The Boyne Island smelter: an impact study

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Outline Australia is one of only three energy abundant countries in the world with a fully integrated supply chain for producing raw aluminium ([18]). The In particular, Bauxite from Weipa, North Queensland, is refined and smelted in Gladstone, Central Queensland.

Aluminium smelting is a highly energy intensive process with Boyne Smelter Limited (BSL) in Gladstone consuming approximately one eighth of the total electricity supply of Queensland over the course of a typical year. Like other regions that produce aluminium, Central Queensland is energy-abundant with an active coal-mining and natural-gas industry. The smelter is supported by the coal-fired Gladstone Power Station (GPS). GPS is one of four in the Central Queensland region. GPS has the capacity to supply one quarter of Queenland's annual electricity demand. GPS is unique in that it carries a variable load with the ability to rapidly increase the supply of power in the case of an extended blackout that would otherwise lead to aluminium freezing the pipes and costly damages to BSL.

In this paper, we apply recent methods that we have developed as part of an exercise to build the next generation of Computational General Equilibrium (CGE) models. We build on recent work from the computational economics literature ([3] and [2]).

In particular, we study the economic impact of a permanent closure of the smelter on the Gladstone region. The key local variables of interest are capital, output, consumption as well as gross value added and employment which we model across sectors and over time. We model the broader gladstone region and estimate the impact on the broader supply chain via imports and exports. We present results for the standard 19 ANZSIC divisions and for the economy on aggregate.

Our main insight is that the impact of the shock depends on whether or not the Sector-specific Euler Equations (SEE) hold. Recall that the celebrated Euler Equations of macroeconomics and finance are statements about *aggregate* capital. When they hold, the current value of capital is equal to the expected future value of capital. In other words, capital, and hence consumption, is optimally allocated over time: once we account for uncertainty. In our setting, each sector's new capital is formed by combining inputs from all sectors. As a consequence, each sector comes with its own Euler Equation and together they form the SEE.

- When the SEE hold, the shock is largely contained within the manufacturing sector; though there are knock-on effects to Utilities and beyond this to consumption and more energy-intensive sectors. In essence the economy strives to return to the same growth path that it was on previously as all other sectors are well-capitalised. The optimal economic response is, in effect, to rapidly replace the smelter to the extent that this is possible: given the change in parameters due to the shock.

- When the SEE do not hold, the shock may lead to more significant changes in investment patterns across sectors: other sectors such as mining and agriculture benefit from lower utilities prices and the fall in manufacturing productivity.

To our knowledge these implications of the SEE are novel to the literature. In fact, for the most part, Euler equations are entirely absent from the CGE lieterature. A notable exception is [**?**] policy functions that, under restrictive conditions, are equivalent to the SEE are derived. This gap in the literature follows from the fact that CGE models tend to specialise in the cross section whereas macroeconomic (dynamic stochastic general equilibrium (DSGE) models tend to specialise on the dynamics. As [**?**] point out, in a standard CGE model, current consumption does not take into account all information about the future.

In this paper, by looking at what the implications are when the SEE fail to hold, we are going one step further. A step that is natural given the long history in behavioural economics of exploring what happens when agents are not perfectly rational in how they process information under uncertainty. This step is even more natural and relevant in settings with significant uncertainty and rapid change. These settings are precisely where the canonical expected utility maximisation are most likely to fail: settings where good decisions are difficult to make.

Yet the world we find ourselves is precisely one where we face significant uncertainty and the need for rapid change. Change that will enable us to achieve net-zero carbon emissions by 2050. It is in this setting that we examine the closure of the Boyne Island Smelter.

on the dyndynamic or "recursive" CGE models tend to avoid full intertemporal optimisation. Moreover macroeconomic models that do focus on intersectorsal activity and intermediate production (such as [2]) tend to study log-linear approximations around the steady state going back to [**?**]) tend allocations across time are not o not feature as intertemporal optimality is Aggregate Euler Equations have of course been extensively studied in the macroeconomics and finance literature. Moreover

Summary of results The sectors where there is an impact of substance are Agriculture, Mining, Manufacturing and Utilities. These are ANZSIC divisions A, B, C and D respectively. Our presentation and analysis of results focuses on these sectors. In brief, manufacturing and utilities are both permanently worse off relative to the no-closure status quo. In contrast, mining and, to a lesser extent, agriculture are permanently better off with investment and employment in these sectors increasing immediately after the shock.

