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A Performance Analysis of the Australian Nitrogen Fertiliser Value Chain

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Abstract

Australia's nitrogen fertiliser value chain accomplishes its core goal of supplying a wide range of fertiliser products to end users. There has been a shift over the last 40 years towards increasing reliance on imports over domestic production and, for most of that time, excepting the constraints of 2021-2022 coinciding with high demand, supply has not been an issue. The degree and range of competition by suppliers along the value chain varies. Since trade liberalisation, competition at the raw material end of the value chain has increased as the nitrogen fertiliser market has become increasingly contestable. The retail end of the value chain has a large number of participants in both national and local markets, but distribution and white labelling activities are concentrated within a few firms in the two regional domestic markets. Despite earlier recommendations from the Australian Parliament and the Australian Competition and Consumer Commission, price transparency continues to be an issue. Compared to other highly developed nations, Australian agriculture uses relatively little nitrogen fertiliser per hectare and total use is a tiny proportion of the global nitrogen market. Problems of pollution from nitrogen fertiliser used in agriculture are markedly less acute than elsewhere in the world, which also means that the adoption of enhanced efficiency fertilisers is correspondingly low.

Keywords: Enhanced efficiency fertilisers, nitrogen fertilisers, value chain performance

Introduction

In a companion paper (Wirtz *et al.,* 2023), the Australian nitrogen fertiliser value chain was described and mapped.[1] This was done to trace and understand the flow of product, and the form and extent of services and value added, by the firms operating along the value chain. Recognising recent concerns about environmental damage caused by nitrogen fertilisers, a particular focus of the Wirtz *et al.* (2023) analysis was on the potential role of enhanced efficiency fertilisers in the fertiliser market. If economic for suppliers and farmers, enhanced efficiency fertilisers are a technology with the potential to deliver improved environmental outcomes. In this paper, the examination of the nitrogen fertiliser chain is taken further to a formal performance analysis, where gaps can be identified and ways suggested whereby the uptake of enhanced efficiency fertilisers could be increased.

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[1] A theme noted in that paper was the strong historical link between the fertiliser and explosives industries, and in some cases their co-location. Some aspects of the regulation of the explosives industry, as it spills over to the fertiliser industry, is provided in Appendix 1.

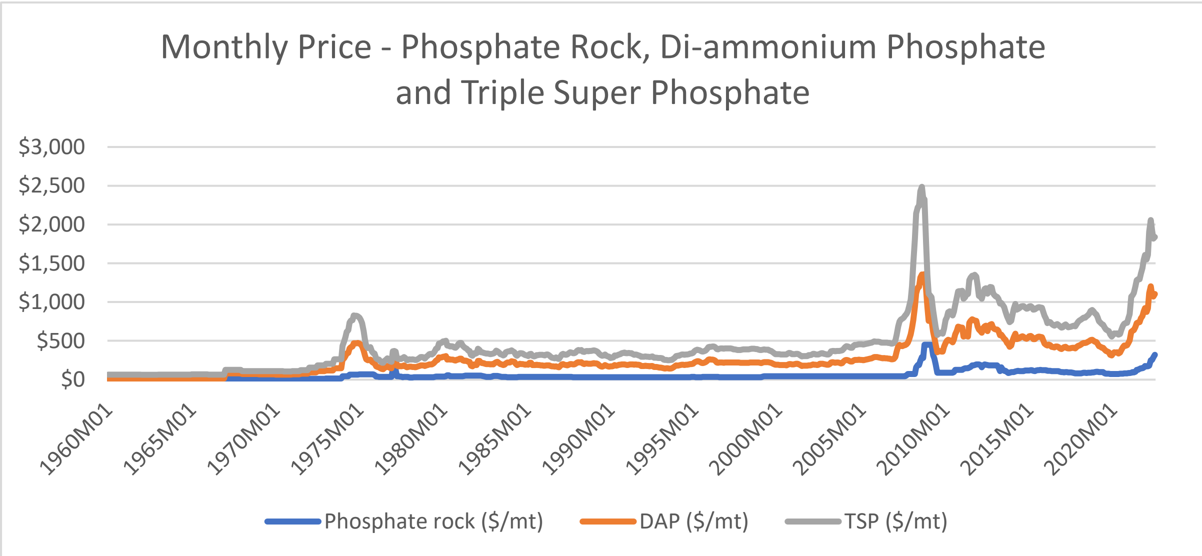
It is instructive to note that finding accurate and detailed historical information on the price paid for fertilisers in Australia, such that they might be compared to other markets, is itself difficult, for a number of reasons. Australia only accounts for 1.3 per cent of total world fertiliser consumption and 3.5 per cent of world imports (World Bank, 2022), resulting in a considerable import dependence. Given that Australia has no tariffs or subsidies for fertiliser production or consumption, and assuming negligible market power by market participants, there should be few, if any, market disparities between the import parity price and what is paid by Australian farmers, minus costs of retail and distribution. Further, the Australian fertiliser market has few, if any, barriers to entry for starting entrants beyond the costs between landing and the customer. The price difference from the import cost would likely be caused by distribution, transport costs, retail margins and risk. As well, large price discrepancies can be the result of the slow supply response in the Australian nitrogen fertiliser market. Orders of substantial quantities (greater than 10kt) can take 2-5 months from the date of order to reach the retail level (ACCC, 2008) and it can take 3-5 years for new capacity to be built.

Before discussing the data inputs and the results of the performance analysis, it is also instructive to review previous formal assessments of this chain, particularly those where participants in the chain were legally required to produce evidence of the structure and operations of this industry.

Allegations of Anticompetitive Behaviour in Australian Fertiliser Markets

During late 2007 and early 2008, large increases occurred in traded phosphorus and phosphorus-nitrogen fertiliser prices, with increases of 100-400 per cent (Figure 1).

Figure 1. Monthly price graph for North African phosphate rock, di-ammonium phosphate, and triple super phosphate, 1960-2022 (nominal $US)



Source: World Bank (2022)

This sudden price rise prompted allegations of price gouging and concerns over market concentration in the Australian fertiliser market. From these allegations, in February 2008, the Australian Senate referred the matter to the Select Committee on Agricultural and Related Industries for inquiry. The Terms of Reference were to examine:

'The pricing and supply arrangements in the Australian and global chemical and fertiliser markets, the implications for Australian farmers of world chemical and fertiliser supply and pricing arrangements, monopolistic and cartel behaviour and related matters.'

Concurrently, in February 2008, the Minister for Competition Policy and Consumer Affairs requested that the Australian Competition and Consumer Commission (ACCC) examine fertiliser prices. These subsequent reports contained significant detail on economic and social aspects of the Australian fertiliser industry.

The Final Report from the Parliamentary Inquiry was released in August 2009 (Commonwealth of Australia, 2009). It had a focus on the structural components of the Australian fertiliser market, as well as receiving submissions from stakeholders. Evident in many submissions was anger at major fertiliser suppliers for behaviour thought to be 'price gouging' and the overall effect that the higher prices of fertiliser were having on farm margins (section 2.9). The core of the challenges faced by Australian farmers was summarised by the submission of the National Farmers Federation (NFF) to the Inquiry which stated:

'The higher fertiliser and chemical prices are eating into the margins…. This is forcing farmers to adjust their production systems, often at the expense of productivity'. (2.12)

The Parliamentary Inquiry concluded that the causes of increasing fertiliser prices came from several sources, which had compounding effects on prices. First, as the International Fertiliser Industry Association (IFA) had indicated, aggregate global fertiliser demand had increased by 5 per cent which was above previous trends (2.20). The IFA further identified five factors affecting world fertiliser demand during 2007-2008, viz.:

- Growing world population (2.24) causing an increase in global aggregate demand for calories.
- High global commodity prices (2.29) because of the lag between planting and harvest and strong global demand for calories.
- Increased biofuel demand placing pressure on commodities (2.30): as the production costs of nitrogen fertiliser are linked with global fossil fuel prices, biofuel (mainly derived from corn) was seen as a way to reduce consumer fossil fuel prices. Also in 2006, leaded petrol additives were phased out in the United States, which left ethanol as the major source for fuel refiners to raise octane levels (Hertel *et al.*, 2010).
- Shifting dietary patterns to higher quality protein diets in developing countries (2.32).
- Increasing urbanisation and land used for crops for biofuel production reducing the supply of high quality arable land for food production, meaning higher levels of inputs to farm production were needed to maintain productivity (2.34).

The IFA also noted that, on the supply side of the fertiliser market, 2007 was a year of record production (2.35). Increasing fertiliser supply involves considerable time lags to build new capacity and requires considerable capital. In times of high volatility of prices there can be a much lower propensity to invest in new production capacity along the value chain when little assurance exists about the levels of future prices and profitability.

