Deloitte Access Economics

The economic impact of paraquat

Syngenta Australia Pty Ltd

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Deloitte.

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Glossary

APVMA	Australian Pesticide and Veterinary Medicines Authority
Broad spectrum herbicide	Herbicide that is formulated to control both broad leaf and grass weeds. Can also be referred to as non-selective.
BAU	Business As Usual – refers to a counterfactual scenario that is considered to reflect an average future path for the entire economy. In this context, the BAU is a scenario where Paraquat remains available on the market. Deviations from the BAU represent the incremental economic impacts of deregistering Paraquat.
Chemical fallow	A type of fallow in which vegetative growth is killed or prevented from growing by the use of chemicals. Tillage for other purposes may or may not be used in chemical fallows.
CPP	Crop protection products include herbicides, insecticides and fungicides that are applied to fields to manage weeds, insects and diseases.
Fallow	Farmland that has been ploughed and harrowed but left unsown for a period, in order to restore its fertility as part of a crop rotation, or to avoid surplus production.
FTE	Full-time equivalent employment is ratio of the total number of paid hours during a fixed time period by the number of hours worked in that period. $\mathrm{FTE} = \frac{\text{Total paid hours worked in given period}}{\text{Normal working hours in given period}}$
GDP	Gross Domestic Product is the market value of all officially recognised final goods and services produced within a country in a given period. Final goods and services are defined as those which are not used to produce other goods or services.
Minimum tillage	A form of tillage that does not invert the soil and retains a protective layer of crop residue throughout the year. Also known as conservation tillage.
Selection pressure	An agent of differential mortality or fertility that tends to make a population change genetically.
Tillage	The mechanical manipulation of the soil and plant residues to prepare a seedbed for crop planting.

1 Executive Summary

Syngenta Australia Pty Ltd engaged Deloitte Access Economics to conduct an independent assessment of the economic impact if paraquat was deregistered for use in Australia. Syngenta manufactures and markets paraquat under the name Gramoxone® and Spray.Seed® (the latter is a paraquat + diquat mix), and is one of several manufacturers worldwide. This study considers all products containing paraquat that are sold in Australia, not just those marketed by Syngenta. A full list of products containing paraquat is in Table C.1.

While Syngenta has funded this study, they did not specify the assumptions or parameters used in the economic modelling. The work incorporated scientific literature as well as comments and suggestions from external subject matter experts and users of paraquat in Australian agriculture. Deloitte Access Economics has not independently verified the scientific evidence, and have relied on it to infer these economic impacts.

It is acknowledged that the estimates in this report are based on these perspectives, and that there is ongoing discussion about potential health implications of paraquat use. This report focuses on the economic impact of paraquat on agricultural production and does not aim to quantify these other potential health effects.

Background

Paraquat is a herbicide used for a range of crop protection purposes.

This report addresses the economic impact of paraquat, so that its economic benefits can be considered in determining the implications for agriculture of any future regulatory action relating to paraquat products.

The role of paraquat

The herbicide paraquat is off-patent and is sold under a variety of brand names by a number of manufacturers, and in mixtures with other herbicides. Based on the scientific literature and stakeholder contributions, there are several key uses for paraquat in agriculture:

1. **A non-selective herbicide.** Paraquat is used as a non-selective herbicide to control a wide spectrum of weeds both before sowing annual crops and within perennial crops.
2. **To control glyphosate-resistant weeds.** Glyphosate is a widely-used and effective herbicide, except in cases where resistant populations of weeds have become established, or where glyphosate is not fully effective for other reasons. Paraquat is commonly used in controlling weeds, either in rotation with, or as a double-knock application after, glyphosate. In combination, glyphosate and paraquat enable minimum tillage crop production methods.

3. **A herbicide that does not run off into waterways.** Paraquat binds tightly to the soil and becomes inert in the soil,[1] so does not leach into sensitive river or marine environments. The most relevant application is for controlling weeds in sugarcane crops adjacent to the Great Barrier Reef.
4. **A herbicide that can be used in wet climates.** Paraquat is rainfast within minutes after application. This is valuable in climates where there are infrequent windows of dry weather to apply glyphosate.
5. **A herbicide that can be sprayed in vineyards and orchards.** Paraquat is a contact herbicide and does not affect roots or bark (it is only effective when sprayed on green plant material), so can be sprayed to control weeds much closer to, and under, vines and fruit trees, in comparison to other herbicides.

There are other uses for paraquat, including as a desiccant or harvest aid, and to control 'hard to kill' weeds. However, the above list provides the main applications for which research shows there are few substitutes and the potential for significant economic impacts.

Modelling and results

The scenario modelled here is that all herbicides that contain paraquat are no longer available for sale from 1 July 2013 and after a 12 month period all farm inventories of paraquat are assumed to be exhausted. From 1 July 2014, it is assumed that there is no equivalent effective alternative to paraquat. The economic modelling reflects what would happen under this scenario to farm output, production and exports, as well as downstream economic impacts on the sectors that process farm outputs (such as food and beverage manufacturing).

Estimation of the value of paraquat was supported by consultations with subject matter experts and industry stakeholders. Three methods of estimating impacts were used, as a cross check on the different data sources available.

Together, these three methods of estimating the value of paraquat build up a picture of its contribution to agriculture, as summarised in the figure below. Direct expenditure is the smallest estimate of the value of paraquat, as it must be worth at least what is spent on it, in order for rational farmers to purchase it in the first place. The net present value of this weed control cost is estimated at $570 million, based on retail value, over a 10 year period.

Consideration of the pro-rata impact of paraquat provides a larger estimate of its value. This method attributes a proportion of the gross value added of agricultural output attributed to paraquat as a share of all herbicides (a straight pro-rata share without allowing for interaction with glyphosate). This takes into account its contribution as a herbicide, inclusive of what is spent to purchase and apply it. This measure of the value of paraquat is estimated at $1.3 billion over a 10 year period.

Finally, the yield loss interaction method considers what would happen in the absence of paraquat, with glyphosate resistance increasing exponentially before plateauing. This method includes the direct effects of paraquat (killing weeds directly) and the positive

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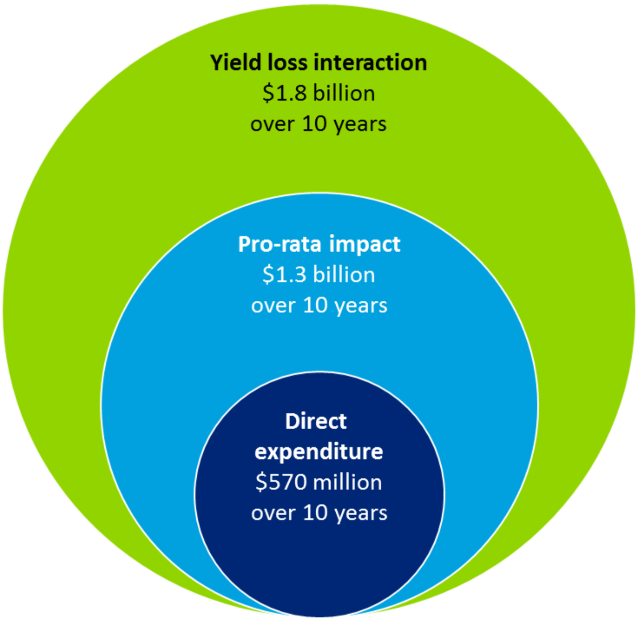
[1] See for example http://www.epa.gov/oppsrrd1/REDs/0262red.pdf

externality generated by paraquat (maintaining the effectiveness of glyphosate to kill weeds as well). This leads to an increasing yield loss over 10 years and accounts for paraquat's contribution to production, but also its contribution to crop protection more broadly. The resistance management role of paraquat in supporting the ongoing use of glyphosate is a further measure of its value considered in this method, resulting in a higher estimate of its value. Over a 10 year period, the net present value of this yield lost (less the cost of purchasing) is estimated at $1.8 billion. This only includes agricultural yield impacts.

The economy-wide impacts on the Australian economy and industry over the period of 2013-2025 were estimated using Computable General Equilibrium (CGE) modelling. The impact on GDP is estimated at $362 million per annum by 2025. The absence of paraquat is expected to reduce Australian exports on average by $109 million per annum below the business as usual case. The loss of full time employment is expected to peak at 594 FTE employees in 2017. Agricultural output is expected to decline by $390 million per annum by 2025 (all $ figures are in 2012-13 dollars).

Figure 1.1: Estimation of the value of paraquat on farm output, three methods



The scientific literature shows that paraquat is an important element of an integrated weed management strategy (in combination with glyphosate), and is without a close substitute. The absence of paraquat would result in a significant reduction in the options available for weed management, leading to an annual decline in agricultural output of $390 million, and a decline in GDP estimated at $362 million per annum by 2025 (in 2012-13 dollars).

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2 Role of paraquat

Paraquat is a broad spectrum herbicide used predominantly for the control of weeds. Its rapid binding and inactivation properties allow it to complement a number of existing crop protection techniques. In combination with minimum tillage, it has played a key role in the movement towards more sustainable farming.

This chapter discusses paraquat’s various uses in more detail. It is based on our review of scientific literature, contributions from external subject matter experts including agronomists, and users of paraquat.

2.1 Glyphosate resistance

Since its introduction in 1974, glyphosate has been widely used in agricultural and non-agricultural contexts in Australia. Glyphosate has a number of versatile attributes that add to its value as an herbicide. Perhaps the most recognised feature is its use as a broad spectrum herbicide that effectively controls many annual and perennial weeds. Unlike some previous herbicides, glyphosate has no soil activity, allowing the sowing of crops shortly after application. Glyphosate has also been found to have low mammalian toxicity, making it relatively safe for use by non-professionals (Bayliss 2000). These factors, combined with the relative affordability of glyphosate, have made it the largest selling crop protection chemical in the world and the most important agricultural herbicide. It is estimated that glyphosate accounts for around 80% of total sales of broad spectrum herbicides in the Australian market.

The prolific use of glyphosate has not come without some unintended consequences. Chief among them is the overreliance on glyphosate as an herbicide rather than investing in diverse weed management strategies (Preston, 2012). For these growers, the discovery of glyphosate resistance is particularly threatening as more weeds compete with crops for moisture and nutrients, potentially reducing crop yield and quality. At present, paraquat is considered to be the only effective broad spectrum pre-sowing weed control available in Australia when glyphosate resistance is an issue (Neve et al, 2002).