Relative to status quo, when labour is mobile, the positive response by mining and agriculture reduces the immediate shock to aggregate output to just under 1.5% and the economy has caught up within 10 years. When labour is immobile, the immediate shock to aggregate output is just under 6%, and the economy remains 1% smaller than under the status quo in the long run. The truth is likely to lie somewhere in between. The impact on consumption is small but positive for the same reason that mining and agriculture respond positively: the price of utility goods (such as electricity and water) permanently fall by 10% as a result of the closure. In future work we will exploit the flexible nature of our intertemporal modelling approach to explore the case where Utilities prices remain high due to the fact that Gladstone is connected to the National Electricity Market.

The Gladstone Economy To come from [12] and the 2020 report for QTC.

Background to the shock Prior to the closure of the smelter, we assume that all sectors of the economy grow at a rate of 1.5% to 1.8% and that their growth path is balanced. Thus the stock variable capital grows at approximately the same rate as flow variables such as output. This assumption is justified by virtue of the fact that BSL is forty years old, and much of the local aluminium industry was established in the sixties and seventies. The main exception is Gladstone's second alumina refinery, Yarwun Alumina Refinery (YAR), which opened in 2004.

Current capital Direct estimates of current capital per sector are unavailable at the regional level. To do so, we exploit the intertemporal features of our model to evolve the economy optimally and endogenously over a long period of time (approximately 70 years). This approach ensures that, at the time of the shock, the distribution of capital across sectors, at the time of the shock, is independent of the initial distribution of capital. Indeed, current capital depends only on the parameters of the model with our estimates of productivity factors and investment flows playing a key role.

Estimating the parameters

Our first source of data for estimating the share parameters of the model are the 2019 ABS input-output tables (5 and 8) for the Australian economy. Table 8 provides a full account of the individual flows from sector to sector and from sector to household and government. For example, the flow of goods (such as bauxite) from the mining sector to the manufacturing sector is a combination of local and imported goods and an estimate of the total value of this flow can be found on table 8. An estimate of the domestic share of this composite flow can be found on table 5 and imports are found by taking the difference between table 8 and table 5. For the present study, we aggregate the above tables from 114 IOIG industries to the 19 ANSIC divisions (A, B, C, ..., S).

The second source of data is the 1997 US "Make" and Capital/investment Flows tables from the Bureau of Economic Analysis in the US. This is a commonly used table that also features in the influential paper [2]. We were able to adapt this to the 2019 Australian economy on the basis of investment (Gross Fixed Capital Formation) data from the Australian input-output tables and the GFCF by Industry by Asset type tables, also from the ABS. With minor modifications, the traditional RAS method/algorithm works well to ensure row column balance for this table in isolation.

We regionalise the above tables using a combination of 2016 census data and Remplan so as to bring the economy as close as possible to the current Gladstone economy.[1] Regionalising national account data in a top-down manner is inherently imprecise and difficult. To ensure robustness of our results, we created three different versions of the Gladstone economy using two different methods which we now describe. Regardless of method, the main results all point in the same direction. Our reasons for preferring the second method are that the resulting collection of tables not only look more reasonable, they also perform better with the model.

The first method is the traditional RAS technique where (given estimates of sectoral output, employment imports and exports for a region) one estimates the individual flows between sectors by minimising the *relative* entropy subject to row-column balance (a form of regional accounting).[2]

The second method is more targeted. It involves the assumption of constant returns to scale and, whilst keeping the Australian economy broadly intact, using accurate data on specific flows between sectors, households and exports, we make specific modifications to the table. In contrast with the first method, no attempt is made to ensure the table is balanced. Instead, we focus on ensuring that key transactions are in proportion to what we observe in available data. In particular, we obtain precise estimates for the cost structure of the Aluminium sector and scale up key transactions for electricity supply in accordance with data on output from the Rio Tinto annual accounts ([9]), electricity prices ([15]), export and import data from Gladstone port ([8], and well-known estimates of cost from sources on aluminium production such as [18] and [16]. We then run the "burn-in phase" for a variety of parameters and choose those that yield an economy that best matches the regional data we have. Our main concern with the second method is the risk that the tables we have generated paint a more diverse picture of the Gladstone economy than is in fact the case. That is to say, there is the possibility that some other sectors are more reliant on the smelter than our results suggest. We propose to deal with this concern by conducting systematic robustness checks for a wider variety of parameters.