The Parliamentary Inquiry report also detailed the changing nature of the nitrogen fertiliser market during the 2000s as a result of decreasing ammonia production in the United States, caused by historically high prices of natural gas. Natural gas prices increased to over $US10/MMBtu during 2005. At the same time, productive capacity had steadily increased in countries like Qatar and Saudi Arabia, both becoming leading suppliers to the Australian fertiliser market by the late 2000s (Wirtz *et al*., 2023, 110).

Outside of supply and demand pressures, the Inquiry considered the effects of the concentration of market shares and how that affected price transparency (2.77). The discussion in this section related to whether Australian fertiliser suppliers were price-makers or price-takers. Multiple submissions to the inquiry claimed a relationship existed in which fertiliser prices rose with commodity grain prices, effectively eroding marginal gains available to farmers (2.89). One submission to the inquiry observed:

'Do you think that the price of fertiliser would have increased so much if the price of wheat had not doubled, and canola gone from $600 a tonne in December to $850 a tonne in February?' (2.80)

Some argued to the Inquiry that suppliers were increasing prices to levels of whatever the market could bear, while others argued that fertiliser prices rose alongside agricultural commodities as a result of increased global demand deriving from the more valuable and profitable grain crops. Incitec Pivot, in their submissions to the Inquiry, took the latter view explaining that the company, along with other Australian fertiliser manufacturers and retailers, are very small players in a globalised market and, as such, are price-takers (2.82). Australia was a net importer of fertiliser products with highly seasonal and weather-dependent demand (2.81). Prices that Australian suppliers can charge are determined on an import parity basis, i.e., the price a purchaser would expect to pay for equivalent imported goods.

The committee also investigated the implications of price transparency in the Australian fertiliser industry at the regional and national market level. Concerns were raised by the NFF that the collapse of global fertiliser prices in late 2008 was not passed forward to the farmer clients (2.115). This concern was echoed in another submission in which it was claimed that Australian farmers were paying 2-3 times as much as American farmers for their fertiliser and explicitly singled out Incitec Pivot for acting anti-competitively (2.116). In a contestable market, a firm operating with a significant market share and contriving to generate super-normal profits would expect before long to be confronted by strong competition from short-term entrants. The description 'contestable' has the assumption that barriers to entry and exit are low, there are insignificant sunk costs, and there is equal access to technology (Khemani *et al*., 1993). Realistically, none of these conditions can be met perfectly or promptly in any market but, in the context of the Australian fertiliser market, contestability is near as the traded product is widely produced as a commodity, and effective sunk costs are low because any new competitor is readily able to import product from abroad.

The Parliamentary Report cited allegations of price fixing of ammonia between Incitec Pivot and Orica (3.7), reporting claims that these two companies had raised prices in parallel through 2007 and 2008 (3.12). The allegation was made that Orica had been unwilling to sell ammonia directly to customers from their Kooragang Island plant in Newcastle because of a commercial agreement between the two firms. This allegation was categorically denied by Incitec Pivot (3.8) who noted that, in a supply sharing agreement between the two firms, the price of ammonia was dictated by the price of urea which followed world import parity prices.

Value Chain Performance Measurement

Measuring the performance of a value chain is a critical component of value chain research. Aramyan (2007) provides a conceptual framework to assess the performance of a food value chain which uses four main performance indicators across connected fields - business efficiency, flexibility to change, responsiveness to customers, and food quality. This approach can be applied to most agri-food supply chains. However, the concept of measuring food quality in the context of the nitrogen fertiliser value chain presents a difficulty. In this analysis, the concept of sustainability is substituted for the concept of food quality, with 'sustainability' referring to the adoption of new pollution-reducing technologies and the availability of pollution-reducing management solutions.

The concepts for assessing the performance of a value chain as set out in Aramyan *et al.* (2007) relate to earlier work by Luning *et al.* (2002) and Luning and Marcelis (2006). In those papers, the authors analysed the technological and managerial functions required to maintain food quality control in agri-food supply chains. These functions included quality, cost, availability, organisational flexibility, dependability, and customer service, all concepts which are able to be applied to the nitrogen fertiliser value chain.

Governance is another core concept in value chain research for understanding how firms in the chain coordinate their production and transformation activities. Governance structures are described by Gereffi *et al.* (2005) as a spectrum of different coordination mechanisms, from markets with low intrinsic coordination to hierarchies dominated by vertically integrated firms with rigid and elaborate coordination structures. This concept of governance encompasses the idea of 'lead firms' which exercise various types and levels of power on the rest of the value chain. These notions have been described and discussed in Wirtz *et al.* (2023).

In undertaking the analysis of the performance of the fertiliser value chain in Australia, the results are assessed against three criteria: (i) how value chain members approach sustainability of nitrogen fertiliser use; (ii) the availability of enhanced efficiency fertilisers (EEF) products; and (iii) access to chain support services such as soil testing and agronomic services for which sustainable nitrogen fertiliser use can be encouraged.

Metrics and Data Used

The primary criterion in the Aramyan framework of value chain performance is efficiency of the supply chain. Efficiency refers to how well resources are used in the value chain by its members. Assessing efficiency involves considering the financial and economic measures of production, costs of production, profits, returns on investment and inventory management. As many nitrogen fertiliser value chain participants are small to medium enterprises with no requirements to publicly publish this information, in calculating value chain flows in the following the emphasis is on larger companies that are publicly listed and for which information is obtainable.

Flexibility is the second measure of performance. To evaluate flexibility, consideration is given to how well the overall supply chain responds to the volatility of product flows. The original Aramyan framework has flexibility in the context of agri-food value chains and how well farms respond to the inherent medium- and longer-term volatility of agricultural production systems. Nitrogen fertiliser, being an input, needs to be evaluated differently. The indicators used for fertiliser are volume flexibility, delivery flexibility and backorders.

Responsiveness is the third indicator in the performance evaluation framework. Whereas flexibility refers to how well value chain members respond to medium- and longer-term volatility, responsiveness refers mainly to how well firms respond to short-term changes in product flows. Responsiveness in fertiliser value chains deals with day-to-day fluctuations in fertiliser demand. How well individual members respond to a specific farmer request for fertiliser in days to weeks is able to be measured. The indicators considered in this study focus on the infrastructure provided by fertiliser retailers and distributers to facilitate providing nitrogen fertiliser to buyers in the short term, including the ability to respond to sudden orders.

Sustainability is the fourth criterion evaluated. Purvis *et al*. (2019) describe the concept of sustainability using a three-pillar perspective of social, economic, and environmental characteristics. There is considerable overlap between these perspectives. In this regard, the primary focus of the sustainability criteria is on economic and environmental aspects of nitrogen fertiliser use in light of an objective of increasing the presence of EEF products in the total supply of nitrogen fertiliser. This incorporates questions of how available EEF products are to producers, how well they work, their shelf lives, and how they are marketed.

Assessing these four indicators of the performance of a value chain, particularly that of efficiency, requires inserting into the value chain map presented in Wirtz *et al.* (2023) detailed information about values of products at different stages of the chain as well as the volumes of products. Since many of the transaction points are embedded within vertically integrated businesses, values at those points are not available publicly, so estimates and inferences have to be made based on the costs incurred for the provision of specific services. This is done in the following section.

Quantifying the Value Chain

As mentioned above, to assess the selected four indicators of value chain performance requires putting information into the value chain map presented in Wirtz *et al*. (2023) about values of products at different stages of the chain as well as volumes of products. The aim is to identify gaps in the value chain depicted in Figure 5 below with the view that a gap that exists in the provision of EEFs is able to be identified and action to reduce the gap may be facilitated.

Offshore elements of the value chain

Natural gas and manufacturing

Methane (CH_4), commonly referred to as natural gas, is the primary hydrogen feedstock for industrial ammonia production. The largest and most cost competitive natural gas deposits are located in the Middle East, Central Asia and Northwest Siberia. This geographic area contains approximately 70 per cent of the world's proven oil and gas reserves. Other natural gas producing regions include the Caribbean and Southeast Asia. Much of the world's nitrogen fertiliser production is concentrated in these regions as a result of the comparative advantage stemming from close proximity to this essential natural resource input.

The relative cost of transporting natural gas is also an important factor determining the location of ammonia production. The cheapest option for transport is via natural gas pipelines. Despite being capital intensive, pipelines can move large quantities of natural gas cheaply and require relatively little support infrastructure. This is in comparison to liquified natural gas. Liquification is a relatively energy intensive process which requires costly infrastructure to process on and off vessels, as well as storage for offloaded gas.