The evolution of glyphosate resistance

Resistance begins when a single weed is found to have a mutated gene that inhibits or neutralises the impacts of glyphosate. Historically, the probability of this occurring is very low. However, once the weed has mutated, it has the opportunity to propagate and produce offspring, with the resistance offering a competitive advantage to the plants with resistance genes. In this way, over time and across generations of plants/weeds, selection pressures intensify as more glyphosate applications are made. Resistant weeds multiply and out-compete the remaining non-resistant weeds. Unless they are met with an effective herbicide or alternative treatments (e.g. tilling), it is possible for entire fields to consist of resistant weeds.

Glyphosate resistance has been found across a range of situations including grain cropping, chemical fallows, in orchards, vineyards, along irrigation channels, along fence lines, railway rights of way and roadsides. While it is likely that there are other factors at play, the one trait which is common in all confirmed cases is that glyphosate resistance has occurred where there has been intensive and largely exclusive use of glyphosate over 15 years or more. This suggests key risk factors for the development of glyphosate resistance are:

- use of glyphosate once or multiple times a year over a long period of time
- no other effective herbicides are applied
- no other forms of weed management are conducted.

Paraquat has been found to help restrict the evolution of glyphosate resistant weeds. These benefits can be achieved either through alternating between paraquat and glyphosate for broad spectrum weed control at different times within a season or between seasons (known as rotating the mode of action), or through using paraquat under a 'double knock' system. The double knock method involves using glyphosate, followed by an application of paraquat (often mixed with diquat) 1 to 14 days later to kill survivors of the initial glyphosate burndown.

The effectiveness of this process is primarily due to the fact that paraquat and glyphosate have different modes of action. They are independent chemicals that act on a weed in different ways (paraquat is an inhibitor of photosynthesis at photosystem I, while glyphosate is an inhibitor of EPSP synthase[2]). Accordingly, they are grouped differently – CropLife Australia classes glyphosate as a Group M chemical, while paraquat is classified as Group L. By hitting weeds with at least two different modes of action, the system ensures that the maximum number of weeds is affected, and individual plants that have evolved resistance genes are not allowed to reproduce.

An economic model of the double knock strategy presented by Llewellyn et al in 2005, found that in the long term, farmers benefit from the adoption of this strategy. However, he notes that, in relative terms, implementing the system is more expensive in the short term.

Over time, the double knock system has been adjusted, with different options being developed. It retains the principle of diversity in weed control as the most effective solution.

The double knock method using paraquat is also effective in the absence of glyphosate resistance. While genetic resistance is the primary cause of weeds surviving glyphosate applications, other factors may also lead to some weeds remaining. These include wind, moisture, dust or spray misses. Employing the double knock method means that these weeds will be sprayed again, thus ensuring that as many weeds as possible are eradicated.

There have also been suggestions that rather than the annual intensity of glyphosate use, it is the lack of other weed management practices that may serve as the best predictor of resistance development (Powles, 2006).

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[2] Grains Research & Development Corporation and CropLife Australia (2008)

Confirmed cases of glyphosate resistance in Australia

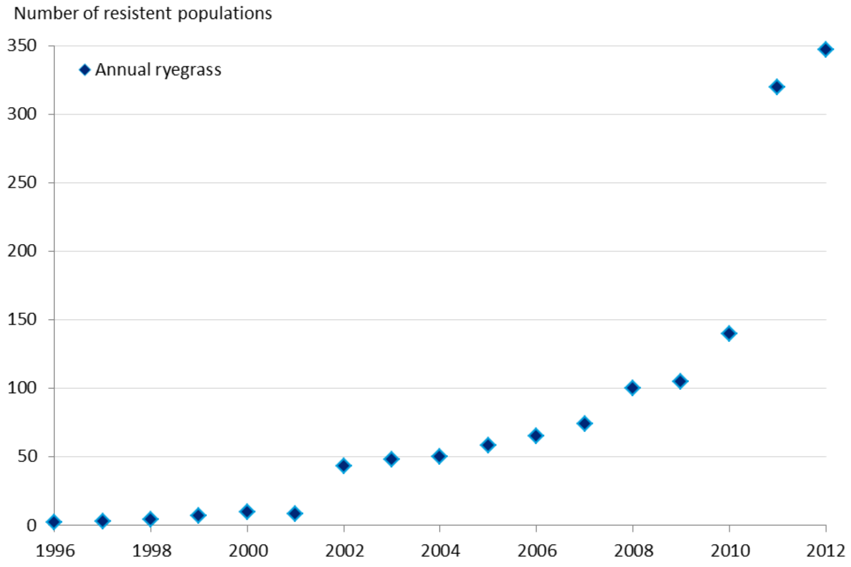
According to the Australian Glyphosate Sustainability Working Group, which includes industry and academic members, the first documented case of glyphosate resistance was reported in populations (i.e. groups of plants) of annual ryegrass (*Lolium rigidum*) on a no-till farming operation in Victoria, followed shortly by another discovery from an apple orchard in New South Wales in 1996. Over the ensuing 16 years, the number of populations exhibiting *Lolium rigidum* resistant to glyphosate reported in Australia has continued to rise.

More recently, several other glyphosate resistant weed species have also been identified, including in populations of awnless barnyard grass(*Echinochloa colona*) in New South Wales in 2007 and liverseed grass (*Urochloa panicoides*) in the same state in the following year. In 2010, glyphosate resistance was documented in populations of fleabane (*Conyza bonariensis*) in Queensland and New South Wales and in windmill grass (*Chloris truncata*) again in New South Wales. In 2011, glyphosate resistance was documented in great brome (*Bromus diandrus*) in South Australia.

To date, there are 347 documented glyphosate resistant populations of annual ryegrass, 58 of awnless barnyard grass, 49 of fleabane, 10 of windmill grass, three of liverseed grass and one of great brome. Chart 2.1 and Chart 2.2 illustrate how glyphosate resistance in weeds has increased over time in Australia, exhibiting an exponential growth pattern.

That noted, there is no compulsory reporting of resistant weeds, and as such the data is likely to be incomplete. As a result, the available data on reported cases of resistance was viewed as an under estimate of the true extent of glyphosate resistance. Hence, section 3 examines other data sources to derive a more accurate estimate of the extent of paraquat use.

Chart 2.1: Number of glyphosate resistant populations in Australia, annual ryegrass

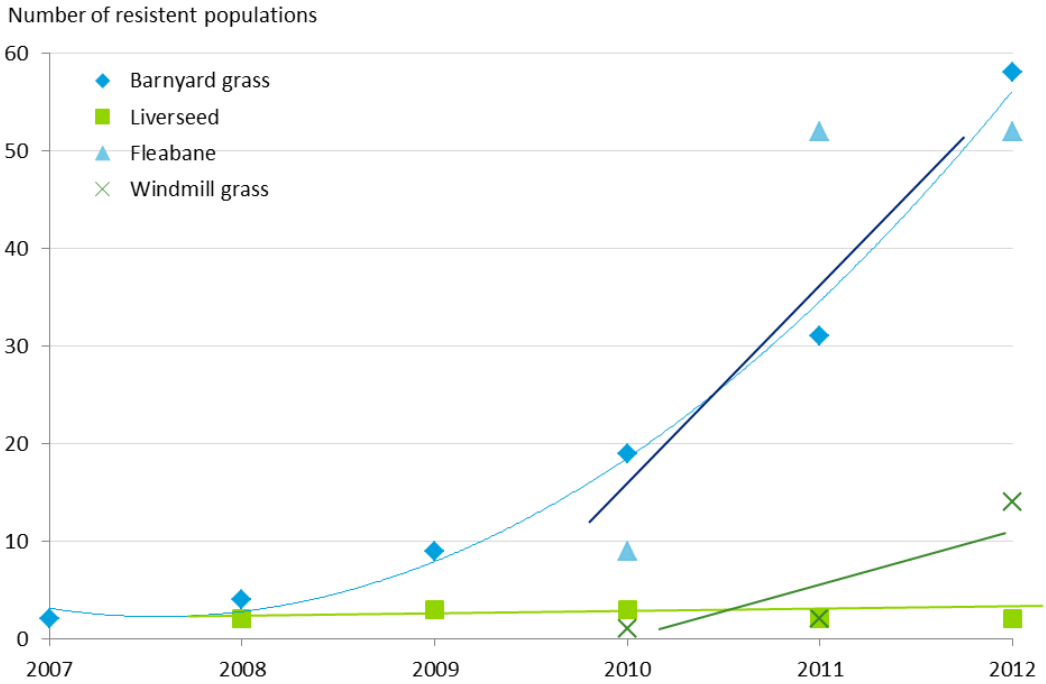


Source: Australia Glyphosate Sustainability Working Group. Note: as this chart shows self-reported data, the apparent exponential increase shown in this chart would require more evidence to support this conclusion. It is however reasonable to say that there is an increasing trend evident.

Despite the widespread and frequent use of glyphosate in Australia, the number of species which have been found to be resistant to glyphosate has evolved at a relatively slower rate and remains rare compared to international experiences (Heap, 2004). Across the world, 24 weed species have demonstrated glyphosate resistance, compared to the six species presently identified in Australia.

This is not to imply that the same trends, both in terms of the number of glyphosate resistant species and the rate at which resistance spreads in populations, will continue into the future. Materially different conditions in agricultural activity, such as the possible restriction or deregistration of paraquat, technological advances, or changes in farming behaviour are likely to impact the future level and nature of glyphosate resistance in Australia.

Chart 2.2: Number of recently discovered glyphosate resistant weeds in Australia



Source: Australia Glyphosate Sustainability Working Group. Trendlines calculated by DAE. Note: This chart does not include Brome Grass, in which resistance was documented in South Australia in 2011.

2.2 Conservation tillage cropping

Tillage had long been considered as an essential component of traditional agricultural systems. Tillage can be described as the mechanical manipulation of soil and plant residues to either prepare a seedbed for crop planting or for the control of established weeds. The benefits of tillage are many, including loosening soil, enhancing the release of nutrients from the soil for crop growth and regulating the circulation of water (Reicosky and Allmaras, 2003).

It is, however, a role in weed management that often underlies the motivation for tillage. Tillage in its simplest form affects weeds by uprooting, dismembering and burying them deep enough to prevent re-emergence. In doing so, tillage changes the soil environment and inhibits weed germination, sometimes by moving their seeds both vertically and horizontally (Swanton et al, 2002).

