}\right) = \ln\left(\frac{Y_t}{Y_{t-1}}\right) - \bar{S}_{K,t}\ln\left(\frac{K_t}{K_{t-1}}\right) - \bar{S}_{N,t}\ln\left(\frac{N_t}{N_{t-1}}\right) - \bar{S}_{L,t}\ln\left(\frac{L_t}{L_{t-1}}\right)$$

where  $\bar{S}_{j,t} = \frac{1}{2}(S_{j,t} + S_{j,t-1})$ , for  $j=K, N, L$

- Taking exponents we get:

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

where  $Y_{t,t-1}$  is (one plus) the growth rate of output and the input index  $I_{t,t-1}$  is computed as a Törnqvist index as follows:

$$I_{t,t-1} = \left(\frac{K_t}{K_{t-1}}\right)^{\frac{1}{2}(S_{K,t}+S_{K,t-1})} \left(\frac{N_t}{N_{t-1}}\right)^{\frac{1}{2}(S_{N,t}+S_{N,t-1})} \left(\frac{L_t}{L_{t-1}}\right)^{\frac{1}{2}(S_{L,t}+S_{L,t-1})}$$

- This is consistent with ABS practice.

## Unit resource rent approach

- Consistent with Hotelling (1931), let  $V^0$  and  $V^1$  denote the market price of an ore body (which in this case is a non-renewable resource) at the beginning and end of period 1, so that:

$$V^t = P^t S^t \quad \text{for periods } t=0,1$$

- Assume  $P^t$  is the price of one unit of ore at the beginning of period  $t$  and  $S^t$  is the corresponding stock of the ore body
- Assume expectations about the value of revenues generated by the ore extracted during the first period and expectations about price at the end of the period are realised
- Assume  $R^1$  denotes the net revenue (sales less extraction costs) during period 1 and  $r$  is the opportunity cost of capital at the beginning of period 1 then:

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



## Unit resource rent approach

- Following Brandt-Schreyer-Zipperer, the total cash flow generated by mining  $D^1$  units of ore during period 1 is defined as:

$$R^1 \equiv (p^1\alpha - w^1\beta)D^1 = u^1D^1 = (\text{revenue generated} - \text{associated costs}) \times \text{depletion}$$

where  $\alpha$  is a positive vector of ore final product

$p^1$  is the period 1 market output price vector

$\beta$  is a positive vector of input requirements for mining one unit of ore

$w^1$  is the corresponding period 1 market input price vector.

- Thus  $u^1 \equiv p^1\alpha - w^1\beta > 0$  is the unit rent user cost of mining one unit of the ore body during period 1.
- The end of period user cost value is then:

$$U_N^1 \equiv V^0(1+r) - V^1 = (1+r)[(1+r)^{-1}R^1 + (1+r)^{-1}V^1] - V^1 = R^1 = u^1D^1$$

## Traditional user cost

- $P^0$  is the beginning of the period price of ore and  $P^1$  is the end of period price of ore  
 $S^0$  is the beginning of the period stock of ore and  $S^1$  is the end of period stock of ore
- We can define period 1 expected inflation rate for the price of a unit of ore body as:

$$1 + i \equiv P^1 / P^0$$

and the period 1 depletion rate as  $\delta \equiv 1 - \frac{S^1}{S^0}$

- Recall earlier:  $U_N^1 \equiv V^0(1 + r) - V^1$
- Substituting these definitions yields the following user cost value:

$$\begin{aligned} U_N^1 &\equiv P^0 S^0 (1 + r) - P^1 S^1 = P^0 S^0 (1 + r) - P^0 (1 + i) (1 - \delta) S^0 \\ &= P^0 [r - i + (1 + i)\delta] S^0 \end{aligned}$$

where  $P^0[r - i + (1 + i)\delta]$  is the traditional user cost of capital, except  $\delta$  is the depletion rate rather than the usual “wear and tear” depreciation rate

## Comparing the two approaches

- Diewert and Fox (2016) showed that under the assumption that expectation formed at the beginning of period are actually realised at the end of the period – the two user cost value formulae are equal to each other.
- Thus, the unit resource 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.
- It is extremely unlikely that this assumption will hold.
- The traditional user cost approach does not require this assumption to hold.
- This suggest that this is a more reasonable approach to valuing non-renewables for productivity.
- Key challenge of the traditional user cost is that expected values for  $\delta$  and  $i$  have to be formed.
- There are difficulties in deciding how to estimates these parameters in an unambiguous manner and the user cost estimates may be sensitive to the choice of model, even becoming negative.