The parameters in detail A sample of the productivity parameters that we calibrate through the burn-in phase are the following:

[1]We will replace this data in due course with data from latest census and local industry data from BLADE.

[2]Relative to the Australian input-output tables mentioned above.

Table 1: Productivity parameters per sector

Divisions	A	B	C	D	E	...	I	J	K	L	...
No shock	31.2	31.7	32.6	21.9	31.6	...	31.4	31.1	21.8	21.9	...
Shock	31.2	31.7	26.1	21.9	31.6	...	31.4	31.1	21.8	21.9	...

Initially productivity parameters were simply set using standard approaches such as formulas for the minimum unit cost. Since this did not produce reasonable output values in the long run, we adjusted these values to reflect the higher output in sectors where output is higher. These modifications are relatively small on the whole. The only exceptions were to divisions D (Utilities), K (Finance) and L (Real Estate). These were set at 70% of the levels that were assigned using standard methods such as the minimum cost of producing a unit adjusted by regional output per sector. The reason for this is that otherwise these sectors become excessively large during the burn-in phase. Division L is where the exceptional IOIG sector "Ownership of Dwellings" is allocated. Ownership of dwellings constitutes 30% of all gross fixed capital formation as per ABS data. Arguably this is relatively unproductive capital given that it is essentially housing.

In table 1 we see that the shock entails a 20% fall in the productivity of manufacturing (C). This, on the one hand, is necessary because otherwise the endogenous optimal investment process will simply return capital to its previous state as if the smelter had never closed. On the other, we argue that such a fall in productivity is reasonable given that the Aluminium sector is so well vertically-integrated. It can also be viewed as capturing perception of higher risk of investing in Gladstone manufacturing after the closure of the smelter.

To specialise the Australian table to Gladstone, the key transactions for which we adjust parameters are the following (all specialisation ratios are relative to Australia):

1. exports of Manufacturing are three times domestic usage.
2. the specialisation ratio for Mining purchases by manufacturing is 2.
3. the specialisation ratio for Manufacturing purchases by manufacturing is 1.5.
4. the specialisation ratio for Utility (electricity and water) purchases by Manufacturing is 7.
5. the specialisation ratio for imported Mining goods (such as bauxite) is 5.
6. finally, we include the subsidy as a payment to capital.

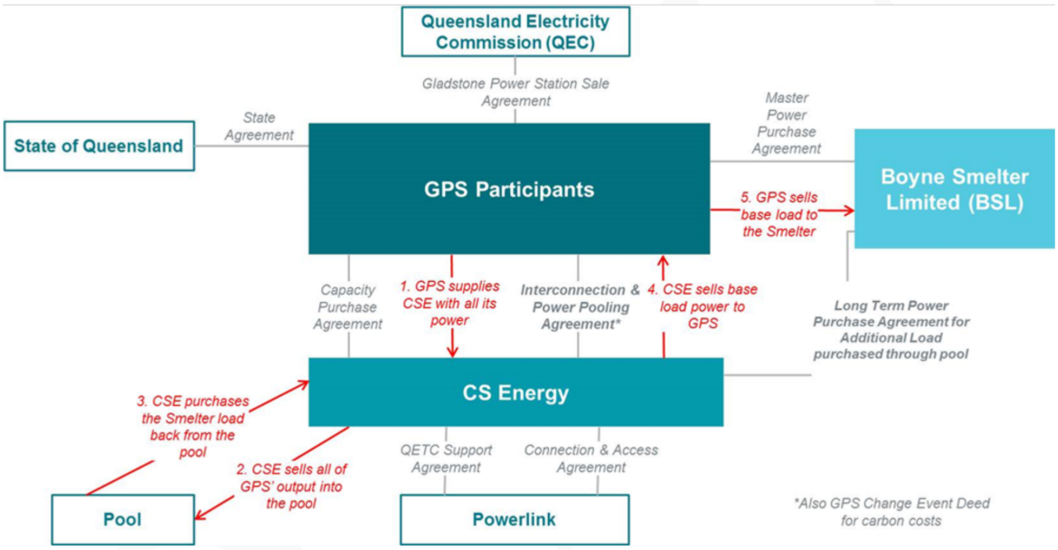
According to our calculations, the subsidy to aluminium amounts to \$174M.