A urea production plant planning model from the UNIDO's *Fertilizer Manual* (1998) was used to estimate the costs of production per tonne of urea. Natural gas is the primary feedstock used but the price is volatile. The monthly average spot price for January 2020 was chosen as the base cost of gas to remove any noise generated by the subsequent COVID pandemic and the resulting volatility of petrochemical markets. It is estimated that the costs of production of urea at that time were approximately $A375/tonne. Compared to the World Bank's *Pink Sheet Commodity* data (World Bank, 2022) on urea for the same period, this estimate is about $A50/tonne higher. Within the UNIDO's *Fertilizer Manual*, the authors recommend that plant authorities source natural gas on long term contracts to save money through volume, instead of being marginal buyers at the whims of spot prices. The use of such contracts may explain this price difference.

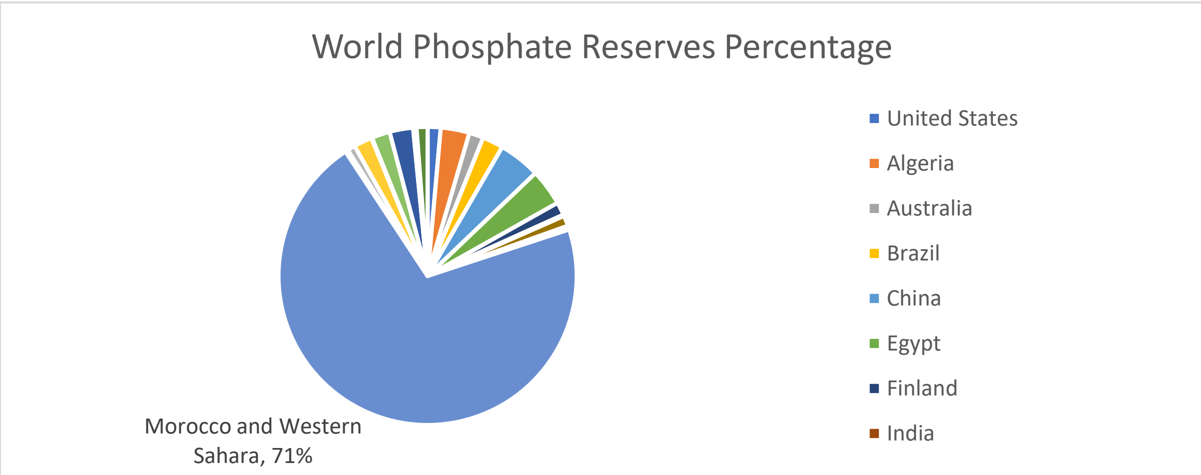
Phosphate rock, sulphates, and ammonium-phosphate fertilisers

Phosphates are mainly sourced from phosphate rock deposits and, along with sulphur, are often combined with nitrogenous fertilisers. Ammonium-phosphate fertilisers are supplied as mono-ammonium phosphate (MAP) or diammonium phosphate (DAP).

Phosphates are a non-renewable resource mined from sedimentary and igneous deposits. To be traded on the global market as phosphate rock, it must contain at least 28 per cent phosphorus pentoxide (US Geological Survey, 2021). This concentration is achieved through a process known as 'beneficiation through froth flotation', in which low value gangue minerals are separated from the ores (FAO, 1988).

Sedimentary deposits are the source of approximately 80 per cent of total world phosphate rock production, owing to their geological concentrations and ease of mining (UNIDO, 1998). These deposits take several geological forms. Surface alluvial deposits such as the historically large deposits seen in places such as Nauru and Christmas Island, were the first to be exploited at large scale. These deposits offered very high-grade phosphate rocks with relative ease of mining. Since the late 20th and early 21st century, most of these deposits have been depleted. Morocco has the largest known remaining reserves (Figure 2).

Figure 2. World phosphate rock reserves, 2021



Source: (US Geological Survey, 2021)

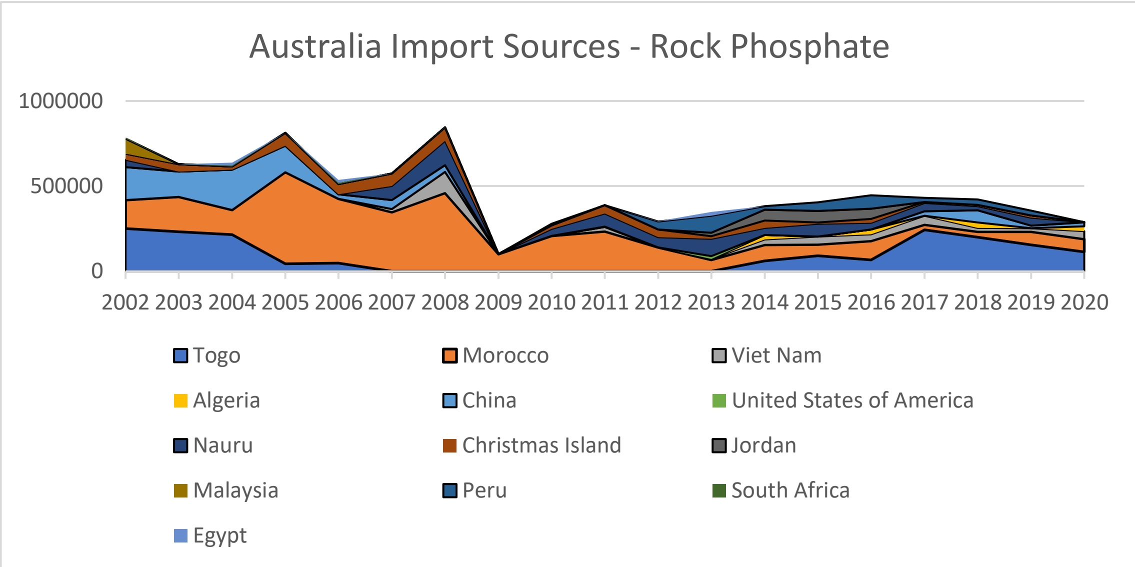
The major producers of phosphate rock are the United States, China and Morocco, together accounting for about 75 per cent of global production. Production from the United States and China is mostly used for domestic agricultural application. Morocco accounts for 33-37 per cent of world exports, followed by Jordan which supplies between 15-20 per cent of exports. There are no major signs of forward and backward linkages between offshore phosphate rock producers and onshore producers, possibly because phosphate rock is a globally traded commodity with a standardised grading system.

Australian rock phosphate imports have historically been volatile, in both quantity and price. Prior to 2016, Morocco was consistently the greatest source of imports but, as a result of human rights concerns in Morocco-controlled Western Sahara, mainly from European shareholders, Incitec Pivot paused imports from the country between 2016 and 2022 (Figure 3). Prior to 2016, Morocco accounted for between 25-96 per cent of imports. Since 2016, Togo, with less than 3 per cent of the world reserves, has supplied between 33-52 per cent of the rock phosphate imported into Australia.

The large decline in rock phosphate imported into Australia in 2008, as shown in Figure 3, is attributable to two events: first, the sharp increase in the price of rock phosphate and of phosphate fertiliser, as shown in Figure 1; and second, the closure of two phosphate fertiliser processing plants in Australia and the opening of the new plant at Phosphate Hill by Incitec Pivot. Taken together, these effects caused the use of rock phosphate to decline and the use of mono-ammonium phosphate and diammonium phosphate (MAP/DAP) to increase.

In terms of volume, 93 per cent of all phosphate rock imported into Australia is used for mineral phosphate fertilisers, mainly MAP/DAP and triple/single super phosphate. This is done at three major locations: Incitec Pivot's Geelong single superphosphate plant, IPF's Phosphate Hill MAP/DAP plant near Mt Isa (~1000kt/year) and CSBP's Kwinana fertiliser plant (see Wirtz *et al*., 2023).