## Relationship between income and capital

SEEA 2012 (para 5.120) states: *"Resource rent is thus derived from standard SNA measures of gross operating surplus by deducting specific subsidies, adding back specific taxes and deducting the user costs of produced assets (itself composed of consumption of fixed capital and the return to produced assets). As noted above, resource rent is composed of depletion and the net return to environmental assets."*

Gross operating surplus	Consumption of fixed capital		Capital services produced
	Economic rents	Return to produced capital	
		Return to non-produced capital	Capital services non-produced
	Depletion		

- Mining GOS can be allocated to both capital and subsoil resources
- The return to produced assets is based on a mark up of costs using cost of extraction data, mining industry capital stock and an appropriate discount rate

## Data

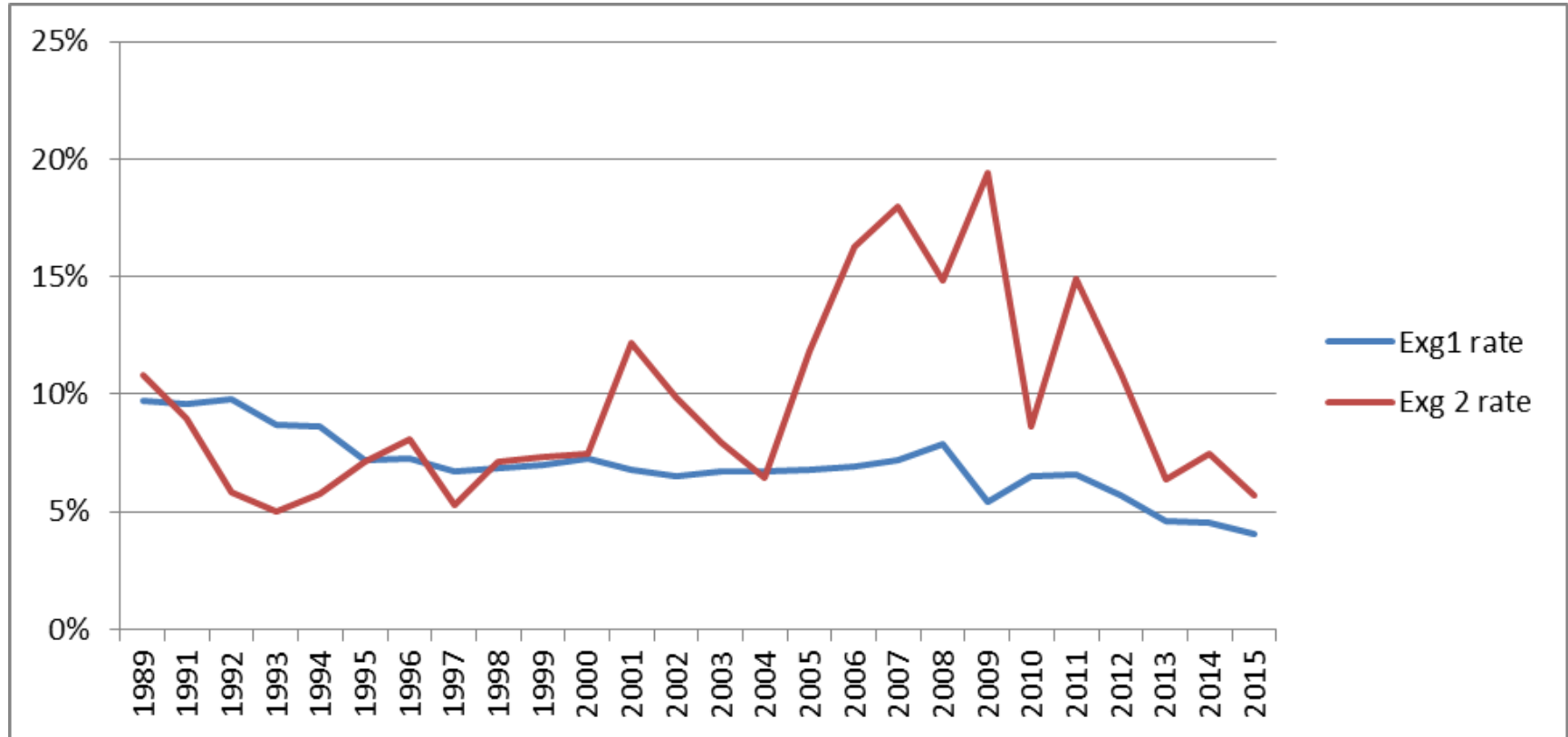
- Economically demonstrated reserves (EDRs) and production of mineral resources are obtained from Geoscience Australia in Australia's Identified Mineral Resources
- Mineral extraction costs are provided by a private consulting firm
- Prices are obtained from a number of publically available sources, including the Australian Financial Review and the Bureau of Resources and Energy Economics' quarterly publication Resources and Energy Statistics
- 27 subsoil minerals are included

Antimony	Gold	Natural Gas
Bauxite	Iron ore	Nickel
Black coal	Lead	Petroleum - Condensate
Brown coal	LPG - Naturally occurring	Platinum
Cadmium	Lithium	Rare earths
Copper	Magnesite	Silver
Cobalt	Mineral sands - Ilmenite	Tin
Crude oil	Mineral sands - Rutile	Uranium
Diamonds	Mineral sands – Zircon	Zinc