There are also several downsides of tillage. It has been found to adversely affect soil structure and cause excessive breakdown of aggregates, leading to soil erosion in higher rainfall areas. In turn, the soil erosion can cause pollution in waterways, through the sediments and the nutrients attached to them. Intensive tillage can also negatively impact environmental quality by accelerating soil carbon loss, moisture loss and greenhouse gas emissions (Hartzler and Owen, 1997). Such concerns have fuelled interest in finding tillage or production systems that minimise the negative impacts to the environment, maintain crop productivity and allow sustainable weed management.

The emergence of conservation tillage

The invention of paraquat in mid-1950's enabled the Imperial Chemical Company (ICI) to pioneer the commercial development of no-tillage (or conservation tillage) cropping systems (Derpsch, 2008). From the 1970's, there was a substantial shift towards reduced tilling crop establishment systems in Australia and around the world. The launch of glyphosate in 1974 provided a highly effective means of weed management, reducing the need for tillage in many situations.

Conservation tillage has become an umbrella term and can refer to many types of tillage and residue management systems. Typically, conservation tillage can lower the physical movement of soil to the minimum required for crop establishment and production. A meta-analysis by Price et al in 2011 indicated that when consistently practiced as a soil and crop management system, conservation tillage has the potential to greatly reduce soil erosion and improve soil quality, water quality and plant-available water.

In addition, conservation tillage forms an important component of modern integrated weed management systems. Combining herbicides with some degree of tillage allows for the control of weeds that are not easily destroyed by tillage alone. The lower levels of soil disturbance that occur under conservation tillage mean that weed seeds are typically concentrated in the surface soil. This makes them more prone to germination, making them susceptible to herbicide application, which overtime can accelerate weed seedbank decline.

The discovery of glyphosate resistance in various weed populations has put more emphasis on the need for diverse weed management techniques. Growing awareness of the risk of glyphosate resistance, and actual incidence of resistance is leading to an increasing role for paraquat in conservation and no-tillage farming systems in Australia.

In the absence of paraquat, one possible outcome may be a decline in conservation tillage, especially without the development and adoption of diverse and complementary weed control strategies. Alternative weed management systems such as the utilisation of crop and herbicide rotation, or high residue cereal cover crops (i.e. where more biomass is left on the ground) are required in order to support the continued practice of conservation tillage.

2.3 Other alternatives for weed control

While herbicides are considered the main means of weed control in many countries, there is increasing recognition that their use will have to be integrated with greater use of non-chemical methods. Non-chemical weed control options (harvest weed seed destruction systems, chaff carts, windrow burning and baling) are playing an increasingly important role in weed management on Australian broadacre farms, but Syngenta notes that these tactics, individually or in combination, do not replicate the role played by a non-selective herbicide (either glyphosate- or paraquat-based products) in modern Australian cropping systems.

There are some other experimental options for weed control, such as burning or microwave treatments. A review of microwave heating applications by Brodie et al in 2011 indicated that the high energy cost involved makes it an uncompetitive option when compared to other thermal methods such as direct burning with an open flame.

Our understanding is that these methods are still in the early stage of research and development. In intensive agriculture (such as horticulture, vineyards and orchards) it may be possible to use labour intensive weeding and mulching. However, these methods again involve significant additional costs compared with the cost-effective herbicides currently available.

An alternative herbicide, glufosinate (sold under the name Basta®) is registered for use in horticulture and has recently been registered for use in summer fallow situations prior to cereal plantings. Glufosinate is considerably more expensive than paraquat, is only effective under certain climatic conditions and is not registered for the control of a number of key resistant weeds (e.g. annual ryegrass) in a summer fallow situation.

Taking these factors into account, the modelling results assume that there are no readily-available and cost-effective alternatives to control glyphosate-resistant weeds other than paraquat, particularly in broadacre applications.

2.4 Soil runoff into waterways

Herbicides that are inappropriately applied, or applied before unforeseen weather events, can find their way into streams and rivers and could potentially result in adverse environmental impacts through soil runoff. In this way, rivers that contain farm runoff from upstream catchment land can transport contaminants such as pesticides, nutrients and sediments far away from their point of origin.

A study undertaken by Kennedy et al in 2011 on the impacts of pesticides on the Great Barrier Reef outlines some of the implications of soil runoff. Recent reef monitoring studies have found higher levels of chemical concentrations following large rainfall events in Queensland.

In most cases, the concentrations of crop protection products leaving farms in runoff are low and unlikely to negatively impact on the environment (Nobel et al, 2009). However, from both a legal and product stewardship perspective it is important that applicators take measures to ensure products remain within their intended application area. Some of these precautions include spraying away from water and minimising drifting risk.

Paraquat’s distinctive behaviour in soil includes rapid and tight binding to clay, humus and other organic materials. Due to the speed of absorption, it can remain bound for many years in an inactive state, ensuring that chemical release can be inhibited in the face of changes in the climate, soil condition or soil management techniques. This means that leaching and runoff from paraquat residues is minimised.

2.5 Wet climates and low temperatures

In recent years, extreme wet weather during the harvest season across large areas of Australia’s winter cropping zone has raised weed management issues for many grain growers. For instance, in 2011, the Australian Glyphosate Suitability Working Group reported that wet conditions promoted the growth of existing weeds in the standing crops, with summer weeds germinating as soil temperatures increased. These issues are magnified during consecutive wet harvests as it increases the difficulty in managing longer term weed problems.

Paraquat’s rapid binding process means that rainfall shortly after application has little to no detrimental impact on its effectiveness as an herbicide. Other herbicides, such as glyphosate, tend to wash off in such circumstances. Even in the more extreme conditions of the Australian tropics, it has been found that sufficient levels of paraquat are able to enter leaves within a 30 minute window before rain can wash away significant amounts (Srinivasan, 2003).

In addition, unlike most herbicides, paraquat is effective under low temperatures when weeds demonstrate little active growth. This makes paraquat a viable option for early season seedbed preparation and for orchard crops in the autumn.

2.6 Between row applications for orchards and vineyards

The application of non-selective herbicides as a directed spray under and between perennial tree and vine rows is an effective method for controlling many weeds. In some cases however, there is a greater risk of crop injury, especially where drift occurs during application. In this regard, despite its effectiveness as an herbicide, glyphosate is not preferred for spraying under or between rows because of the inevitable contact with the crop.

Glyphosate tends to move quickly from the point of contact throughout plants, with even small quantities able to cause extensive damage (Evans, Hashem and Diggle, 2009). Other herbicides such as oxyfluorfen also have limitations in between row applications due to their soil residue and contact activity and, hence, is only used post emergence if the spray can be accurately directed (Qasem, 2009).

Paraquat is widely used for inter row weed control and to remove weeds growing between and under the crop rows. It poses much less risk to crops and unlike soil residual herbicides, can be applied at lower rates without leaching or affecting following crops. Although paraquat too is a broad spectrum herbicide, paraquat will only cause localised leaf damage where the droplet lands because it does not move through plants with a systematic action, nor does it produce vapour (Srinivasan, 2003). Instead, paraquat can effectively be applied under trees and vines, or prior to the planting of horticultural crops.

Paraquat is increasingly being considered for use across Australia's orchards and vineyards, not only because of suitability to applications under tree and vine and between rows but also to combat growing glyphosate resistance in these fields (Preston, 2012). Historically, farming practices under vines and orchards in Australia have been heavily dependent on glyphosate as the primary method of weed control, having a greater usage rate and intensity of use than any other sub sectors.

In an industry where glyphosate resistance is already on the rise, the removal of paraquat would amplify selection pressures in vineyards and orchards across Australia. In the absence of paraquat, consultations suggest (see Chapter 4) that orchard and vignerons will continue to use glyphosate (albeit becoming less effective over time). Glufosinate is also a higher cost alternative which could be employed in horticulture and is further discussed in the Chapter 3.

2.7 Other applications

Many farm enterprises alternate fields between annual pasture with livestock, pulses, and grain production. In the technique known as pasture topping, paraquat may be used in the pasture phase late in the growing season to minimise pasture seed production that would affect crop production in subsequent years. This is because pasture species such as rye grass are, in a cropping circumstance, considered as weeds.[3]

Glyphosate in combination with paraquat may also be used to maintain weed-free fields (i.e. fallow) and for total vegetation control in years when drought or severe weed infestations result in crop failure.

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[3] For further information on crop topping, see for example: Pulses Australia :
http://www.pulseaus.com.au/pdf/Desiccation%20and%20Croptopping%20in%20Pulses.pdf, and,
WA Department of Agriculture and Food:
http://www.agric.wa.gov.au/objtwr/imported_assets/content/pw/e-weed%206%2020%20aug%202010.pdf

3 Data on paraquat usage

The previous section described the uses of paraquat. This section provides detailed statistics on the usage of paraquat.

3.1 Sales and volumes

The Australian Pesticide and Veterinary Medicines Authority (APVMA) is the government authority responsible for the assessment and registration of agvet chemicals, including glyphosate and paraquat.

Wholesale sales revenue data from the APVMA indicates that, for the period from 2007-08 to 2011-12, sales of all chemicals containing paraquat (i.e. paraquat only and paraquat + diquat mix) averaged over $67 million each year. A list of all paraquat products registered by the APVMA is presented in Appendix C.

Paraquat-only products generated average wholesale revenue of $27 million over these five financial years. Over the period, the share of wholesale revenue from paraquat-only products increased from 33% in 2007-08 to 63% in 2011-12. This highlights a greater role of paraquat-only sprays in the market in recent years, compared with paraquat mixes.

This compares to the market for glyphosate, which raised average annual wholesale revenue of $411 million in the last five years. The glyphosate market is substantially larger than the market for paraquat products, six times larger on average (in terms of $ sales rather than volume), reflecting its relative importance in the weed management mix. Globally, sales of paraquat in 2011 reached US$640 million, while the market for glyphosate was US$4.19 billion (Report Linker, 2013).

That said, the efficacy of glyphosate is threatened by resistance issues, and other circumstances that cause glyphosate to be less than fully effective. Hence, while paraquat represents a much smaller market than glyphosate, it has an important role in ensuring the ongoing effectiveness and sustainability of the much larger glyphosate market.