Figure 3. Australian import sources of rock phosphate, 2002-2020



Source: ABS (2021)

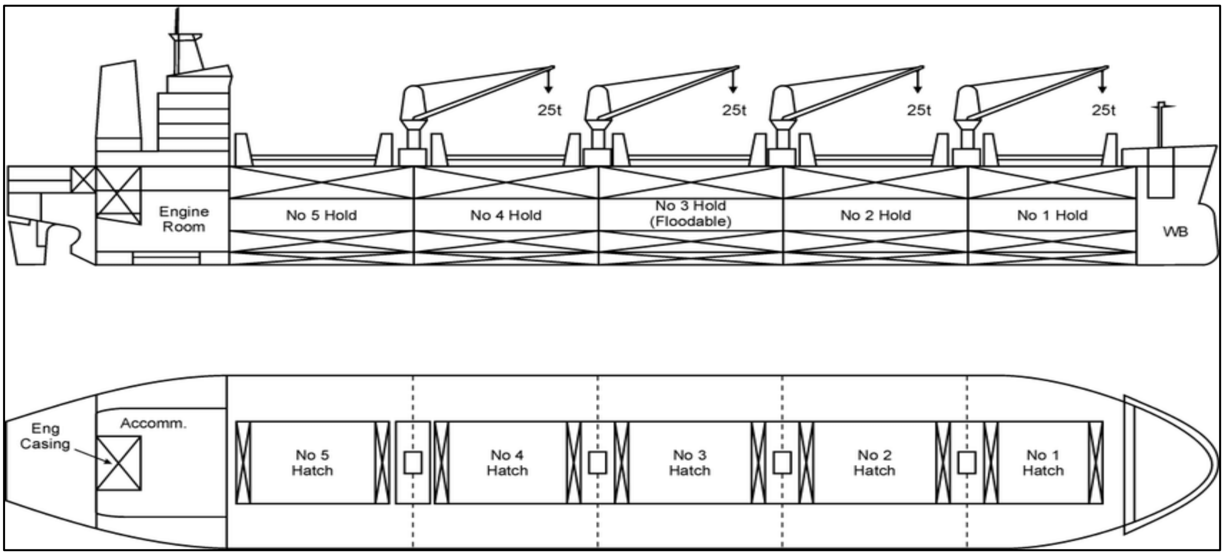
The Phosphate Hill plant of Incitec Pivot is a joint phosphate mine/fertiliser plant location with ammonia facilities to produce MAP/DAP. The production of MAP and DAP require significant amounts of sulphuric acid to produce the phosphoric acid, 50-60 per cent of which is obtained from Glencore's Mt Isa cooper smelting facility, with the balance coming from imported elemental sulphur.

Bulk shipping, transportation, and importation

Nitrogen fertiliser is shipped in a number of ways depending on the form in which it is used on farm. The four major types of nitrogen fertiliser (Urea, MAP/DAP, Ammonia), in three possible forms of application (solid, liquid and gas), present different logistical challenges in global value chains.

Moving nitrogen fertilisers long distances, as solid or liquid products and bulk or bagged, is primarily done by bulk cargo carrier vessels. These vessels can range in size from relatively small 3,000 DWT (dead weight tonnes) capacity mini bulk carriers for smaller ports with limitations of vessel draft depth, to larger vessels with ~200,000 DWT capacities (though the largest vessels are largely used for metallic ore and thermal cargos). Ships with capacities of 25,000-80,000 DWT are the ship size of choice for bulk fertiliser transport *(Chris Lawson, pers. comm., 2022)* as they can navigate into nearly all of Australia's ports, including the smaller and less equipped regional ports near agricultural centres such as Portland and Port Lincoln. As shown in Figure 4, Handysize vessels generally have five cargo holds and four 25–30-tonne bucket cranes for cargo unloading at destination ports.

Figure 4. Diagram of a standard Handysize bulk cargo vessel



Source: (Akyar, 2018)

Solid cargos have to be kept dry during their voyage as any water will cause caking, rendering them unfit for use, and will also cause corrosion of the vessel. Further, ships chartered to transport fertiliser products into Australian have to observe biosecurity standards as set out in the Biosecurity Act of 2015 (discussed below in the onshore value chain elements section).

Rates for bulk cargo are arranged through the Baltic Exchange based in London. Re-constructing a precise price for transport for fertiliser to use in value chain analysis is difficult as the origins of cargos vary and route pricing is based on quotes between the charterer and the shipping company. As a proxy, the Baltic Exchange Baltic Handysize index, which measures the spot freight prices for 38,200 DWT Handysize vessels, is used. Prices paid by the shipper (the party which orders the goods) are determined by either length of voyage (cost per day) or total tonnage carried (cost per tonne) in the charter contract.

Obtaining exact information on the terms of shipping contracts is difficult as they are not usually publicly available. Estimates available for daily shipping costs inclusive of staffing and fuel indicate approximately $US10,000-$30,000[i]; these costs were often towards the lower end of the range before the current Covid pandemic. Assuming a 30-day voyage between the Port of Hamad in Qatar, which is located next to QAFCO's fertiliser plant, and the Port of Melbourne, on a standard Handysize vessel of 38,200 DWT, and considering the fees of loading and unloading at both ports, an approximate cost of bulk cargo ocean travel for each tonne of bulk urea fertiliser is $A33.50 (Table A2). The estimate made here is similar to that by the ACCC (2008) which was a range of $A35/tonne for 2000 and $A125/tonne in 2008. Another estimate obtained was approximately $A55/tonne for bulk solids and $A64/tonne for bulk liquids ocean transport without port costs (Whitelaw, 2022). The average of the three estimates excluding port costs provides a value of $A46/tonne and $A62/tonne in aggregate transport costs. The extreme 2008 price can be attributed to the substantial increase in shipping costs of that period, with the benchmark Baltic Dry Index (BDI) reaching historical peaks. The price calculated by the ACCC for 2000 is roughly equal to those prevailing in early 2020 assuming the BDI as a proxy.

Onshore elements of the value chain

Biosecurity charges

The importation of nitrogen fertiliser into Australia is regulated under the Biosecurity Act 2015 (Commonwealth of Australia, 2015) and the Biosecurity (Prohibited and Conditionally Non-prohibited Goods) Determination of 2016 (Commonwealth of Australia, 2016) via the Department of Agriculture's import policy governing chemical, mined and synthetic fertilisers (Department of Agriculture, 2019). The act requires the goods to be free of biological and chemical contaminants in accordance with Australia's longstanding zero tolerance biosecurity policy. Management of this policy is covered under the Department of Agriculture's 2004 Imported Inorganic Bulk Cargo Fertiliser Assessment and Management Policy (Department of Agriculture, 2019). The policy provides a risk classification level to both bulk carrier vessels and value chains at three levels (Level 3 requiring the greater number of checks and audits), depending on biosecurity audit results.

The audit process is carried out largely external to the Department though a number of approved surveyors at both domestic and international locations[ii]. As a result of Australia's biosecurity laws surrounding bulk dry fertiliser imports, a decreased number of ships are available for the cartage between ports. A ship could arrive at an Australian port with a load of bulk dry fertiliser and leave with one of grains, but not the other way around as any ship that has carried cargo that could be a potential biosecurity hazard such as commodity grains or foodstuffs would require significant biosecurity checks (although this is generally not an issue for Australia as the country only infrequently imports commodity grains.

Transportation

Transportation modes between nodal points in the domestic nitrogen fertiliser value chain vary considerably. Train and truck transport are generally the only forms of transport for the transport of nitrogen fertiliser products, in either liquid, bulk or bagged, or gaseous forms. Fertilisers account for 8 per cent of all rail freight in Australia (BITRE, 2014), moving products between coastal areas to the largely agricultural inland for the bulk of the journey before reaching intermodal points of transport which is undertaken by various trucking companies and customers.

The Department of Infrastructure and Regional Development has maintained statistics on freight rates across Australia for both road and rail since 1965, as reported in Grain Trade Australia (2022). Since the beginning of data collection, there has been a general downward trend in freight costs for both road and rail, with real costs coming down from 10-14c per tonne per kilometre in 1965 to 4-8c per tonne per kilometre in the early 2000s. Prices have generally risen to 9-16c, as indicated by Grain Trade Australia road bulk handler site location differential (Grain Trade Australia, 2022)[2]. Before the early 1980s, road freight costs were generally 2-4c per tonne higher than that of rail. This could be explained by a decline of government support for railways and an increase in truck capacity. These figures are not specifically the costs of transporting fertiliser as the data gathered by the Department is the average of quotes for interstate routes for both road and rail, but the figures provide the clearest available information about the cost of freight. Given the heterogeneous nature of fertiliser freight transport, it is difficult to calculate prices. The combinations of transport options are numerous: a farmer may own a truck to transport grain to a grain bulk handling site and backload fertiliser, independent contractors can be used between a farm and retail outlet, or the retail outlet could have their own delivery operations.

Distribution and retail

Distribution and retailing are the key inseparable components of the way nitrogen fertilisers are aggregated and sold before reaching their final destination and use on farm. Aggregation in

[2] Werneth to Geelong Terminal Location differential of $12.50 divided by 77km (Grain Trade Australia, 2022).

warehousing complexes is the central role of the distribution component, done mostly by the lead firms in the value chain.

The retail end of the nitrogen fertiliser value chain has a range of complexities in how governance structures coordinate sales and distribution. The retail fertiliser market in Australia is one in which distribution-centric lead firms such as IPF and CSBP are largely absent, instead supplying a wide array of lead retail chains such as Elders and Nutrien Ag Solutions, and independently run small-medium enterprises such as those represented by Combined Rural Traders, all of which engage in a level of product white labelling. The fertiliser retail trade overlaps with the wider farm and agricultural supplies and agronomic services retail market due to the cross competencies associated with their sales. Despite this overlap, there are still a significant number of mainly small-medium sized firms that focus exclusively on fertiliser sales. As discussed in Wirtz *et al.* (2023), it is not uncommon for retail outlets to maintain strong linkages with distribution lead firms in formal and informal exclusive supply relationships. These relationships can provide benefits in the form of access to fertiliser product labels which can have brand value, especially in fertilisers focussed on niche uses and specific production systems. For example, horticultural production systems have more differentiated fertiliser products from which to choose than other agricultural production systems.