## Traditional user cost approach - choice of model

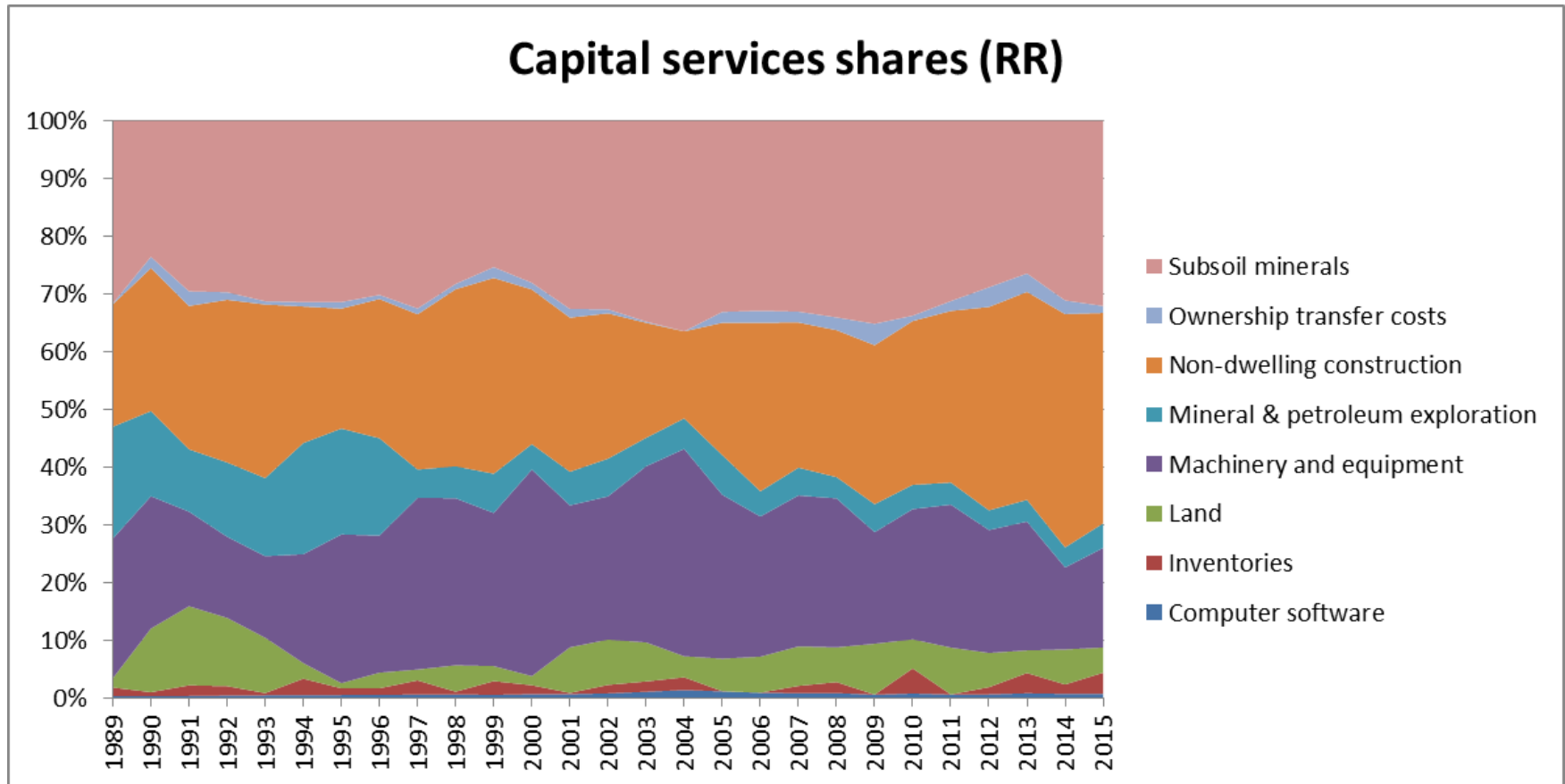
	$\delta$	$r$	P	Revaluation term
$U_{N,T\_Exg1}$	extraction rate	Exogenous = RBA business loan rate	-	Yes
$U_{N,T\_Exg1\_sm}$	extraction rate	Exogenous = RBA business loan rate	5 years moving average	Yes
$U_{N,T\_Exg2}$	extraction rate	Exogenous 2 = Endogenous rate for produced capital with floor of CPI + 4%	-	Yes
$U_{N,T\_Exg2\_sm}$	extraction rate	Exogenous 2 = Endogenous rate for produced capital with floor of CPI + 4%	5 years moving average	Yes
$U_{N,T\_Exg2\_noreval}$	extraction rate	Exogenous 2 = Endogenous rate for produced capital with floor of CPI + 4%	-	No