Table 3.1: APVMA revenue data - all products containing paraquat ($m)

	2007-08	2008-09	2009-10	2010-11	2011-12
	$m	$m	$m	$m	$m
Paraquat-only products	23.0	19.0	20.2	31.5	40.1
All products containing paraquat	70.4	53.8	59.4	68.6	63.8
All products containing glyphosate	608.0	316.7	361.5	401.3	372.2
Paraquat as % of glyphosate sales	12%	17%	16%	17%	17%

Source: APVMA, 2013

Over time, in dollar terms, the market for paraquat-only products has grown. The market for all paraquat products has fluctuated and is currently below the level of five years ago, and the market for glyphosate has declined by nearly 40%, again in dollar terms, over five years. As a proportion, paraquat has increase as a proportion of glyphosate sales. Broadly, this may reflect the growing importance of paraquat in weed management strategies, driven by the resistance issues related to glyphosate which have had an impact on sales and volumes. The exchange rate, drought and the global market for manufacturing herbicides have also caused fluctuations in prices and volumes.

The data in Table 3.1 above is based on sales of herbicides. Wholesale data from Syngenta, on the volumes and costs of two of its products, Gramoxone® (paraquat) and Spray.Seed® (paraquat + diquat mix) was used to determine a weighted average wholesale price of paraquat products over the same time period.

2013 price data on Gramoxone® and Spray.Seed® was used to determine a weighted average retail price of $5.65, assumed to be the price for 2011-12. In comparison to the weighted average wholesale price, a retail markup of 9% was established. It is assumed that this retail markup has been constant from 2008-09 to 2011-12. Weighted average retail prices are shown in the table below.

The revenue data above, divided by the average retail price for each financial year, provided an estimate of the volume of paraquat sold in each year. This is summarised in the following table.

Table 3.2: Nominal revenue, prices and volumes

	2007-08	2008-09	2009-10	2010-11	2011-12
Sales of all paraquat products ($m)	70.4	53.8	59.4	68.6	63.8
Weighted average wholesale price ($/L)	7.85	9.36	6.90	5.86	5.18
Weighted average retail price ($/L)	8.57	10.21	7.53	6.40	5.65
Volume per year (million L)	8.2	5.3	7.9	10.7	11.3

Source: APVMA 2013, Syngenta data 2013, and DAE calculations

It can be seen that the price of paraquat fell from $9.36/L in 2008-09 (wholesale) to $5.18/L in 2011-12. There was a price spike in paraquat in 2008, correlated with the concurrent increase in the cost of glyphosate. A range of factors led to the increase in the price of glyphosate. These included the release of Roundup Ready crops which are resistant to glyphosate, allowing farmers to spray without damaging crops, as well as high global commodity prices for crops, a worldwide shortage of phosphate used in production and high costs of additional production.

Over the period shown in Table 3.2, the volume of paraquat sold per year increased from 8.2 million litres to 11.3 million litres, an increase of almost 40% in volume corresponding with a nearly 35% fall in price. While paraquat has been available in the market for many years, the data indicate that demand has rapidly increased for it in recent years, likely attributable to recent developments (around resistance, hard-to-control weeds and other issues).

3.2 Paraquat application

The costs of paraquat application include the retail cost of the herbicide (markup over wholesale prices), the cost of labour and the cost of equipment including tractors and boom sprays. Other non-monetary costs include the emissions from tractors running on diesel fuel.

Paraquat is used in the production of a range of crops, commonly following the use of glyphosate or another herbicide, or on its own. These crops include cereals, pulses and other broadacre crops. The total number of hectares treated with paraquat annually is estimated at 7.7 million hectares. This is based on Kleffman (2011) data from which a weighted average application rate of 1.27L/ha, sprayed 1.16 times per year was derived[4]. The gross value of production of the above crops treated with paraquat annually is approximately $24.2 billion (ABARES 2012, ABS 2012).

The retail cost of paraquat is an indicator of its value to agriculture. The retail markup over and above the wholesale price includes payments to other supply chain participants, such as distributors. On a per litre basis, this markup is low, with a weighted average retail price of $5.65 per litre ($6.99 and $4.75 per litre for Spray.Seed® and Gramoxone® respectively). Price data for other manufacturers of paraquat were not available.

Expenditure on paraquat allows an inference of its value. For farmers to purchase and continue using paraquat on crops, its value to them must at least be equivalent to the expenditure on the herbicide. This method of estimation is further explored in section 4.2.

Data limitations and gaps

Where possible, data was sourced from studies or reports on the use of paraquat in Australian agriculture. To some degree however, estimates were made of the magnitude of particular parameters based on the data at hand.

For example, while data was available on the wholesale revenue of paraquat in a given year (from APVMA for all manufacturers of paraquat), the volume was inferred based on a weighted average price of paraquat products from Syngenta. While this technique would provide a reasonable estimate, it is noted that there is more than one manufacturer of paraquat products and sales data was not available for each of the manufacturers.

The number of hectares sprayed with paraquat annually was estimated based on this inferred volume and the application rate for paraquat. Again, this provides an approximate magnitude; however, actual application rates can vary in different agricultural contexts and this may not be the most appropriate measure.

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[4] The Kleffman data also provided an indication of the number of hectares sprayed, but suggested a lower number of hectares treated that did not reconcile with the regulator's (APVMA) revenue data, possibly due to the size of the data sample. Hence, greater weight was given to the regulatory data from APVMA.

4 Direct impacts

Key points

From a direct expenditure (willingness to pay perspective), the net present value of expenditure on paraquat costs $570 million in 2013 dollars over a 10 year period using a 7% real discount rate. This is likely to be a conservative measure of the value of paraquat, as benefits would likely be at least as great as the direct expenditure on purchasing and applying paraquat.

A pro-rata estimate of the value of paraquat results in a benefit of $1.3 billion over a 10 year period. This measure attributes a share of the gross value of agricultural production to paraquat, based on its proportion of the herbicide market (again, in 2013 dollars, 7% real discount rate). This method is a straight pro-rata without accounting for the impact of paraquat when used in combination with glyphosate.

Under the yield loss scenario, the value of paraquat is determined by the value of the yield lost in absence of its use. Over a 10 year period, the net present value of this yield lost is estimated at $1.8 billion. This highlights the impact of increasing glyphosate resistance developing over time, noting the interaction between the loss of paraquat itself and the flow-on effect of a decreasing effectiveness of glyphosate. This is our preferred estimate of the direct impact on agricultural output that would occur if paraquat was deregistered.

Other scenarios, including the increased cost of farm production, tillage and special uses, are also considered in this chapter.

4.1 Methodology overview

The advantages of paraquat can be separated into private benefits and public benefits (positive externalities).

Private benefits of paraquat include:

- minimising glyphosate resistance on each farmer’s land;
- managing weeds in wet areas where glyphosate is less effective, or in other situations where glyphosate is less than fully effective;
- crop topping of pulses (a harvest aid or desiccant);
- targeted spraying in orchards and vineyards; and
- facilitating minimum tillage farming practices, in combination or rotation with other herbicides.

Some of the public benefits of paraquat usage include:

- minimising glyphosate resistance in gene pools that spill over property boundaries;

- environmental benefits as a no-runoff herbicide;
- minimising wind and water erosion over landscapes through reduced cultivation; and
- slowing the spread of glyphosate resistance beyond the farm gate.

With this myriad of uses, it is difficult to precisely quantify the total economic impact of paraquat potentially being deregistered for sale in Australia. Thus, we have focused on quantifying the private benefits of paraquat. The lists above are also not mutually exclusive – more than one benefit may occur simultaneously (for example, resistant weeds in orchards).

To measure the economic impact of paraquat, we estimate the direct expenditure (willingness to pay), the pro-rata gross value of production attributable to paraquat and the yield loss and expected crop production and profit in the absence of paraquat being available.

Other possible methodologies for estimating the aggregate benefit were not quantified, but are discussed in a broader context.

We have also reviewed the properties and effectiveness of paraquat and the uses for it in practice, through interviews with farmers of various crops and discussions with specialists in herbicide research. This information has helped to sense-check our estimates.

4.2 Direct expenditure (willingness to pay)

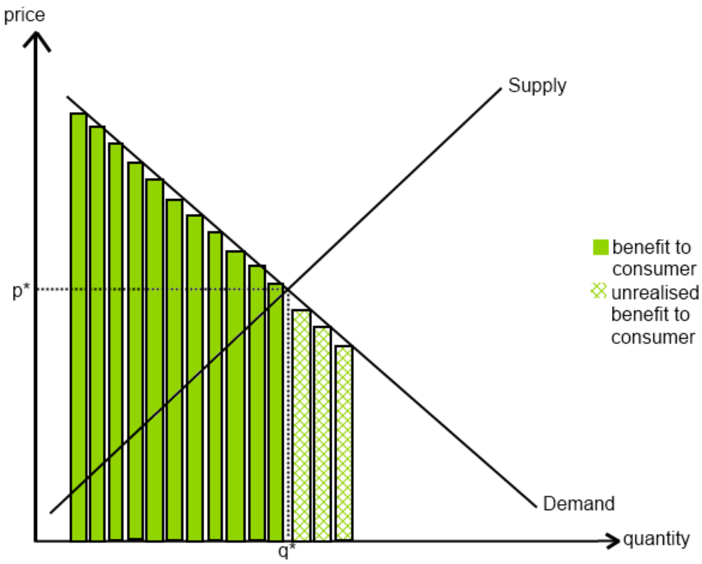
Theoretical underpinning

This method considers a willingness-to-pay valuation based on revealed preference data.

Economic theory states that rational consumers (in this case, farmers) will only purchase an item while the marginal benefit of an extra unit purchased is greater than or equal to the marginal cost of the purchase. More simply, any individual farmer will only buy and apply paraquat so long as the benefit exceeds the cost.

This is illustrated in Figure 4.1 below. The box under the demand curve at every quantity represents the benefit that a consumer gains (or their willingness to pay) for that unit. This decreases as the quantity consumed increases. When the price exceeds the additional benefit, consumers will not purchase additional goods, as this represents a loss to the consumer.