Subsidies to aluminium smelting have been well-debated in Australia for over 20 years [6]. In 2015, the Government-Owned Corporation CS Energy described its contractual obligation to GPS as onerous [17, page 10].

In our calculations, we assume that BSL pays around \$60 per MWH. This is significantly lower than current wholesale future electricity prices of around \$120 for the calendar year 2023 [1]. Assuming that BSL would pay wholesale prices in the absence of a subsidy, we estimate that the subsidy per MWH to aluminium production at BSL is \$60. Given that 14MWH are required to produce a single tonne of aluminium, and BSL currently produces 502KT per annum, we are able to obtain an estimate of the current subsidy to aluminium production at BSL, approximately

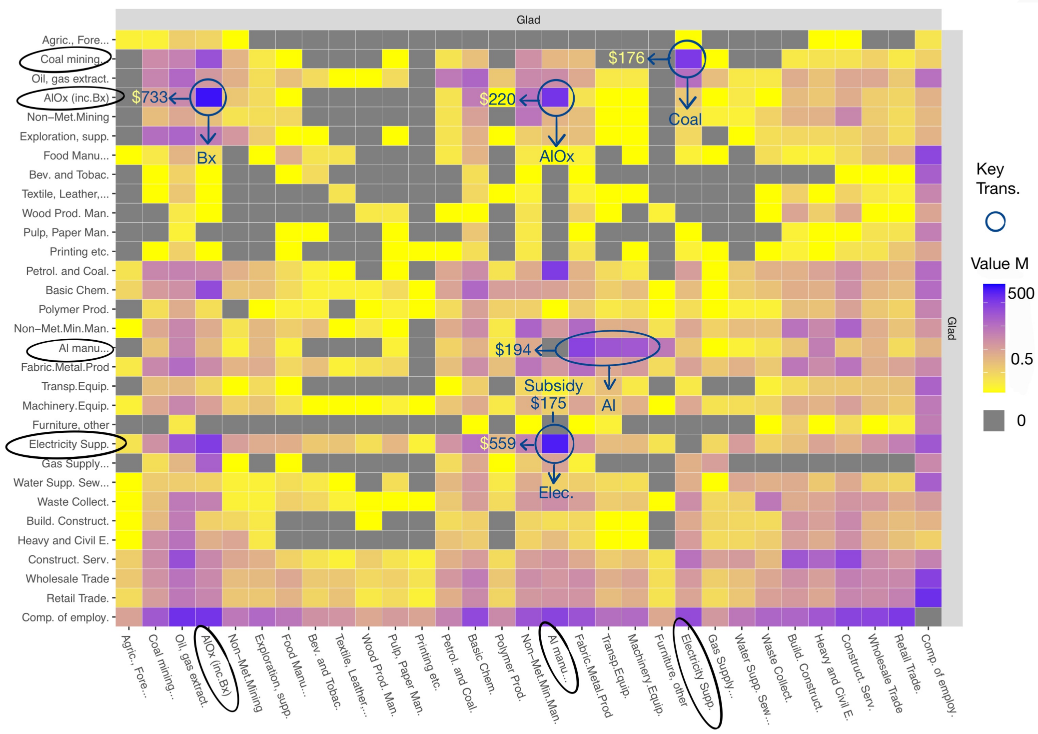
$$\$419.16\text{M} = \$60 \cdot 14 \cdot 499\text{K}$$

Figure (i): The structure of the Interconnection and Power Pooling Agreement



CSE sells GPS's Electricity output at wholesale prices (\$120) and sells the base load quantity of approximately 7,000GWH per annum back to BSL (indirectly via GPS) at prices net of subsidy (\$60). This has lead it to publicly describe its contract with GPS as onerous [17].

Figure (ii): The input-output matrix (AUD millions) for the status quo Gladstone economy



In this heatmap, key, large transactions are represented by blue or violet squares. Yellow transactions are smaller. Grey stands for zero/no transaction.

Summary of status quo economy The final values for flows between sectors are intended to capture the key features of figure (ii) a table that we constructed for a previous report for QTC. Figure (ii) presents data of the same type as table 8: composite flows of domestic and imported goods. For the present study, we need to pair this data with estimates of a richer set of parameters which we derive from table 5 and US capital flows.