In the Australian fertiliser market, large firms comprise a significant share of the total volume, but do not necessarily retail directly to customers (Wirtz *et al*., 2023). Instead, a large number of independent and chain retailers operate in the retail fertiliser market. Key buyers or 'resellers' are independent retailers or middle-operators who act as intermediaries between firms and customers (Kaplinsky and Morris, 2001). The business of these retailers extends beyond fertilisers into general farm supplies and services. There are significant economies of scale with retail in larger geographical markets such as those present in regional centres, since fewer outlets are required the greater the number of customers. As well, though, smaller, mostly independent retailers operate to meet demands in the smaller markets. Similar to supermarkets, chain farm supplies stores such as an Elders or Nutrien Ag are viable in markets that demand substantial volumes of nitrogen fertilisers and other supplies. Smaller outlets have the market fit to function in the smaller markets, working not necessarily on volume but convenience and specialisation, akin to a local food retailer. This type of business in the value chain is represented in two different ways: small town independent farm supply stores, but linked to buying groups such as Combined Rural Traders in their association with Nutrien Ag or to Australian Independent Rural Retailers with Elders.

Calculating the cost components of retailing nitrogen fertiliser is difficult so, again, proxy measures have to be used. The ACCC (2008) calculated in 2007 that the wholesale margin for nitrogen fertilisers was approximately $100/tonne. They did this by using the difference between the free-on-board price of urea and the wholesale price, a value which does not differentiate between distribution, retail, and transport costs.

Exact current time series data for urea in the Australian market were unobtainable, so three different proxy measures were calculated. First, the distribution earnings before tax and interest from Incitec Pivot Linited's (2020) *Annual Report* was used, divided by the sale volume. This gave a value of $24.70/tonne. The second proxy used revenue from distribution from IPF minus calculated costs of manufacturing from the model derived from the UNIDO's *Fertilizer Manual* (1998). This gave a value of $27.98/tonne for distribution. The third approach used the margin by-product figures from Elders Limited (2020) *Annual Report*. This provides a detailed picture of their specific product margins at the retail level. Some 13 per cent of Elders rural products turnover of $229m was in fertiliser sales, moving 809kt of total fertiliser products[iii], giving a figure of $36.98/tonne. The advantage of this proxy is that Elders serves both the eastern and western fertiliser markets and is not involved in the manufacturing of nitrogen fertiliser, instead having a core focus on retail. An average of the first two values at

$26.36/tonne and Elders fertiliser retail margin of $36.98/tonne gives a total of $63.34/tonne. This is the proxy measure used for the cost component for distribution and retail. This value is significantly lower than that found by the ACCC in 2008 though, as discussed above, considering the new firms involved in retail and distribution in the Australian fertiliser market, it is likely that competition has reduced margins since the ACCC study.

Putting all that information together allows the identification of value flows in the Australian fertiliser value chain. This is shown in Figure 5.

Performance Analysis

Efficiency

Production costs, distribution costs and profit

Production costs associated with the manufacturing of nitrogen fertilisers are inherently linked to the price of natural gas. Using the production model that was discussed above, over the period of 2000-2022 it was found that natural gas amounted to between 18 and 65 per cent of production costs. The price of natural gas in the model was taken from the Henry Hub natural gas price (World Bank, 2022), which often serves as the standard spot price for world natural gas markets. This has limitations as nitrogen fertiliser plant operators often do not purchase gas through spot market transactions, but rather operate via medium- to long-term supply agreements, which are often priced considerably lower than that of the spot natural gas market (UNIDO, 1998). The wide range of production costs does indicate the supply pressures which push up fertiliser prices.

Despite this, as shown in Wirtz *et al*. (2023, Figures 3 and 4) the price of urea more closely follows the price of wheat than the price of natural gas. This could be for a number of reasons: there may be a lag between input prices for urea and production costs, or high agricultural commodity prices might cause increased demand for urea inputs. In the Australian production environment, the size of the Australian nitrogen fertiliser market fluctuates with the weather and expected returns from production. Consequently, the profits of nitrogen fertiliser companies such as Incitec Pivot can be markedly variable (Figure 6).

Incitec Pivot’s returns on fertiliser manufacturing and distribution are closely correlated with that of global fertiliser prices (Figure 7) (using urea as an indictive figure).

These figures do not differentiate the organisation’s manufacturing and distribution costs as only recent annual reports provide this detailed breakdown. It would be fair to assume that other comparable domestic manufacturing and distribution firms have similar margins given that nitrogen fertiliser is traded at import parity price plus costs of distribution.

Flexibility

Volume flexibility

There are numerous difficulties in measuring the volumetric flexibility of the nitrogen fertiliser supply chain. Aramyan (2007) suggests customer satisfaction, volume, and delivery flexibility as indicators. The first is beyond the scope of this paper as the lead firms do not report such information and it would require a large survey across numerous types of nitrogen fertiliser customers. The second and third indicators can be measured. Aramyan (2007) suggests measuring the demand variance between profitable output volumes.

Figure 5. Australian Nitrogen Fertiliser Value Chain. Source cost components sourced from 2020 period. Product flows estimated, final cost per tonne figure based on urea