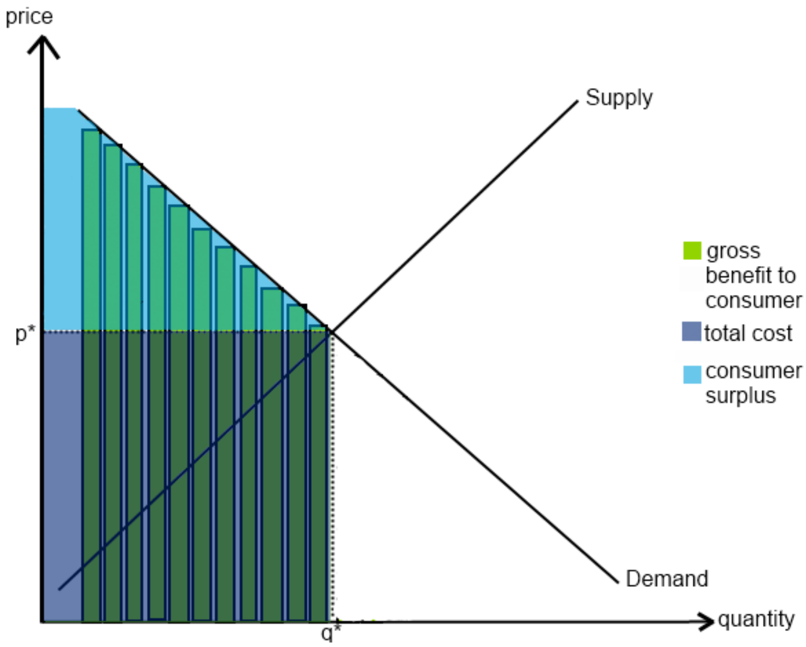
Figure 4.1: The benefit from purchasing goods



Source: DAE, 2013

Given the economic principle of diminishing marginal returns, illustrated by the downwards-sloping demand curve, it follows that gross benefit to consumers must be at least as great as the gross cost of goods; that is, the net benefit to farmers (the consumer surplus) must be greater than or equal to zero. This is illustrated in Figure 4.2.

Figure 4.2: Gross benefit to consumers



Source: DAE, 2013

Thus, the gross cost of paraquat serves as a conservative estimate of the gross benefit derived by farmers from using it. In this section, we only calculate the actual expenditure on paraquat, not the consumer surplus.

Estimating the benefit

The economic value of paraquat is the amount that farmers are willing to pay for the chemical. Its value comes from this retail cost, net of the cost of labour and capital associated with its application.

- Chemical costs
    - $Chemical\ cost\ (\$/Ha)\ = retail\ cost\ of\ paraquat\ (\$/L) \times application\ rate\ (L/Ha)\ \times applications\ per\ annum\ (n/year)$
    - **Annually, direct expenditure on paraquat sprayed is estimated at $64 million. Over a 10 year period, the net present value of this herbicide cost is estimated at $450 million**

Table 4.1: Assumptions and parameters – willingness to pay

Parameter/assumption	Value	Source
Retail cost of paraquat	$5.65/L	Agsure.com.au, 2013, weighted average
Application rate	1.27L/ha	Kleffman, 2011.
Applications per year	1.16	Kleffman, 2011.
Number of hectares sprayed	7.7 million	Based on APVMA 2013, Agsure 2013, Kleffman, 2011

The product of the above four parameters align with the average sales of paraquat.

Cost of applying paraquat

As well as the cost of purchasing paraquat, we need to take into account the cost of applying paraquat per hectare to derive a total, which can be calculated as the sum of chemical, labour and equipment costs:

- Chemical costs
    - $Chemical\ cost\ (\$/Ha)\ = retail\ cost\ of\ paraquat\ (\$/L) \times application\ rate\ (L/Ha)\ \times applications\ per\ annum\ (n/year)$
- *Plus:*
- Labour costs
    - $Labour\ cost\ (\$/Ha)\ = labour\ cost\ per\ hour\ (\$/h) \times hours\ per\ hectare\ (h/Ha)$
- *Plus:*
- Equipment
    - $Equipment\ cost\ (\$/Ha)\ = equipment\ cost\ per\ hour\ (\$/h) \times hours\ per\ hectare\ (h/Ha)$
- *Equals:*
- Cost per hectare

The total cost can then be calculated by multiplying the cost per hectare by the number of hectares sprayed. The number of hectares sprayed is inferred from APVMA, (2013) Agsure (2013) and Kleffman data (2011).

- **When the costs of application are also taken into account, annual expenditure on paraquat is estimated at $81 million. Over a 10 year period, the net present value of this weed control cost is an estimated $570 million.**

Table 4.2: Assumptions and parameters – willingness to pay

Parameter/assumption	Value	Source
Labour cost	$23/hr	Consultations, value above award rate
Hours per hectare	0.05	NSW Department of Primary Industries, 2013
Equipment operating cost	$21.61/hr	NSW Department of Primary Industries, 2013
Number of hectares sprayed	7.7 million	Based on APVMA 2013, Agsure 2013, Kleffman, 2011

Assumptions and limitations of this method

This measure is based on an estimation of expenditures incurred on buying and applying paraquat, and so is likely to be a conservative measure. Benefits to farmers from this expenditure would likely be at least as great as their actual expenditure on the herbicide.

It should be noted that a relevant consideration could be the expenditure on paraquat alone (excluding application costs), as this is the appropriate measure of its economic value (particularly if another product could be applied in its place). However, in the counterfactual where paraquat is deregistered, and there is not a readily available alternative, those labour savings would accrue and are thus valid to include.

4.3 Pro-rata value of crop protection products

Following the methodology used in CropLife America, this methodology estimates the private benefits attributable to the use of paraquat using a top-down approach. This method considers the gross value of production for crops that use paraquat and assigns a proportion of this production that is attributable to its use, based on paraquat's pro-rata share of total herbicide use.

This estimate is larger than the direct expenditure as it takes into account the value of paraquat inclusive of its price, in terms of its contribution to agricultural production (that is, the agricultural *output* due to herbicides, rather than just the *input* costs of herbicides).

1. Estimate total value of crops that use paraquat:
    - Value of crops where paraquat would be used is estimated using Syngenta estimates, APVMA sales data, and ABARES data on gross value of production for these commodities.
        - This accounts for differences in the mix of agricultural commodities grown in Australia versus America, and adjusts the CropLife America estimates accordingly
        - For this study, the crop categories used in this estimation include barley, citrus, cotton, forage crops, grapes, oil seed rape, pasture, pome fruits, stone fruits, sugarcane, vegetables, wheat, other cereals and other crops.

2. Estimate proportion of the total crop value that is attributable to herbicide (following the CropLife America report methodology):
    - Crop value due to herbicide estimated at 25%
        - Based on 20% from the CropLife America report and L.P.Gianessi and N.P.Reigner *The Value of Herbicides in US Crop Production* Weed Technology Journal (2007)
        - Adjusted upwards for Australian conditions using a factor of 1.26 (Deloitte Access Economics, 2013, forthcoming) based on relative crop protection expenditure per hectare and per dollar of production, between Australia and the US. This factor allows for Australia's different composition of agriculture, poorer soils and lower rainfall.
3. Determine the share of total herbicide value which was attributable to paraquat:
    - Estimated as paraquat's share of herbicide use, based on Kleffman data (2011).
4. Estimate paraquat's contribution to total production:
    - $$\begin{aligned} Contribution = {} & Value\ of\ crops\ that\ use\ paraquat \\ & \times proportion\ of\ crop\ value\ attributable\ to\ herbicides \\ & \times share\ of\ total\ herbicide\ value\ attributable\ to\ paraquat \end{aligned}$$
    - **Paraquat's contribution to Australian crop protection is estimated at $183 million annually. Over a 10 year period, the pro-rata net present value of this weed control product is estimated at $1.3 billion.**

Table 4.3:Assumptions and parameters – economic contribution

Parameter/assumption	Value	Source
Gross value of production, crops where paraquat would be used, 2011-12	$24.2 billion	Syngenta crop information, ABARES (2012) and ABS (2012) prices
Crop value due to herbicide	25%	DAE, based on Croplife America (2011)
Paraquat % of herbicide use	3.0%	Kleffman (2011)

Assumptions and limitations of this method

The methodology is based on an American study of herbicide use, and it is noted that there are differences in weed types, resistance levels, application practices, climates, farm productivity and farm costs and yields, compared to Australian agricultural conditions. While there are a number of factors which differentiate the Australian situation to that of the American, herbicide is broadly used in a similar way in both countries to control weeds and improve yields.

To adjust for Australian conditions, a factor of 1.26 was derived based on relative agricultural expenditure on crop protection products per hectare, and per dollar of agricultural production.

The estimation here also uses Australian values for gross value of production, herbicide use and paraquat's share of the total herbicide market.

Further, paraquat’s contribution, as a share of the total herbicide contribution, is estimated as its share of the market in terms of litres sprayed. This provides a useful estimation of its contribution, however cannot fully take into account the nature of paraquat as a herbicide and its role in resistance management. Paraquat’s share of the herbicide market in dollar terms provides another indication of its relative value, accounting for approximately 5% of the market. While the former measure is used, not all ‘value’ is represented in the volume used and this remains an imperfect measure of its contribution.

4.4 Yield loss in the absence of paraquat

This measure uses a bottom-up approach. It estimates the hypothesised yield loss which would result from a proliferation of glyphosate-resistant weeds in the absence of paraquat. This method does not consider the additional losses to private benefit which would result from paraquat being unavailable for other uses, such as in wet climates or crop topping. Rather, the broadacre average is used (which account for the vast bulk of paraquat sales).

Of the three measures, this one provides the highest value of paraquat as it also takes into account paraquat’s impact on the effectiveness of other herbicides such as glyphosate, through its role in resistance management, rather than just the straight pro-rata share of all herbicides or the cost-based measure, above.

The estimation process and the main data sources informing it are as follows:

1. Calculate average yield (tonnes per hectare) of cereal crops.
    - World Bank data on cereal yields
2. Estimate the maximum level of yield loss that a farmer would sustain before either switching to alternative methods of weed control, or changing to alternative land uses
    - It is estimated that farmers would withstand yield losses of up to 15% before switching to alternatives, such as tillage for weed control, or livestock rather than crops.