## Rates of return



Source: ABS and RBA

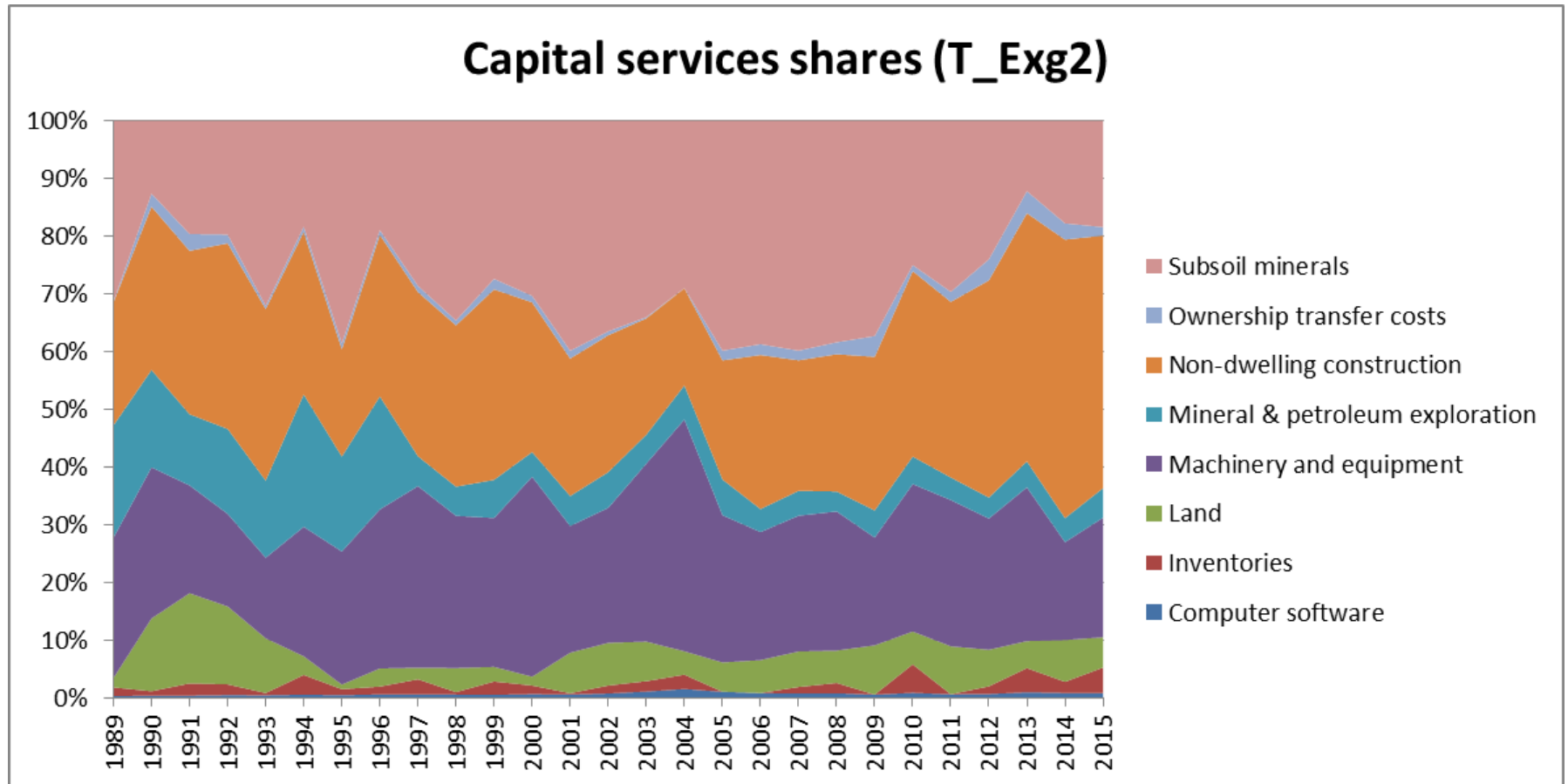
# Capital services shares of the Mining industry with subsoil minerals