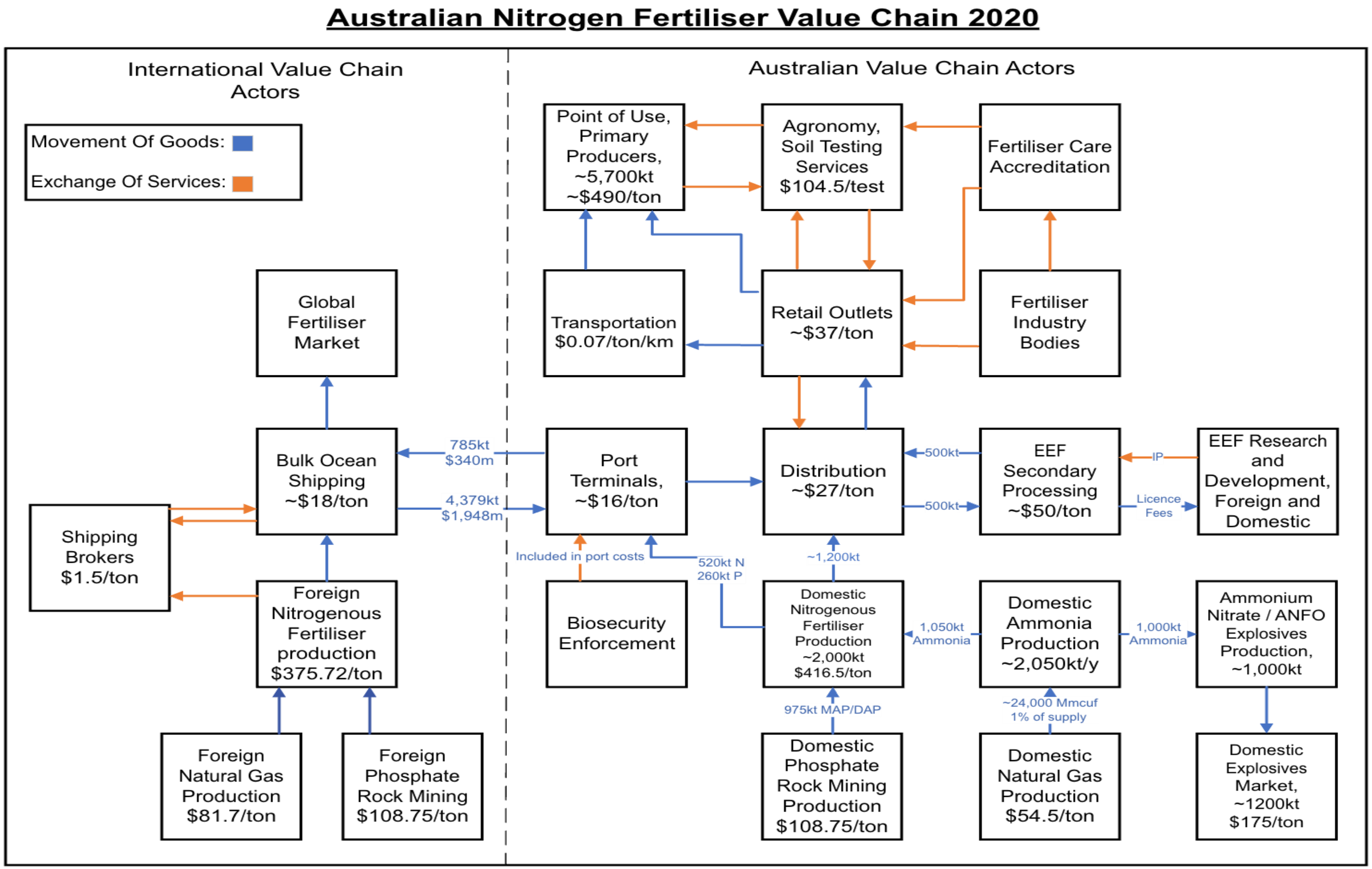
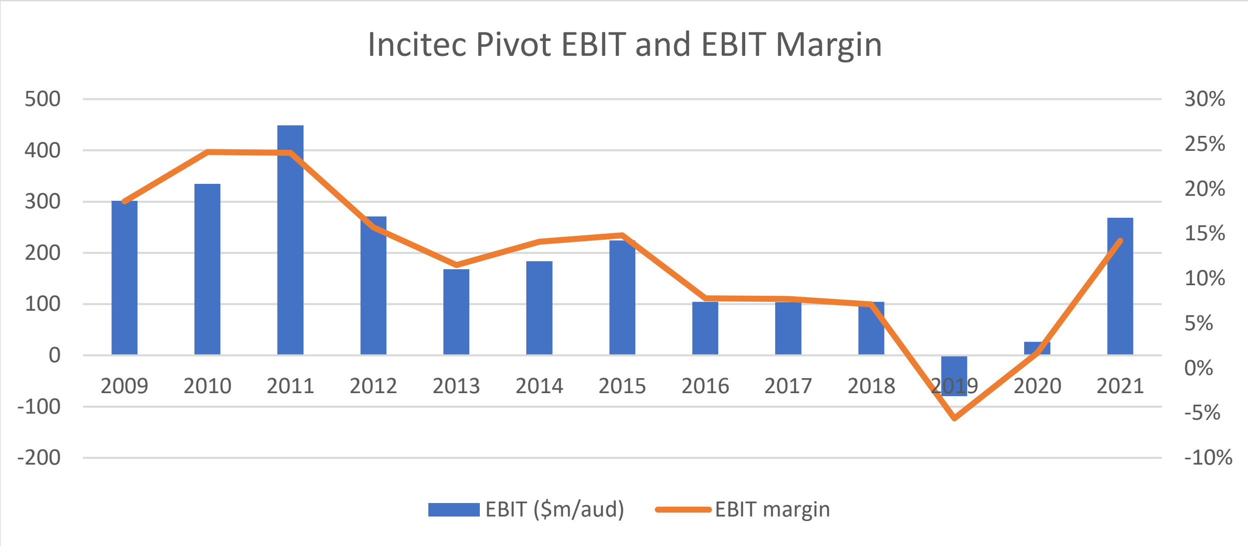
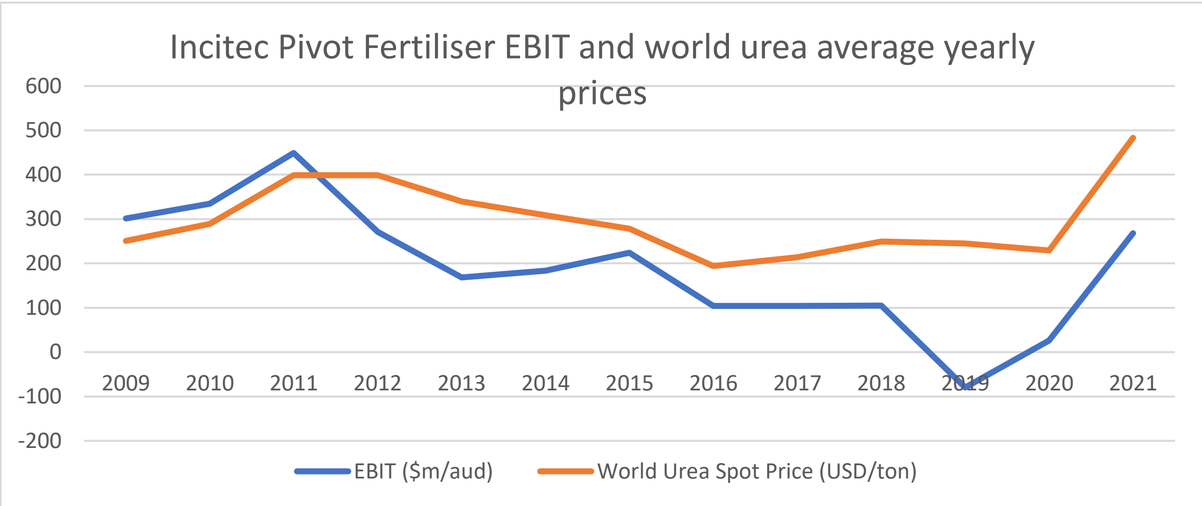


Figure 6. Incitec Pivot Fertilisers EBIT margin and total EBIT



Source: Incitec Pivot Limited (2022)

Figure 7. Incitec Pivot Fertilisers total EBIT and world urea prices average yearly prices



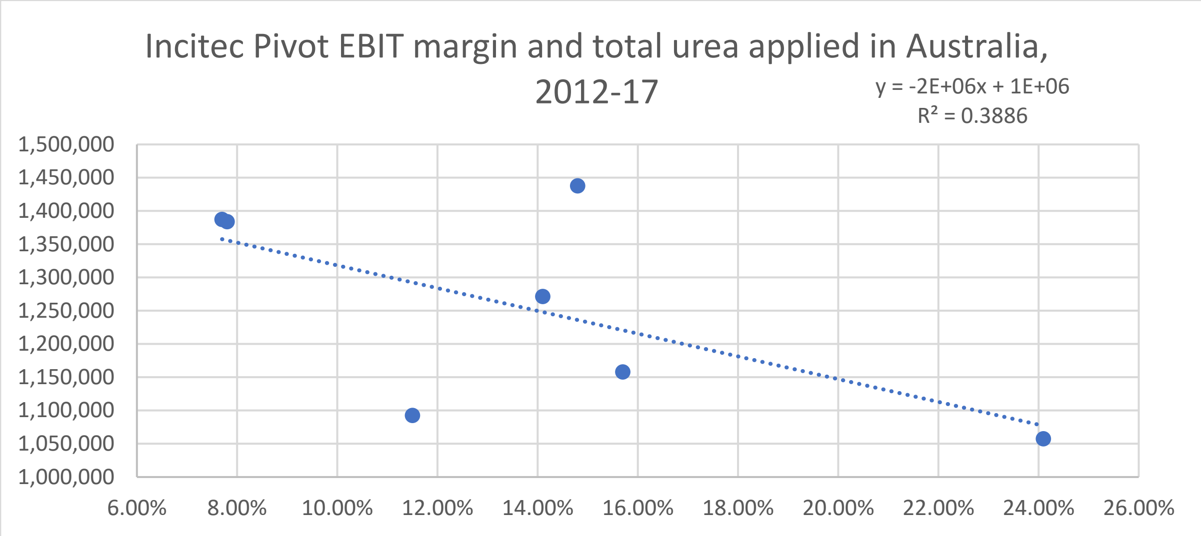
Source: Incitec Pivot Limited (2022) and World Bank (2022)

Comparing the EBIT margin of Incitec Pivot with the total use of nitrogen fertiliser is a reasonable proxy measure for this indicator. As shown Figure 8, there is little correlation between volume and profitability, except a slight decline as a result of higher volume.

Only data from 2012-17 was able to be represented in Figure 8 as this is the only continuous period for which the Australian Bureau of Statistics (2017) has published fertiliser application data. Considering that during 2012-17 Incitec Pivot's fertiliser business delivered strong profits, over a range of annual volumes between 1 and 1.45 million tonnes of fertiliser, it is reasonable to presume the manufacturing and distribution levels of the nitrogen fertiliser supply chain are consequential contributors to this profitability.

Evidence of shortages is one other way that can be used to measure flexibility in handling demand through the value chain. Using newspaper sources as well as corporate documentation, an online search was conducted to find evidence of potential failures in the chain in adequately supplying

Figure 8. Incitec Pivot Fertilisers EBIT margin and total urea applied in Australia, 2012-2017



Source: Incitec Pivot Limited (2022) and ABS (2017)

producer demand. During the period 2010-2020 there was no evidence that any nitrogen fertiliser shortages had occurred in Australia, though tight supply subsequently occurred in 2021 and 2022.