The shock Aside from the 20% shock to productivity and the 25% reduction in manufacturing capital, the scenarios involve modifying status quo transactions as follows:

1. exports of Manufacturing goods decrease by 25%
2. purchases of Mining goods by Manufacturing decrease by 10%
3. purchases of Manufacturing goods by the Manufacturing sector decrease by 60%. This may seem high, but it is in line with the fact that, in Gladstone, most goods are manufactured for export.
4. purchases of Utility goods by the Manufacturing sector decrease by 85%. This significant part of the shock is in line with the fact that the smelter consumes one eighth of Queensland's electricity output.

More detailed analysis of results

Overview Under the assumption that the Gladstone economy remains on a balanced growth path of 1.5% to 1.8% across all sectors, the main takeaway is that only Manufacturing and Utilities are significantly affected in a negative way. In fact, Mining and Agriculture benefit from the lower prices for Utilities and Manufacturing goods as well as an improvement in their relative productivity (relative to Manufacturing). On aggregate, although output, Gross Value Added, employment and exports all fall, consumption is weakly, yet positively (between 0% and 1%) improved as a result of lower prices.

In practice, the 10% fall in Utilities price may be tempered by the fact that Gladstone is connected to the National Electricity Market and so the benefit of lower demand for electricity from the smelter would be spread over a much larger region and population. Indeed for the same reason, the impact on prices is likely to be smaller. This will temper the gains to aggregate consumption. The same holds for the gains to the Mining and Agricultural sectors.

Figure (iii): Aggregate: percentage change relative to status quo over time in years

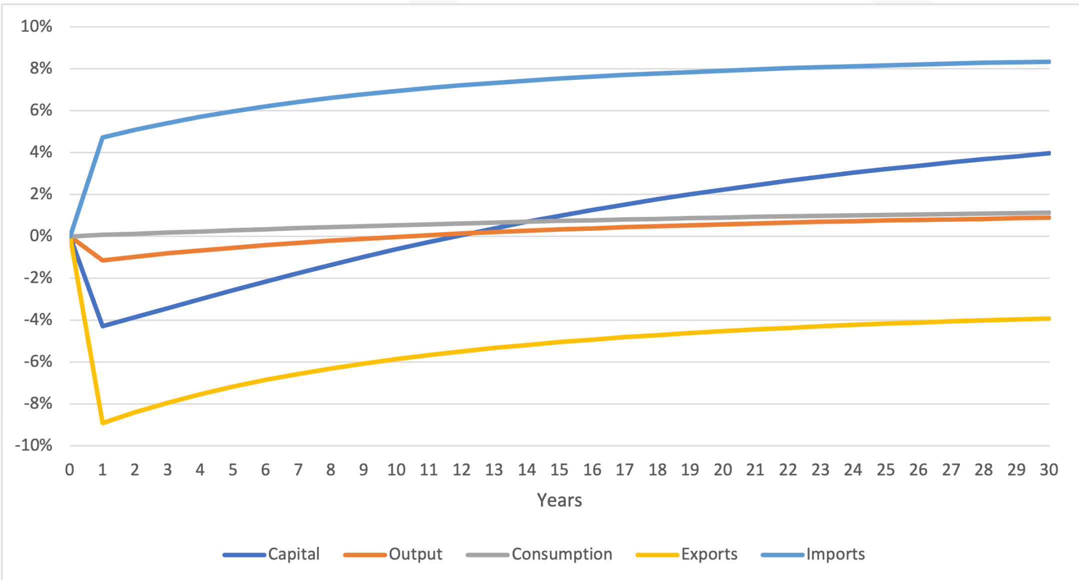


Figure (iv): Agriculture: percentage change relative to status quo over time in years