Source: ABS, author's estimates

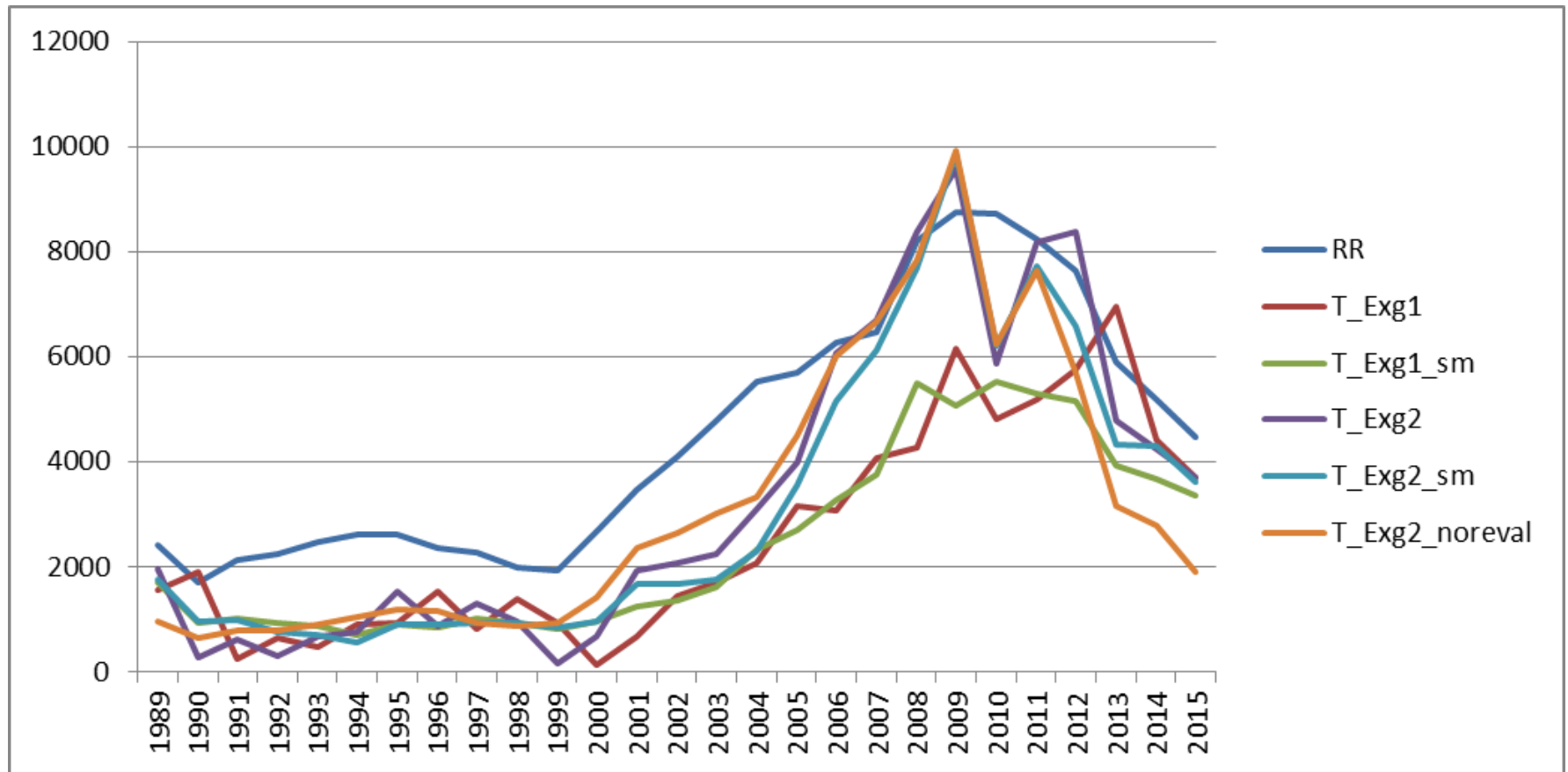


# Capital services shares of the Mining industry with subsoil minerals



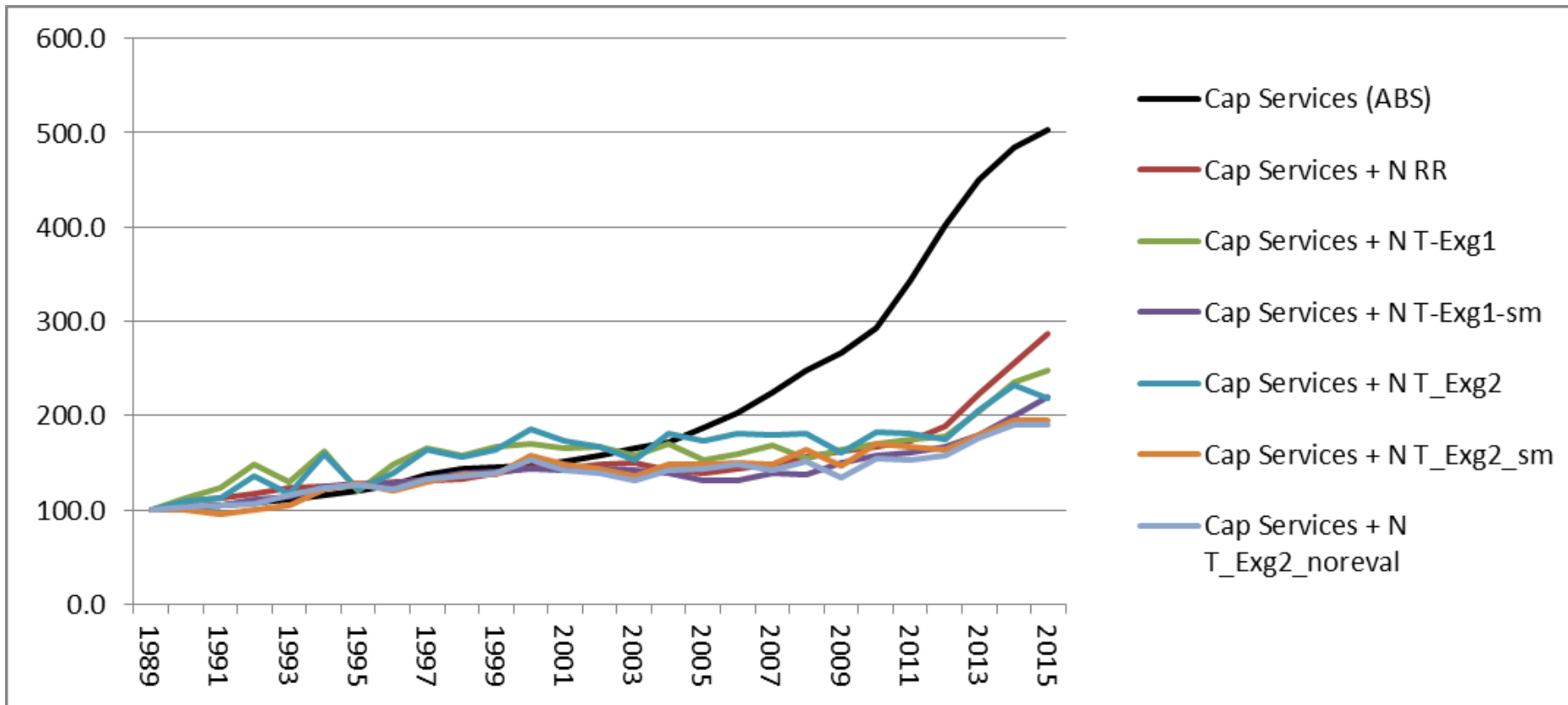
Source: ABS, author's estimates

## Crude oil - user costs comparison



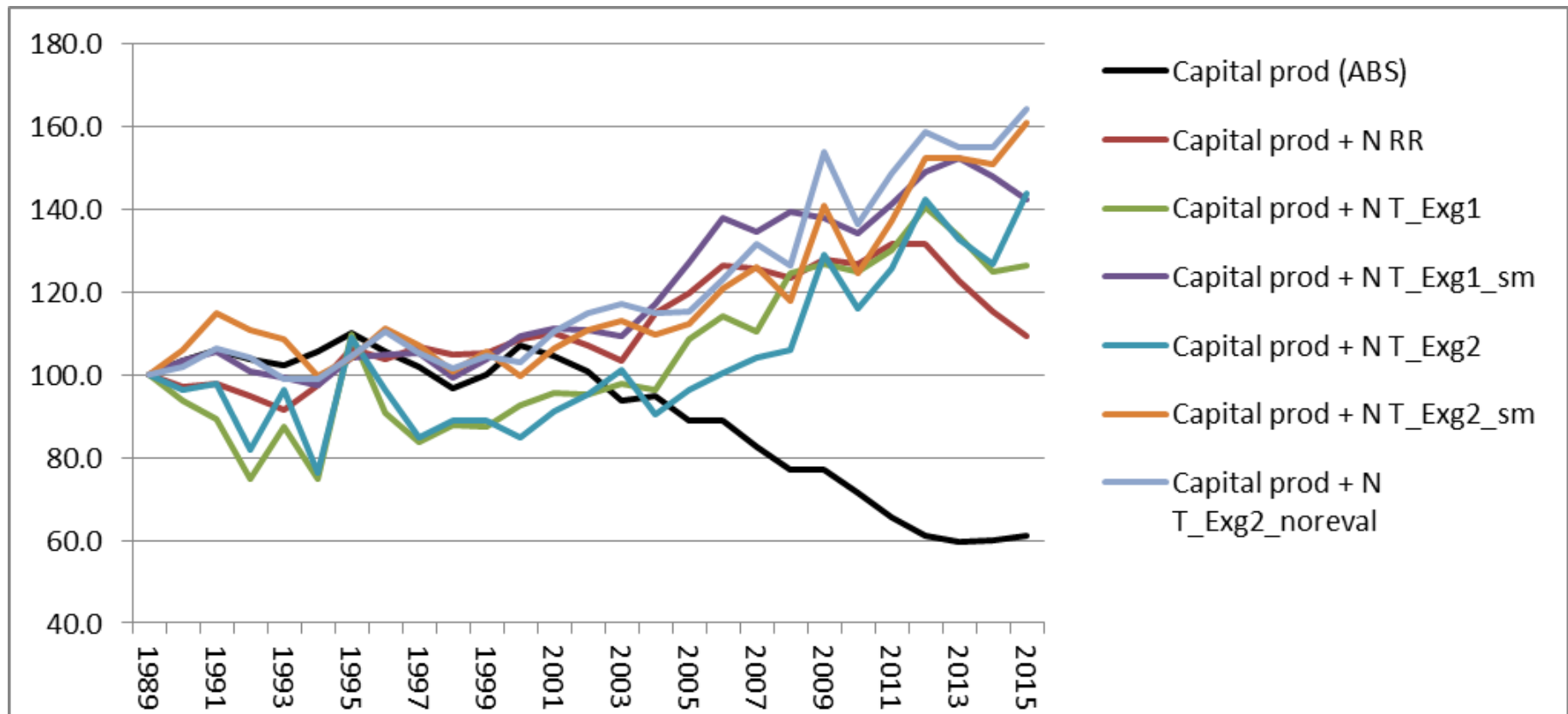
Source: ABS, author's estimates

# Capital services comparison: various user cost of capital approaches



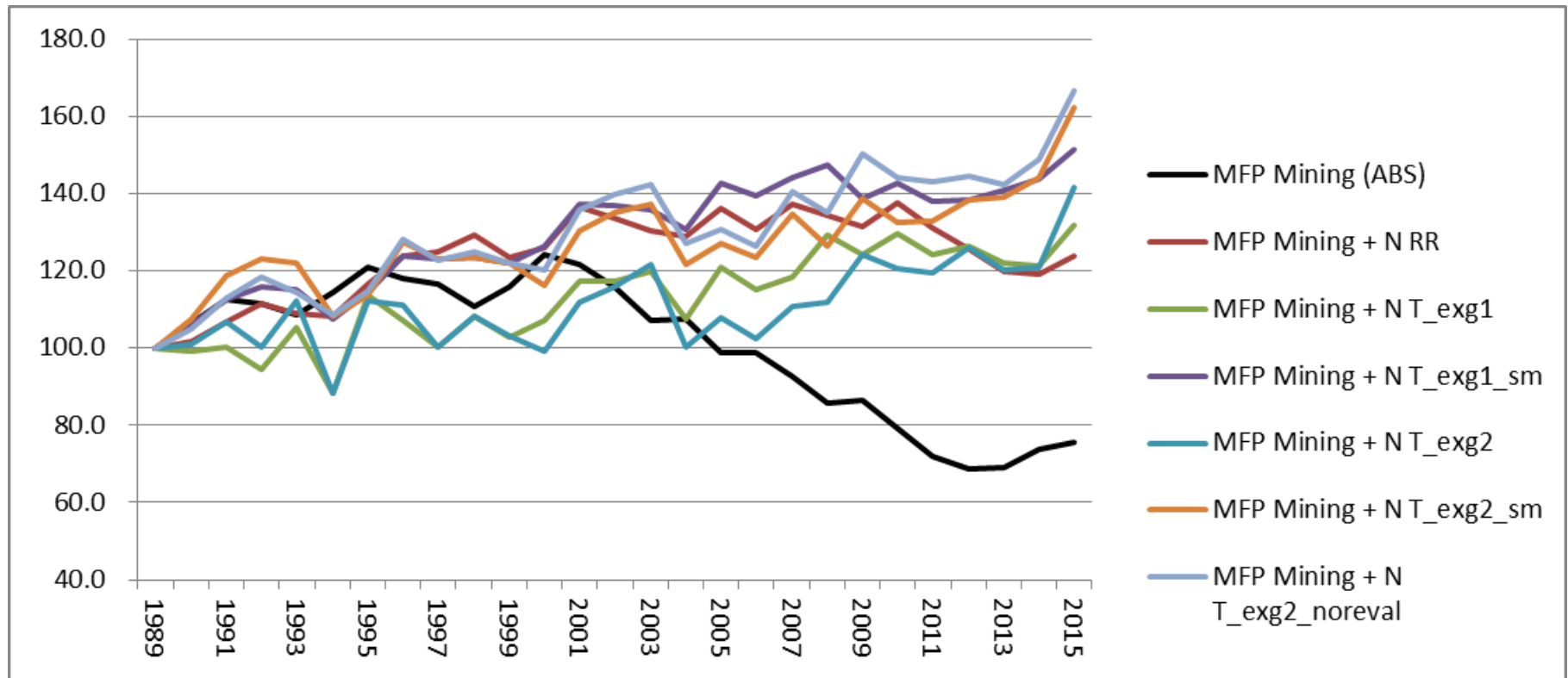
Source: ABS, author's estimates