      This is based on the average yield loss for a range of cereal crops, faced with annual ryegrass competition of 300 plants per square metre (WA Department of Agriculture). Economic weed thresholds are the density of weeds at which control is economically justified. It is noted that paraquat is used in the prevention of glyphosate resistance as well as in the management of existing resistance issues. This threshold is set based on resistance increasing exponentially over five years. At this point, the cost of spraying is less than the cost of lost yields from weeds.
3. Calculate average yield loss per hectare
    - $Average\ yield\ loss\ (T/ha) = average\ yield\ (T/ha) \times yield\ loss\ (\%)$
4. Value yield loss
    - $Loss\ (\$/ha) = average\ price\ (\$/T) \times average\ yield\ loss\ (T/ha)$
        - ABARES data on average farm gate price for cereals used for average price
5. Estimate total economic loss from the deregistration of paraquat
    - This is calculated by multiplying the loss per hectare by the estimated number of hectares that were (formerly) sprayed with paraquat

- **Over a 10 year period, the net present value of this yield lost is estimated at $1.8 billion. In year 3, when the economic weed threshold is reached, the economy-wide cost of yield lost is estimated at $106 million, compared to paraquat chemical and application costs of $81 million.**

Under this method, glyphosate resistance increases over time, causing yield losses to increase until hitting the maximum of 15%. The yield losses here are capped at 15% as farmers would not just keep accepting losses. This estimates where the losses would be capped when a farmer would instead move to another form of production, such as livestock, rather than continue to accumulate further losses in production. In equivalent terms, this yield loss is thus capped at $52 per hectare.

This ‘ramp up’ is exponential, based on an assumption of exponential growth pattern in resistant weeds each period, established in consultation with subject matter experts (see Chapter 5). Thus, it is assumed that yield loss is 1% in the first year that paraquat is unavailable, then 2%, 4%, 8% and finally 15% in the following years.

The net present value of the losses in the 10 years following the hypothetical withdrawal of paraquat is calculated. This value is compared with the predicted cost of continued paraquat use over the same period. This demonstrates that the cost of yield loss increases over time, and over the medium-long term exceeds the cost of spraying paraquat.

Table 4.4: Assumptions and parameters – core scenario

Parameter/assumption	Value	Source
Average yield of cereal crops	1.72 t/ha	World Bank
Maximum yield loss a farmer would sustain before employing alternatives	15%	WA Department of Agriculture. This figure is an average based on annual ryegrass competition of 300 plants per square metre.
Average price of yield	$201/t	ABARES, average farm gate price of cereals
‘ramp up’ of resistance	Doubling each year: 1%, 2%, 4%, 8%, 15% thereafter	Consultations
Implied value of maximum yield loss	$52/ha	Based on above data

The above estimation is based on cereal yields and prices. While the majority of paraquat-treated area (78%) involves the production of wheat and barley (Kleffman, 2011), there are also high-value viticultural and horticultural enterprises which use paraquat.

For example, paraquat use in vineyards involves a higher application rate (around 2.8L/ha compared to 1.2L/ha for wheat and barley). Vineyards have a lower yield per hectare, but a much higher dollar value attributed to this yield. Yield loss interactions with increasing resistance are also different as competition between weeds at the base of vines is different to the competition between weeds and cereals. Per hectare yield losses estimated above for cereals are therefore conservative, with viticultural farmers having a greater capacity to pay for more expensive alternative methods of weed management due to the value of production.

The following tables present similar estimations for the viticulture, pome and nut industries. The 'ramp up' of resistance in these cases is based industry consultations. The yield loss is assumed to double annually as per the cereals scenario, but with a plateau at 5%. The maximum yield losses are calculated based on the 5% yield loss in year 4.

Table 4.5: Viticulture scenario - assumptions and parameters

Parameter/assumption	Value	Source
Average yield of viticulture crops	10.9t/ha	ABARES
Maximum yield loss a farmer would sustain before employing alternatives	5%	Industry consultation
Average price of yield	$659/t	ABARES
'ramp up' of resistance	1%, 2%, 4%, 5% thereafter	Industry estimates
Implied value of maximum yield loss	$359/ha	Based on above data

Table 4.6: Pome (apples and pears) scenario - assumptions and parameters

Parameter/assumption	Value	Source
Weighted average yield of pome crops	24.1t/ha	Apple& Pear Australia Ltd
Maximum yield loss a farmer would sustain before employing alternatives	5%	Industry consultation
Average price of yield	$1,787/t	Horticulture Australia
'ramp up' of resistance	1%, 2%, 4%, 5% thereafter	Industry estimates
Implied value of maximum yield loss	$2,153/ha	Based on above data

Table 4.7: Nut scenario - assumptions and parameters

Parameter/assumption	Value	Source
Average yield of nut crops	1.5t/ha	Horticulture Australia
Maximum yield loss a farmer would sustain before employing alternatives	5%	Industry consultation
Average price of yield	$4,350/t	Horticulture Australia
'ramp up' of resistance	1%, 2%, 4%, 5% thereafter	Industry estimates
Implied value of maximum yield loss	$326/ha	Based on above data

The tables above show that while viticulture and horticultural crops make up around a quarter of the paraquat-treated area, the yield loss from the absence of paraquat can be significant, and much higher than the losses from cereals on a per hectare basis.

This highlights the higher value of the crop which allows for more expensive alternative methods of weed management to be used. Indeed, glufosinate is registered for use on horticultural crops. This is a higher cost alternative to paraquat, at over $50/L at recommended application rates. Its performance is dependent on suitable temperature and humidity conditions at the time of application (Bayer CropScience 2012).

A broader NPV of yield loss including these industries is not estimated here as the interaction with farmers switching to glufosinate, where suitable, would affect the actual yield loss and cost of paraquat in each of the scenarios, noting that they are not close substitutes.

It is anticipated that similar results would be seen for the rest of the horticulture industry, namely higher yield prices and a different ‘ramp up’ in resistance would lead to a higher implied value of maximum yield loss per hectare. Values for the whole horticulture industry are not estimated here due to data limitations in aggregating various values for a range of fruits and vegetables.

Assumptions and limitations of this method

This method is based on assumptions of an exponential rate of increase in weeds, resulting in yield loss increasing up to a point where there is 15% weed loss. After this point is reached, it is assumed that there is no further increase in yield loss due to competition from crops limiting further spread and/or a farmer choosing to pursue an alternative land use (or stop farming altogether, resulting in offsetting savings on other operating costs).

While it is possible to compare gross margins of different land uses such as cropping and grazing, it is difficult to model this ‘switchover’. A fallow period, cultivation and other capital expenses such as fencing could be required, depending on the alternative land use pursued. Hence, it is unclear how long it would be before the land could be productively used for another purpose. In the absence of these details, the yield loss has been assumed to be an ongoing 15% once this level has been reached.

On the other hand, in the paraquat application scenario, the costs of paraquat are assumed to be constant over the 10 year period. Despite resistance to glyphosate increasing over time, it is assumed that there is no change in the application rate of paraquat. Consultations suggested that farmers are unlikely to notice small populations of resistant weeds and would be unlikely to act against an increase in resistance on a small scale.

This is also based on the trend of declining prices for paraquat against an increase in volume sold, and assuming a constant nationwide cost based on these interplaying price and quantity factors. While in practice, this pattern could alter in the upcoming decade, this is not captured in this method of estimation.

Finally, the NPV estimate only takes into account the cereals sector. While this accounts for 78% of paraquat-treated area, it is noted that high-value viticulture and horticulture crops, with higher application rates are included in this estimate and the same average rate ($52/ha). With higher value yield losses in these other sectors, there is more likely to be a change in type of production or weed management rather than accumulation of losses over time, and hence they are not included in the NPV calculation.

4.5 Summary of quantitative estimates

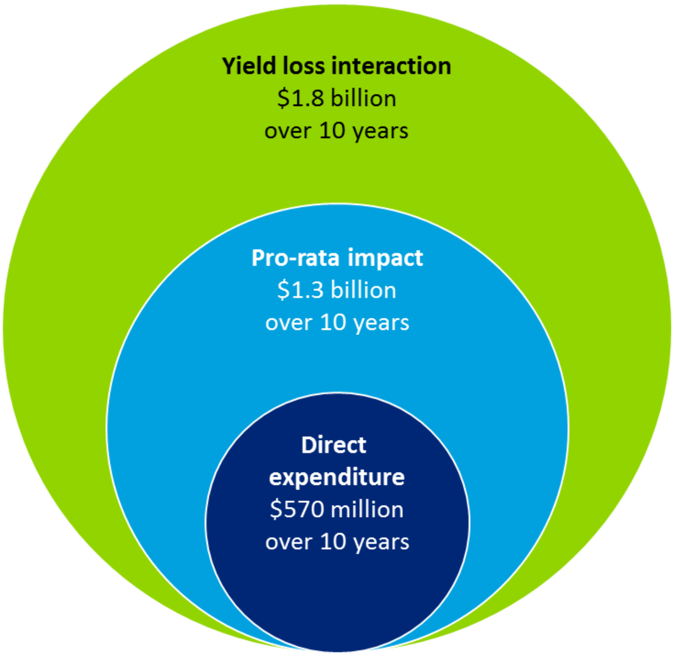
Together, these three methods of estimating the value of paraquat build up a picture of its contribution to agriculture, as summarised in the figure below. Direct expenditure is the smallest estimate of the value of paraquat, as it must be worth at least what is spent on it, in order for rational farmers to purchase it in the first place.

Consideration of the pro-rata impact of paraquat provides a larger estimate of its value. This method attributes a proportion of the gross value added of agricultural products attributed to paraquat as a share of herbicide. This takes into account its contribution as a herbicide in terms of production, above what is spent to purchase it, but only a straight pro-rata as a standalone herbicide and not allowing for the interaction effect when used in a double knock or in rotation with glyphosate.

Finally, the yield loss interaction method considers what would happen in the absence of paraquat, with resistance increasing exponentially before plateauing at the point where farmers would cut their losses or change their landuse. This leads to an increasing yield loss over 10 years and accounts for paraquat's contribution to production but also its contribution to crop protection more broadly. The resistance management role of paraquat in supporting the ongoing use of glyphosate is a further measure of its value considered in this method, resulting in a higher estimate of its value.

All estimates are of 10-year impacts, in 2013 dollars, with a real discount rate of 7%.

Figure 4.3: Estimation of the value of paraquat, three methods



4.6 Other scenarios considered

This section explores other scenarios which could result if paraquat was deregistered. Farmers have a range of available options to manage weeds, including chemical and non-chemical strategies. It is possible that a higher cost weed management strategy could be adopted or tillage could be more widely used.

These scenarios were discussed with stakeholders (see the case studies in Chapter 5) and generally thought to be unlikely to occur in practice. They are discussed further below.