Delivery flexibility

Flexibility in delivery was measured in a qualitative way, looking at the available delivery services provided by lead firms. As there is a strong delineation between the distribution and retail levels of the supply chain, delivery flexibility can be considered at two points. Two examples were found of overlap between these levels of the market. The first overlap was Koch Fertiliser Australia's '*Koch Reservations'* business-to-business, business-to-customer (B2B-B2C) web based[iv] platform which allows Koch Fertiliser retailers to quickly access fertiliser stored by Koch at their supply depots and have it shipped directly to customers. The second overlap was Incitec Pivot's '*Fertshed'* which serves a similar purpose of integrating customers, retailers, and distributors through a web-based platform.

Delivery of fertiliser is very flexible. In an interview (*Charlie Walker*, *pers. comm., 2022*), a senior representative of Incitec Pivot had little doubt about the ability of the company, as well as the industry in general, to meet variable agricultural demand with the existing infrastructure.

Measuring flexibility at the retail end of the supply chain was difficult. As discussed above, transport of fertiliser between retail outlets and farmers is done in various ways, by farmers, by retailers, and by third party contractors. Information about delivery delays and lost orders such that they would be representative of the broader supply chain is not generally available.

Responsiveness

Customer complaints

One major issue found in analysis of the nitrogen fertiliser supply chain concerned transparency of pricing. Price transparency has consistently been contentious along the supply chain and was well-documented in the ACCC (2008) inquiry into pricing and supply arrangements in the Australian and global fertiliser market. A recommendation of that study was that greater transparency in pricing would be advantageous in the fertiliser industry.

Sustainability

Nitrogen pollution

The application of nitrogen fertiliser results in losses from agricultural systems to the environment via a number of pathways that produce negative externalities (Tang *et al*., 2023a). Losses can occur via nutrient run-off, groundwater seepage and gaseous denitrification. These losses can vary greatly depending on the production system, soil type and condition, weather, and land use practices (Cameron *et al.*, 2013). The inherent complexity associated with measuring these physical losses means wide ranges of estimates of these losses are evident in the literature. For example, Dobermann (2005) examined the nitrogen fertiliser use efficiency of 850 grain plot experiments, finding an average efficiency of just 51 per cent. Pan *et al.* (2016) estimated that between 18-64 per cent of applied ammonia is lost through volatilisation, though their analysis did not extend into alternative loss pathways.

While physical losses under real world conditions can be difficult to calculate, measuring their economic cost to the environment is more so. Only recently have efforts been made to calculate economic costs (see Tang *et al*., 2023a). Keeler *et al*. (2016) estimated the external cost of nitrogen in Minnesota in the United States at $0.001-$10 per kilogram of nitrogen applied. The wide range of estimates was due to the multiple loss pathways in multiple forms, as well as the complexity associated with how nitrogen can cascade through the environment in unpredictable ways. Keeler *et al*. (2016) detailed the comparison between their own framework and established social cost of carbon accounting methods to emphasise the difficulties of finding a 'one number' value per unit of nitrogen applied. Carbon pollution studies typically assume that emissions are uniformly distributed in the atmospheric pool and thus cause global damages in geographical dispersed ways. Nitrogen pollution can be quite compartmental or regionalised. Keeler *et al.* (2016) also considered how nitrogen pollution affects greenhouse effects via emissions of nitrous oxide but also draws the contrast that other nitrogen pollution externalities are more often located in a closer vicinity than that of carbon externalities. Nitrogen impacts include degradation of drinking water resources, habitat disruptions to inland and coastal waterways and impacts on public health through increased rates of non-transmissible diseases.

These external costs can be addressed in a number of ways. Governments can introduce regulations to restrict the use of nitrogen fertilisers, or tax or subsidy policies to encourage such reductions. These policies are reviewed in Tang *et al*. (2023b). Another approach is to encourage more efficient use of nitrogen in agricultural production systems.

The '4R' approach to product choice and support

The much-cited 'four Rs of fertiliser use' – the right product, the right rate, the right time, and the right place - are a sound starting point to using nitrogen fertilisers more efficiently (IFA, 2023). Identifying and using the right product starts with considering the products of member organisations of Fertiliser Australia and comparing the various offerings of competitors. Most nitrogen fertiliser lead firms have similar products and the products are applicable to a range of types of agriculture. Further, all major lead firms offer fertiliser nutrient mixing services. A major component to product selection is having access to the required support services to select products through agronomy services and soil testing services. There is considerable access to both forms of advice at the point of sale of fertilisers. The strong links between fertiliser retail firms and agronomic services is the key.

One aspect of the 'right product' choice is the availability of EEF products. Related to the discussion above about the forms of pollution, the inherent variability of the nature and extent of nitrogen pollution provides a context to assessing the trade-offs between the private costs a farm may incur to reduce or shift consumption of nitrogen fertilisers to EEFs, versus the external costs incurred.

Currently the Fertiliser Australia member distributors supply just a few EEF products, though this does not necessarily mean limited use of these products. Wirtz *et al*. (2023) categorised the available nitrogen loss inhibitor EEFs, but there are no statistics on the use of EEFs recorded by the Australian Bureau of Statistics beyond 2017. In 2016-17, EEF products were used on just 1.4 per cent of total agricultural holdings, mostly on horticultural activities.

Role of the Industry Enabling Institutions

Industry bodies and training

The Australian Fertiliser Services Association (AFSA) and the Fertiliser Industry Federation of Australia (FIFA) are the two representative industry bodies for the various services along the fertiliser value chain. Institutional overlap occurs as both organisations represent similar sets of stakeholders, with many of the same members. The AFSA claims to represent local service providers such as spreaders, retailers, and fertiliser agronomists, whereas the FIFA covers manufacturers, importers, and distributors.

In 2005, in a joint initiative for AFSA and FIFA, the ‘Fertcare’ accreditation program was launched. Fertcare is an industry-run training and accreditation program which provides education to fertiliser industry members on best practice fertiliser use in regard to sustainability, profitability, and food safety risks. The logic behind the creation of the program was to provide a credible brand of evidence-backed accreditation for which farmers can look to in deciding who to take advice from.

An independent report about the adoption of the program found it generally met expectations in terms of providing sufficient training (Cummins & Barclay, 2007). It was found that 65.8 per cent of Fertcare-trained participants adopted improved nutrient practices. However, concerns were raised over the implementation of the broad curriculum to people in a diverse number of occupations.

Other private and publicly run accreditations are available along the nitrogen fertiliser value chain. Incitec Pivot Fertilisers, through its subsidiary Nutrient Advantage, offer a number of fertiliser and soil sampling courses centred around agronomic fertiliser use best practices. These courses provide eventual access to proprietary Nutrient Advantage software and tools[v]. Complementary courses such as Agsafe, Chemcert and Soilmate contain significant components surrounding OH&S training for the use of agricultural chemicals, including nitrogen fertilisers.

Consumer services

Consumer services in the nitrogen fertiliser value chain cover a number of activities which facilitate transactions between members of the value chain. This can include standard and Fertcare accredited agronomic services to provide recommendations for both the right level and type of input use.

As mentioned above, numerous participants have subsidiaries and partner organisations involved in the soil testing and agronomic services. For example, IPF through Nutrient Advantage and CSBP’s Soil and Plant Analysis Lab, the lead distribution centric firms, have integrated soil testing services in their organisational structures. Retail end firms, both chain firms such as Elders and Nutrien Ag Solutions, as well as independent farm supply stores, are often more involved in providing agronomic services as part of their wider agricultural core competencies.

The possibility of conflict of interest is unavoidably present in the relationship between agronomists employed by the same organisations as are also involved in the sale of fertiliser products. Still, above all, a major value component of any professional service such as agronomy is reputational value. Given that Australian farmers use fertiliser inputs at a rate well below the OECD average, arguably evidence is weak for supporting a link between the employment relationship between fertiliser retailers and agronomists causing over-application. Future research would be required to establish any causal link.

Discussion

This research into the Australian nitrogen fertiliser value chain has identified a range of governance structures. Tendencies to source raw materials from off-shore and an increasing shift to services along the value chain can be compared to shifts in the Australian economy since the 1990s. Feenstra (1998) describes this as a 'dual global integration of trade and domestic disintegration of production'. Fertiliser manufacturing is a particularly competitive business: the technology for manufacturing is widely available, and the inputs required are standardised commodities as is the case with natural gas. By that logic, nitrogen fertiliser production will gradually shift to those places with the lowest costs, either from regulation, or comparative advantages in the supply of labour or capital. Such a shift off-shore may be further encouraged as countries differentially impose some of the externality costs of carbon dioxide pollution onto polluting businesses. For example, if a major Australian fertiliser firm is included in the large firms that operate under the Safeguard Mechanism and have to meet the requirement of a gradual reduction in their carbon dioxide emissions, and bear the associated costs as they should under polluter pays principles, they will lose competitiveness against imports that are not subject to the same cost. Shifting to operate under conditions comparable with their importing competitors on the domestic market could loom attractive. Results show that the trade of fertiliser products has become increasingly globalised, as production has concentrated around the cheapest natural gas deposits in geographically central locations such the Arabian Peninsula and South and Southeast Asia. These firms may be adequately termed as 'commodity suppliers' as described by (Sturgeon & Lee, 2001).