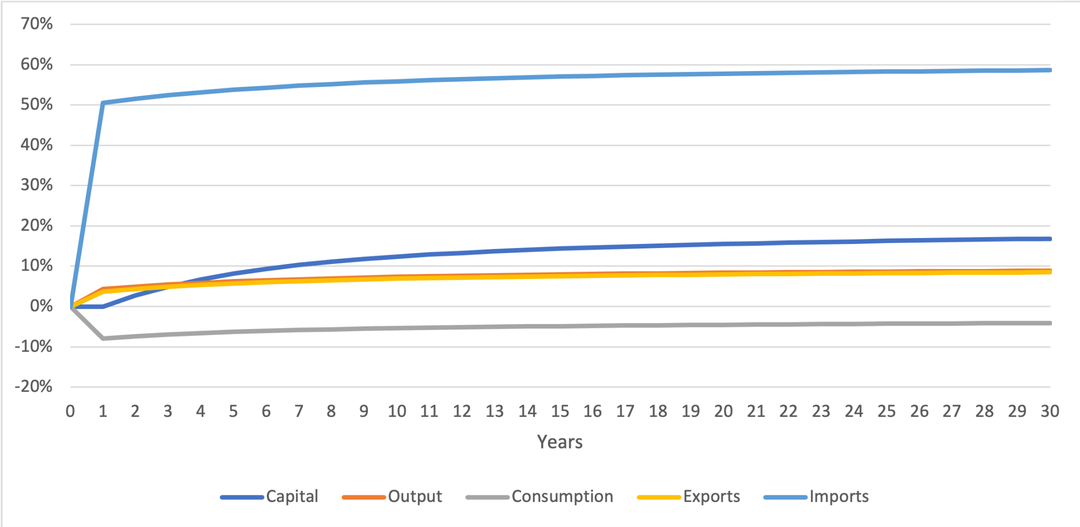
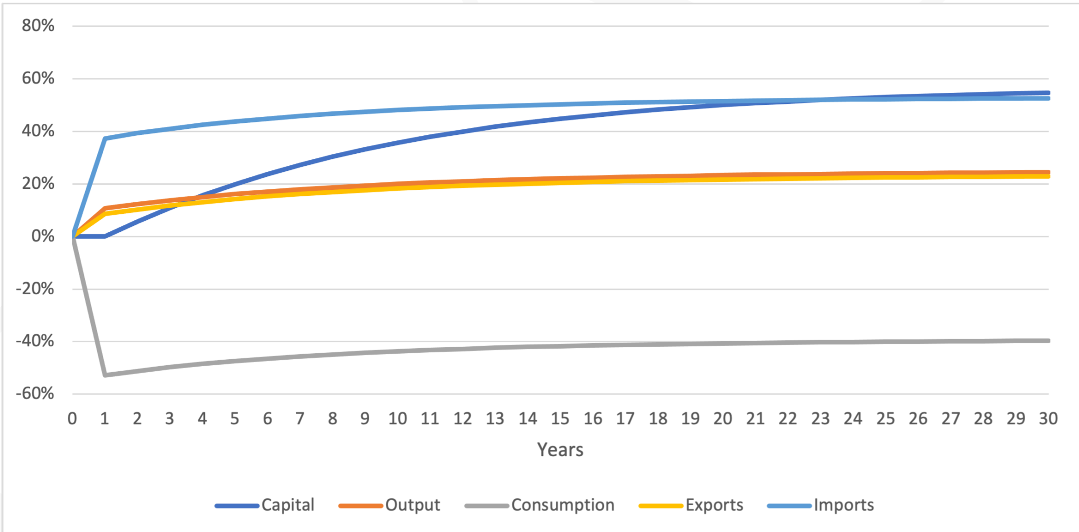


Figure (v): Mining: percentage change relative to status quo over time in years



Note that although the change in consumption of mining is large, it is only a very small part of overall consumption

Figure (vi): Manufacturing: percentage change relative to status quo over time in years