Increased cost of farm production

This scenario suggests that, in the absence of paraquat, farmers would turn to other methods to maintain or increase yield and/or combat weed resistance in their crops.

Firstly, there are few herbicide alternatives to using paraquat. Paraquat is relatively unique in its ability to overcome glyphosate resistant weed populations, with no other alternatives (more expensive or otherwise) currently registered as a direct substitute herbicide in broadacre cropping.

Glufosinate is currently registered as a Group N chemical for use in horticulture. Like paraquat, glufosinate is a non-selective herbicide, and controls over 80 species of broadleaf and grass weeds (Bayer, n.d.), and has recently been registered for use to control certain weeds in summer fallow situations prior to broadacre cropping (Bayer 2013). Under suitable climatic conditions it is absorbed by plant foliage and green stems, with no significant soil activity.

While it is a current, higher cost alternative chemical for use in horticulture, consultations suggest its adoption could be limited due to its relative cost. At approximately $63/Ha,[5] the estimates in section 4.2 suggest that this is economically unviable despite recent availability, given the value of yield of cereal crops.

Hence, in the absence of paraquat, the majority of farmers would not adopt a different herbicide to use in a double knock mix or as an alternative knockdown herbicide, but would instead rely on glyphosate only and likely encounter resistance issues sooner.

Non-herbicide alternatives to paraquat use include increasing physical weeding. Tillage is explored in the following scenario, and smaller scale weeding is generally not feasible or practiced. Manual weeding, mulching or other weed control options were assessed in consultations as being unviable in broadacre cropping – well above our $52/ha tipping point estimate, at which point it makes more sense to cease farming or change landuse rather than to continue to outlay more on crop protection.

Consultations suggested that farmers, in the absence of paraquat, would not be willing or able in financial sense, to sustain the high cost of alternative weed control options over the longer term. Possible alternate options were not only considered to be economically unviable, but also unviable from an environmental and farm labour/time perspective. On this basis, those alternatives appear unlikely to be adopted.

Tillage

This scenario considered increased tillage as a response to the unavailability of paraquat. There were several issues with this scenario raised in the consultations, which made this scenario unlikely to be cost-effective, or even realistic on some lands.

Increased tillage would require use of a high powered tractor and tillage equipment. Farmers on lands where only minimum tillage occurs are unlikely to currently own these

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[5] Bayer recommends application rates of 3.75L/Ha for Basta® (glufosinate) on broadacre crops. Based on retail prices of $335 ex GST for a 20L drum, the implied cost per hectare of Basta® is $63/Ha.

items, as a higher-powered tractor is required for tillage than would be required for sowing, and cultivation equipment may not be used elsewhere on the farm. Consultations suggested that it would be unlikely that farmers would purchase or hire this equipment for the purpose of cultivation to manage weeds, with costs likely to be prohibitive.

That said, the higher cost of tillage is not the limiting factor for increased adoption of this practice. Minimum tillage has increased in general practice in recent years because of its benefits associated with soil structure, moisture retention, carbon emissions and soil carbon, time, practicality and overall sustainability of production. Hence, increasing tillage goes against the trend in agricultural management, with consultations suggesting that farmers are unlikely to adopt a practice that would go against the currently accepted farming model.

A simple estimate of the cost of tillage per hectare, based on the cost of diesel and labour (but not the cost of machinery) appeared to be higher than the farm gate price received for cereal crops. This suggests that areas which may be viable for crop production when herbicide is used as the method of weed control may not be economically viable when this option is removed.

Further, this implies that land which would have been too expensive to farm before the invention of effective herbicides would return to being economically unviable for cropping. Gross margin analysis and consideration of the costs of tillage could suggest a change in land use and production. In graphical terms, for these farms, the cost of production (the supply curve in Figure 4.1) shifts up so that it lies entirely above the demand curve. This means that there is no longer any viable production from these farms, if tillage for weed control became required.

Carbon savings

Associated with the above scenario, there are carbon costs of tillage from both emissions of diesel use and from lost soil carbon due to the disturbed soil.

Reducing diesel use, however, does not confer a carbon benefit to the farmer. This carbon benefit does not translate into financial savings for the farmer (off-road diesel use is not currently liable under the Government’s Carbon Pollution Reduction Scheme) and hence there is little motivation or scope for carbon or cost savings.

Consultations suggested that savings from lost soil carbon would be minimal in Australian farming conditions, and should not be overstated. Soil carbon is most likely to build up in areas with heavy soils and high rainfall, which are not characteristic of many of the broadacre cropping areas where paraquat is commonly applied.

Overall, it was suggested that carbon savings were not significant enough to quantify. From a cost perspective, these carbon savings would have effectively no impact on the farming decision to increase tillage or otherwise.

Special uses

The special uses of paraquat were explored in case studies on use of paraquat in viticulture, apple and pear, and sugarcane (where runoff could affect waterways) and the alternatives if paraquat was not available. These are more a qualitative story and are presented in the next chapter. The direct spending from these uses is already captured in the first two of the three methods above.

4.7 Decision making

This chapter considered the economic value of paraquat by looking at the direct impacts which would occur if it were deregistered by the APVMA. It presented quantification of paraquat's value using three estimation methods. It also qualitatively considered other scenarios which could arise in the absence of paraquat.

Taking this into account, this section presents decision trees summarising the alternatives which could be considered if paraquat was deregistered. Cereals and horticulture are considered separately due to their different likely alternatives.

In particular, cereals and horticulture differ in the suitability and viability of glufosinate as an alternative chemical, and because the higher capital costs and value of production in these industries make it less likely that farms will be converted to other agricultural production such as livestock, or left fallow.

The decision trees show that many of the options presented are unviable. Disadvantages such as high cost or high time requirements outweigh the advantages and make them unpractical alternatives in weed management. This serves to highlight the value of paraquat, in particular because there are few ready substitutes available in its absence.

Figure 4.4: Decision tree for cereals

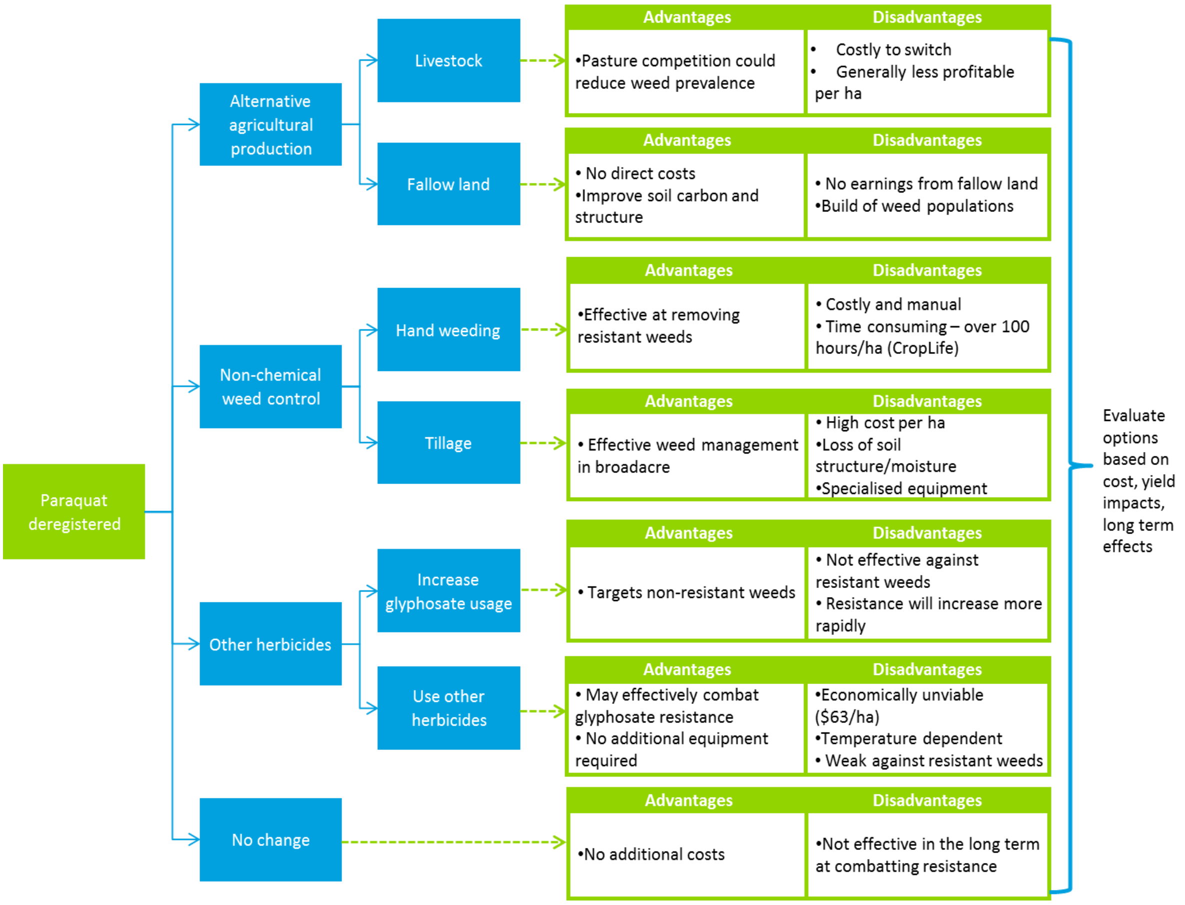
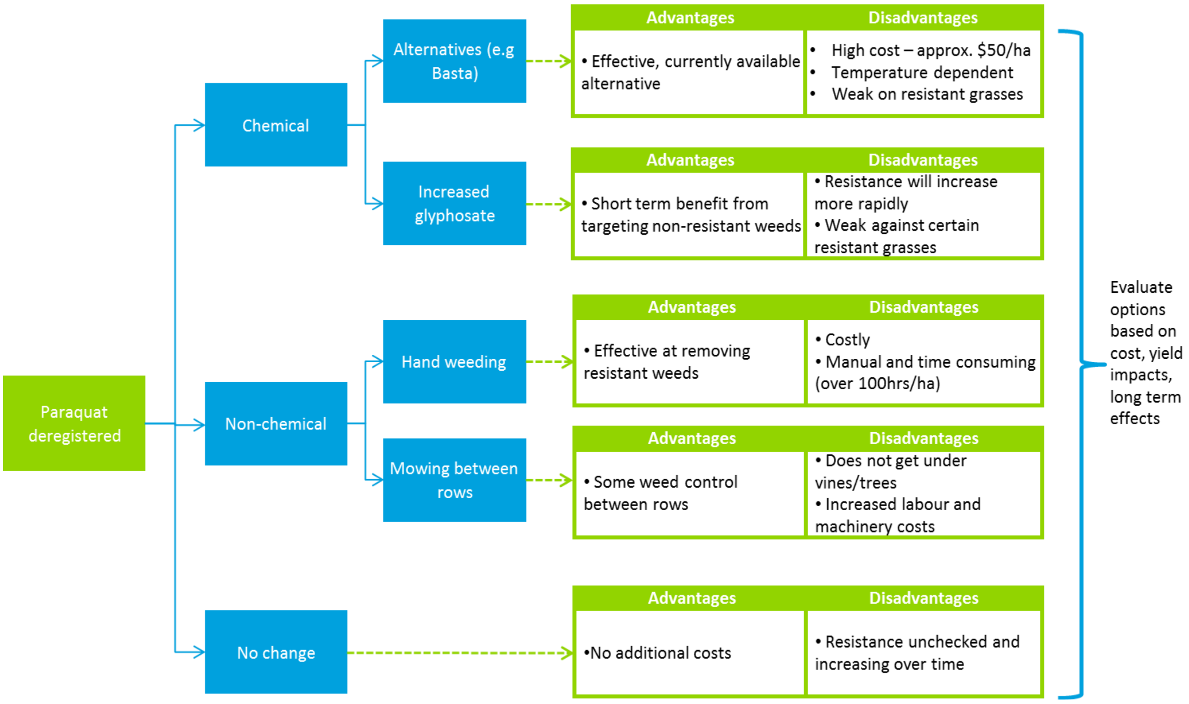