Similarities can be seen with the analysis by Gereffi (1996) of cross-border coordination of production where 'buyer-driven global commodity chains' led to production of light industrial goods shifting to developing economies with comparatively lower labour costs. In the case of fertiliser, the motivation and source of comparative advantage would be comparatively lower costs of natural gas, and, presumably lower labour costs too. An example would be highly competitive gas costs as a result of close internal linkages between state-owned natural gas companies and state-owned fertiliser manufacturers in the case with Qatar's QAFCO and Saudi Arabia's SABIC. As well, transaction costs across borders have decreased considerably through trade liberalisation, communications technologies, and stronger trade institutions.

Trade liberalisation in Australia since the 1990s has seen the reduction and removal of most tariffs. Improved communications technologies have decreased search costs through the development of the internet. The development of consistent bilateral trade frameworks has increased cross border coordination. Specifically in the context of nitrogen fertilisers produced and imported from offshore sources, the 'market' governance structure (Gereffi *et al.*, 2005) would most adequately describe the relational structure between manufacturers and importing firms in the global value chain. The complexity of transactions are relatively low, and the competencies of suppliers are relatively high due to their high degree of specialisation.

Further down the value chain, an increased variety of value chain governance structures emerge. Take for example Incitec Pivot in Eastern Australia. The firm manufactures, imports, distributes to retailers and at times sells fertiliser directly to farmers, which mirrors the hierarchical value chain structure described in Gereffi *et al*. (2005). However, this does not represent all the participants in the Eastern Australian nitrogen fertiliser market. Some of the retailers with which IPF supplies may also obtain nitrogen fertiliser from other distributors, for any number of reasons. Whilst Incitec Pivot may be a lead firm in the context of the whole value chain, it is also a relational supplier to a retail-centric lead firm such as Elders. This heterogeneity of value chain governance demonstrates the difficulty in applying a singular value chain governance categorisation to the nitrogen fertiliser value chain.

It is apparent that the structure of the fertiliser market means that the scope to extract economic rent from retailing nitrogen fertilisers is limited because of the high substitutability of most nitrogen fertiliser products and to weak branding appeal and high retail competition. These characteristics mean volume and location are the critical factors determining profitability in the industry.

Strong forward and backwards linkages exist between retailers and distributors through inventory management technologies and techniques. Two key examples of this were IPF's *Fertshed* and Koch Fertiliser's *Koch Reservations*. Another strong linkage found was through subsidiary retail outlets. Both Elders, through Australian Independent Rural Retailers, and Nutrien Ag, through Combined Rural Traders, have quasi-independent subsidiary outlets through which greater volumes of nitrogen fertilisers can be moved.

The placement of enhanced efficiency fertilisers along the value chain was also of interest. It was found that nearly all of the spraying, mixing and general work required for producing and marketing EEF products was done by distribution-centric lead firms such as CSBP, IPF and Koch Fertilisers. Those firms have natural competencies in being able to provide such products. They have large distribution centres near points of retail, alleviating the short shelf life that EEFs are often derided for, extensive agronomic research and development labs to test these products under Australian conditions, access to capital to build the necessary infrastructure, and the size to work with international firms which often develop the products in the first place. As a result of these factors, distribution and EEF integration activities have significant overlap. Both of these value chain activities are done by a limited number of lead firms, making these points the likely place for policy interventions to promote value chain upgrading.

Concluding Comment

In summary, Australia's nitrogen fertiliser value chain accomplishes its core goals of supplying a wide range of fertiliser products and does so efficiently and profitably. Along the value chain, competition can be variable. While the retail end of the value chain has a large number of participants in both national and local markets, distribution is concentrated within a few firms in the two domestic markets. Trade liberalisation has increased competition and meant the nitrogen fertiliser market has become increasingly contestable. Despite recommendations from Parliament and the ACCC in 2008, price transparency continues to be an issue.

Compared to other highly developed nations, Australia uses relatively little nitrogen fertiliser per hectare, making the problems of nitrogen fertiliser pollution less acute than where use of nitrogen fertiliser is heavy and, sometimes, encouraged by agricultural policies that inflate farm prices received.

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Appendix 1. Ammonium nitrate controls

Ammonium nitrate was the most common nitrogen fertiliser for much of the past century. Derived from the mixture of nitric acid with ammonia, ammonium nitrate is a concentrated solid form of nitrogen fertiliser and was major source of elemental nitrogen in Europe and North America until the end of the 20th century. Compared to urea, the product has beneficial characteristics in cold weather soils, an ability to be applied in liquid and solid forms, and preferable storage characteristics and shelf life (UNIDO, 1998).

However, while ammonium nitrate is not an explosive by itself, it can be converted into an explosive by mixing with fuel oil. Such a mix is widely used as a bulk industrial explosive in the mining industry. The implication for the nitrogen fertiliser value chain is that in several regions (Yara Australia's ammonia production plant on the Burrup Peninsula, near Karratha, and Orica's Kooragang Island ammonium production facility in Newcastle), fertiliser and explosive manufacturing are co-located. As a result of heightened security concerns following a spate of terror attacks in the late 20th and early 21st century, there was increased legislative control of ammonium nitrate in Australia and much of the world. In 2004 the Council of Australian Governments agreed on a unified framework on the control of ammonium nitrate through the introduction of a licensing scheme for manufacture, handling, and use of any production with greater than 45 per cent ammonium nitrate content. The inquiries found that products containing ammonium nitrate were often sold as liquid fertiliser products below the 45 per cent threshold legislated for security sensitive ammonium nitrate, often either having been diluted in water or further mixed with urea, to make urea ammonium nitrate solutions.

Appendix 2. Cost of Production Model

Table A1. Costs of production for a 1000-tpd ammonia/1,750-tpd urea plant

	Units	Quality	\$/unit (1998)	\$/unit (2022)	\$/tonne (1998)	\$/tonne (2022)
Process gas	Gcals	2.96	4	13.42	11.83	\$39.71
Combustion gas	Gcals	1.1	4	13.42	4.41	\$14.76
Catalysts and additives	\$/t		3.24	5.89	3.24	\$5.89
Inert gas	\$/t		0.02	0.10	0.02	\$0.10
Boiler water	m3/t	0.64	0.2	0.36	0.13	\$0.23
Cooling water	m3/t	121.8	0.02	0.20	2.44	\$24.36
Electricity	kWh	150	0.05	0.20	7.5	\$30.00
Effluent treatment	\$/t		0.15	0.27	0.15	\$0.27
Operating supplies	\$/t		0.16	0.50	0.16	\$0.50

Total Variable Costs					**29.88**	**$115.82**
Direct labour	workhrs/tonne	0.3	10	48.67	3	$14.60
Indirect labour	workhrs/tonne	0.3	10	48.67	3	$14.60
Maintenance			13.47	24.47	13.47	$24.47
Depreciation			40.81	60.61	40.81	$60.61
Insurance and taxes			8.16	14.83	8.16	$14.83
Marketing costs			0.71	2.84	0.71	$2.84
Plant overheads			1.49	2.71	3	$2.71
Total Direct Costs					**72.15**	**$134.66**
Total Production Cost per tonne						**$250.48 USD $375.72 AUD**

Source: author calculations. Figures taken from *Fertiliser Manual* (UNIDO, 1998). All figures except process gas, combustion gas and labour are adjusted for inflation by USD CPI since 1998 to 2022 by a factor of 1.87. Combustion gas adjusted to the 2022 January US Henry Hub natural gas price (World Bank, 2022). Labour is adjusted to the average hourly wage in the OECD (OECD, 2022). Plant investment cost are taken from UNIDO (1998). Electricity is set at the Jan 2020 price/kWh of commercial electricity.

Table A2. 38,400 DWT Handysize, ocean bulk cargo and port costs, assuming 48 hours of port loading and unloading and berthing

Activity	**Cost**	**Per tonne**
Bulk cargo vessel charter, $US1 = $A1.50 [v]	$US15,000/day over 30 days, $US450,000	$US12/ $A18
Brokerage at 3.75% on total charter cost	$16,875	$A1.5
Port of Hamad, Qatar combined costs[v]*, 1 Qatari Rial = 0.41 AUD*	1,035,840 QR = $A424,069	$A11
Port stevedoring at Port of Melbourne[v]	-	$A2.73
Wharf access at Port of Melbourne	-	$A1.08
Berth fees at Port of Melbourne	$20,000	$A0.50
Total	-	~$A33.5

Source: author calculations