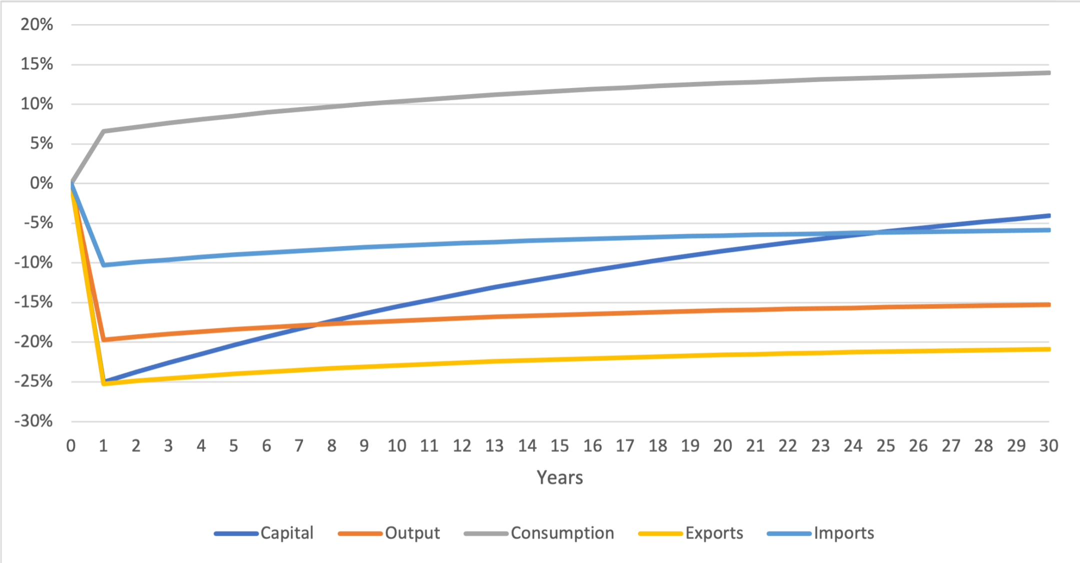
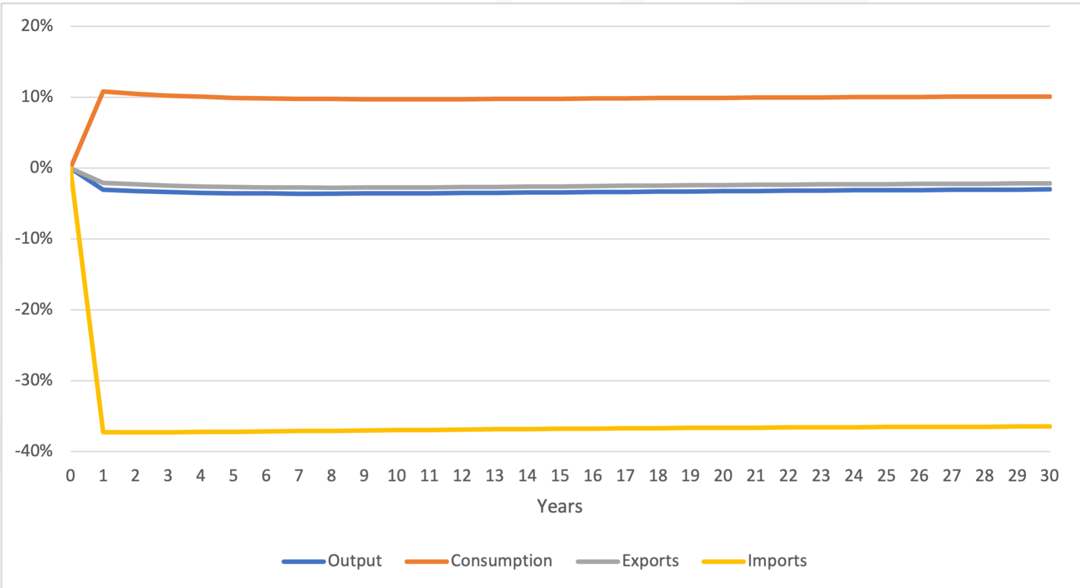


Figure (vii): Utilities: percentage change relative to status quo over time in years



Future work

Robustness check To ensure our conclusions are robust, we intend to run a wider variety of shocks for a variety of parameterisations. This will allow full features of the MAIWAR model to be brought to bear in analysing the Greater Gladstone Economy (and other regions of interest in Queensland). In particular, we will model different forms of adjustment paths, allow for varying degrees of uncertainty and evaluate optimum policy options for the Gladstone economy over time.

Allocating the smelter's land and capital to new production Following the closure of the Kurri-Kurri aluminium smelter in the Hunter regions of New South Wales in October 2012, the process of decommissioning began. Federal and state government approval to repurpose the site for a gas-fired power station was finally given in December 2021: a full nine years after the closure. Our model is well-equipped to study the opportunity cost of such delays. In due course, we will look at future policy actions such as putting the smelter capital such as land to different uses. BSL could for instance be converted into a hydrogen processing plant or some other green-energy facility. This could lead to a structural change and an increase in the productivity of Manufacturing. The model would be well-suited to studying this with an emphasis on estimating the cost of delays and the resulting unproductive capital.

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