## Mining capital productivity comparison: various user cost of capital approaches



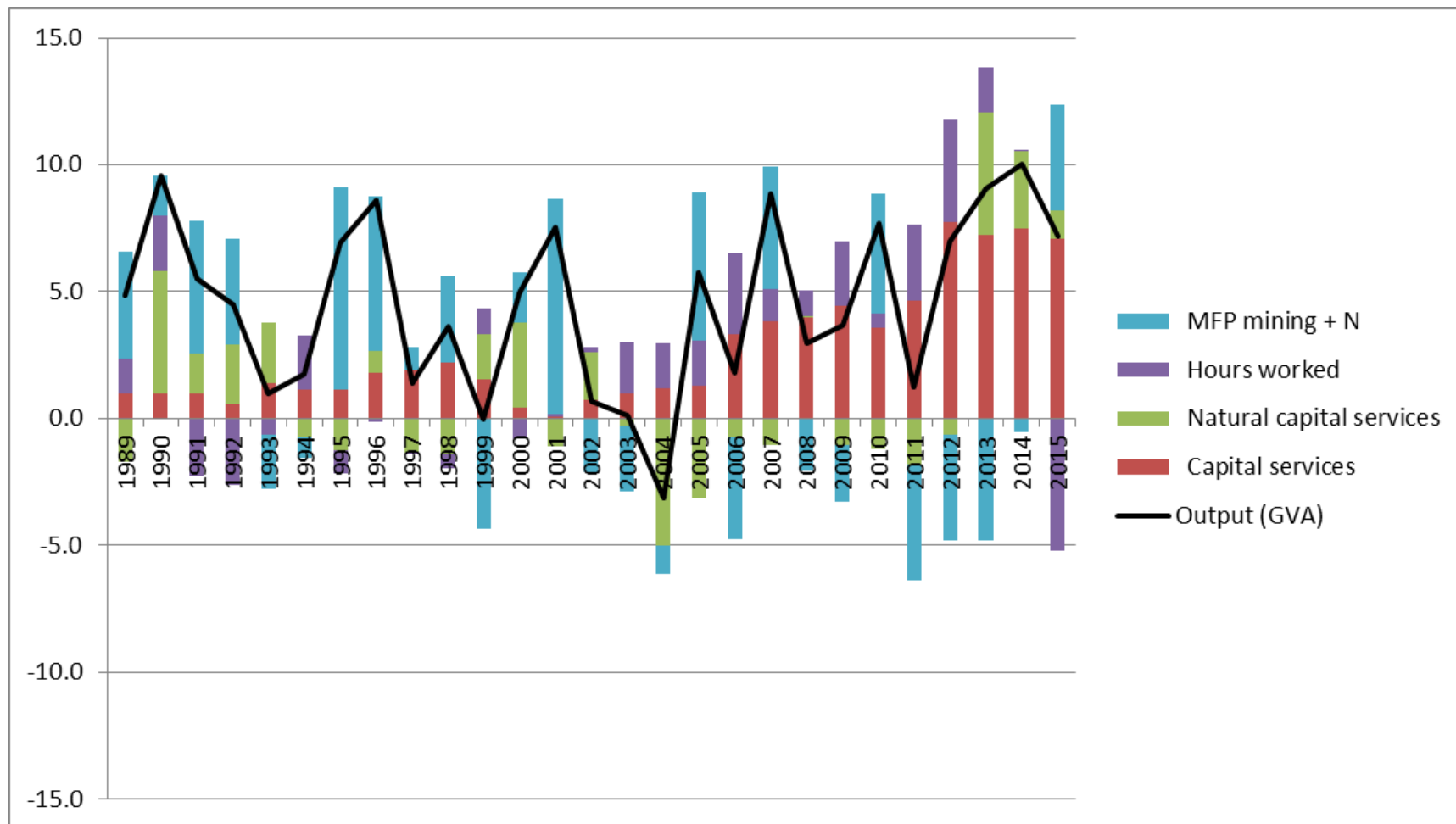
Source: ABS, author's estimates

# Mining MFP comparison: various user cost of capital approaches



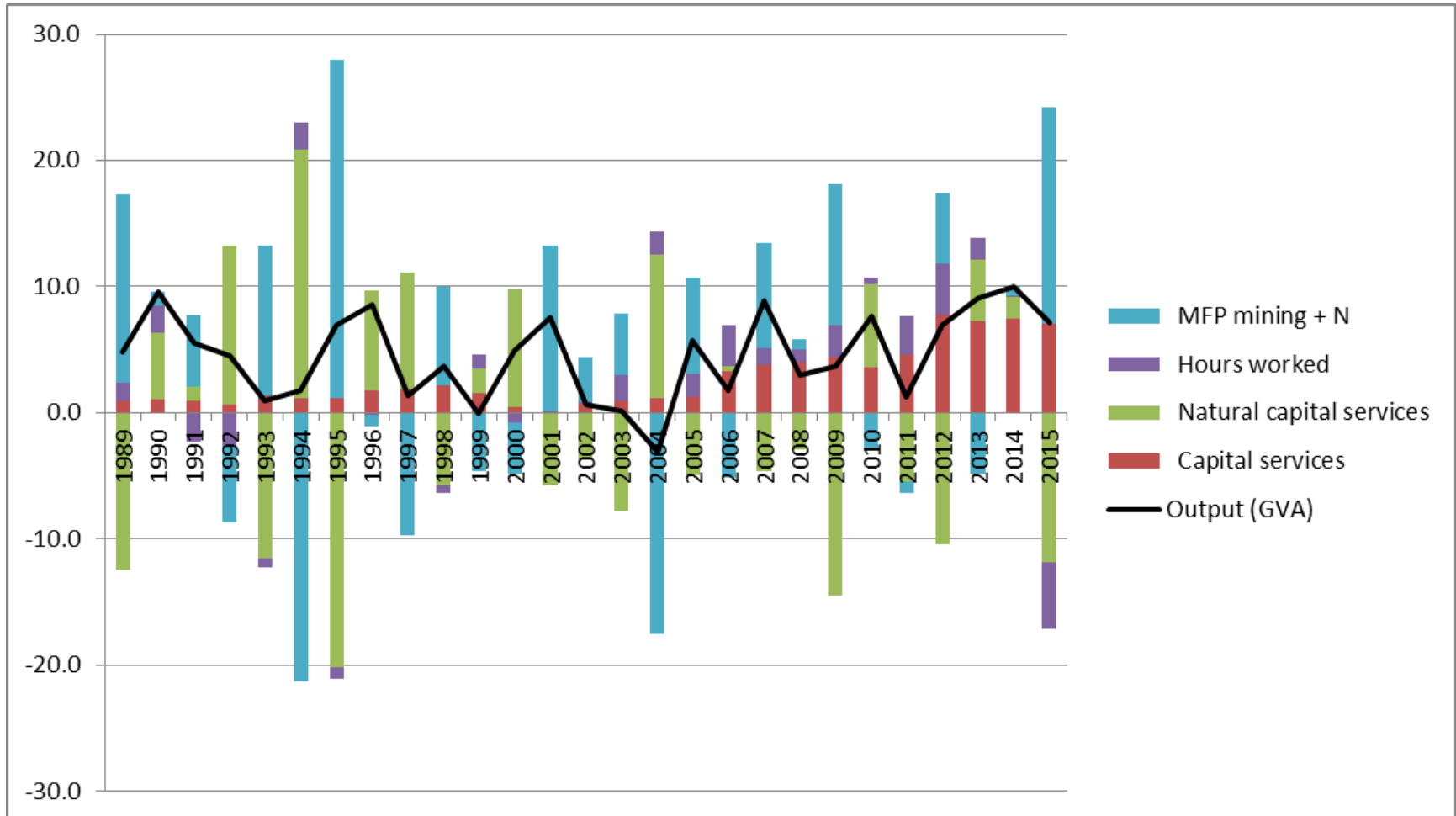
Source: ABS, author's estimates

## Mining MFP growth accounts (RR method)



Source: ABS, author's estimates

## Mining MFP growth accounts (T\_Exg2 method)



Source: ABS, author's estimates

## Conclusion

- The results suggest a significant contribution of natural capital to the value-added MFP growth in the Australian mining sector
- Mining capital services growth is significantly moderated when natural resources are included.
- The impact of adding natural capital changes over time. It is small before 2003-04 and becomes larger thereafter. As a result of the inclusion of subsoil natural resources, aggregate decline in MFP is revised to a small positive growth rate in most years since the 2003-04 growth cycle peak
- This is because natural capital input typically grows slower than produced capital
- Different user cost approaches do impact on the natural capital MFP profile
- The decline in ABS mining MFP cannot solely be explained by recognising natural resources as a factor of production: other factors such as lags associated with investment in new infrastructure will likely have also contributed to the decline