Figure 4.5: Decision tree for horticulture



5 Case studies

A number of case studies were conducted as part of this study on the economic impact of paraquat. The purpose of these consultations was primarily to inform the modelling, with input used to develop and sense-check the parameters and scenarios.

Consultations involved key stakeholders including academics, subject matter experts, agronomists, government departments, and representatives from industry bodies. These stakeholders represented a number of regions/industries which currently use paraquat in weed management, and which would be impacted if paraquat were removed from the market. These included northern NSW broadacre (Moree), southern broadacre (South Australia), sugarcane (north Queensland), viticulture, and apple & pear growers.

Brief notes from the consultations are presented in this chapter.

Subject matter experts

Consultation with academics and subject matter experts, including agronomists, provided insights on the current use of paraquat, likely outcomes if paraquat was not available, and parameters around resistance development.

These discussions highlighted that paraquat is used for prevention as well as management of glyphosate resistance. While most farmers do not have a major resistance problem, it is considered there is high risk of it developing and spreading.

In the case of glyphosate resistance developing, it was thought that the increase would be exponential, with a doubling of the level of resistance each year as resistant populations propagated and spread.

It was noted that the market for paraquat was much smaller than the market for glyphosate. This limits the potential impact from removing it from the market, though it is noted they are commonly used interdependently.

Consultations also suggested that in broadacre agriculture where paraquat is used, there is not much potential for soil carbon to build up, particularly where these regions are characterised by low rainfall and light soils. As such, soil carbon issues should not be a consideration for reducing tillage.

It was unclear as to whether farmers would increase tillage in the absence of paraquat. While there was some evidence of increased tillage in weed management when the price of glyphosate increased in 2008 (due to both supply and demand factors), the high cost of tillage was also identified as a limiting factor to further uptake.

Subject matter experts (continued)

It is likely that profit-maximising rational farmers would make decisions based on their particular farm, gross margins and tillage costs to make the decision whether to increase tillage or not.

They were also available to review the methodology and parameters in the model, to sense-check the figures and the logic behind the calculations.

Southern broadacre

In current practice, paraquat is applied as a broad spectrum herbicide to control weeds prior to planting cereals or canola. Farmers in southern broadacre areas are effectively managing glyphosate resistance at present, however if paraquat was removed as an option, farmers would switch to using glyphosate only. As a result, there would be an exponential increase in weed resistance – doubling on average every two years.

There would likely be a shift away from pulses towards cereals, with the possibility of increased cultivation. It would be unlikely that there would be a shift to livestock production as it is expensive to convert between these two land uses.

Northern broadacre

In the production of wheat, sorghum and dryland cotton, paraquat is used in the herbicide preparation stage during the summer fallow. It is mainly used in a ‘double knock’ following glyphosate application, but can be used on its own.

If paraquat was made unavailable, it was suggested that there would be an increase in the prevalence of awnless barnyard grass, a decrease in soil moisture and a decline in crop yield. Resistance to glyphosate would be an issue after 3-4 years.

While it is possible that Group A herbicides (such as Verdict) could be adopted in the absence of paraquat, resistance to these herbicides would be an issue in 5-10 years. Glyphosate alone is not seen as an effective alternative, in increased applications or otherwise.

Increasing cultivation in weed management could be employed, but only as a last resort. Firstly, it would contribute to soil erosion, and is significantly more expensive than chemical options for weed control. Further, many farmers no longer have the required equipment, including a larger tractor than used for sowing, scarifiers or cultivators.

Apple and Pear

Both paraquat and glyphosate are used in apple and pear crops, early in the season once weeds have emerged in the crop. They are applied on the 'herbicide strip' located one to two metres to each side of the tree.

Paraquat is used in this 'spring flush' of weeds – when it is important to minimise soil disturbance, maintain soil moisture and fertilise crops – and at other times throughout the season. Benefits of using paraquat include it being non-residual, and having less impact in terms of leaching into water tables.

There are also cost advantages to using paraquat in apple and pear farming systems. It provides 6-8 weeks of control after each spraying, has a relatively steady price compared to glyphosate, and no residue problems.

Glyphosate resistance is not noted as an issue in apple and pear farming, unlike in broadacre, but herbicide rotation is practiced to minimise the extent of it occurring.

Given that paraquat is preferred over glyphosate in the apple and pear industry, it was noted that it would be difficult to operate in its absence. While a new herbicide mix would be established, it was thought that it would be less effective in weed management.

Increasing tillage was not thought to be an option in weed management due to the shallow roots of crops. It was thought that disturbing the soil in perennial horticulture systems would instead stir up the seedbank and lead to more weeds resulting.

It was noted that only real negative of paraquat use was its toxicity. However, this was said to be well managed through very good training.

Viticulture

There are not many available alternatives to paraquat in viticulture, where it is seen as the most cost effective herbicide for weed management. It was noted that there was little potential for use of glyphosate, which is only occasionally used as a substitute.

More broadly, there are not seen to be good alternatives to herbicide use. Cultivation only used for table grapes and for dried fruit markets, and organic grapes. Other methods of weed control such as steam, flames and the use of oils are costly and uncommon.

Sugarcane

Paraquat is used in sugarcane to target all weeds, while sacrificing the lower leaves of the sugarcane plant. It was noted that at planting, lower application rates were used than when doing a second pass. This was done from an economic perspective, due to the higher cost of increasing the volumes sprayed per hectare. Given glyphosate's systemic mode of action it does not represent a suitable alternate for this use pattern in cane, as the plants would be killed.

Tillage was not seen as an alternative to use of herbicides due to the associated erosion. The sugarcane industry in Queensland has moved towards more environmentally friendly sugarcane growing and management, with green cane harvesting and trash blanketing adopted. This involves leaving the leaves and tops of the cane as a ‘trash blanket’ instead of burning the stubble.

Benefits of this practice include weed management and protecting the soil from erosion, and can reduce the requirement for herbicide application (though not eliminating the need for it completely).

6 Broader economic impacts

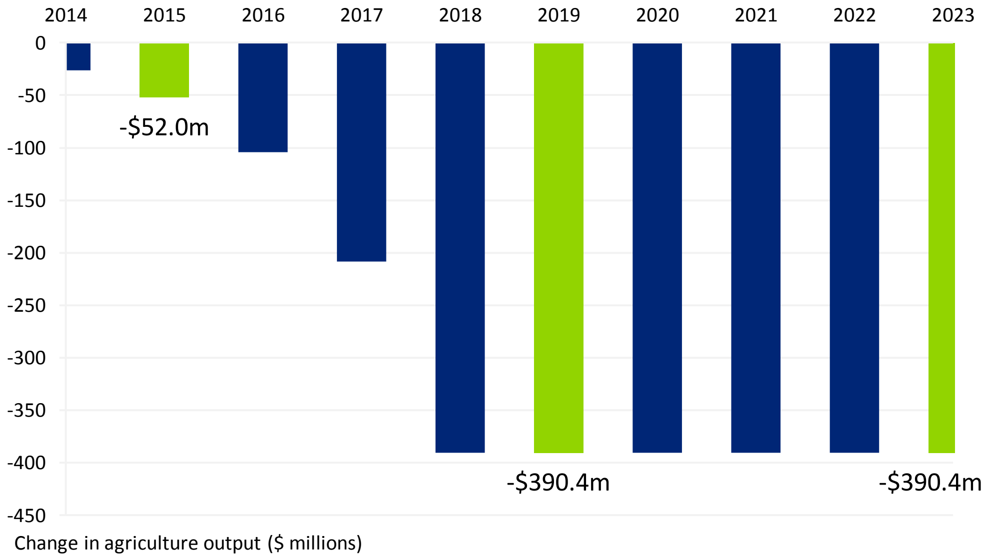
This chapter examines economy-wide impacts on Australia if paraquat was no longer available for sale. The approach uses Computable General Equilibrium (CGE) modelling to estimate the behavioural impact of the Australian economy and industry over the period of 2013-2025. The impacts are measured in terms of their deviation from a business as usual (BAU) case where paraquat is still for sale.

Deloitte Access Economics have used a customised version of our in-house CGE model – DAE-RGEM – to model the estimated impacts of ceasing the sale of paraquat. Further detail on the model is in Appendix B.

6.1 Analytical method

As outlined in Section 4, in the absence of paraquat, farmers would either turn to other methods to maintain yield and/or combat weed resistance in their crops, substitute to alternate land use (which are generally lower value-adding activities, such as running livestock rather than grain crops), or allow marginal land to lay fallow. Even under these alternative methods, glyphosate resistance is expected to increase over time, causing yield losses of 1% in the first year, then 2%, 4%, 8% and 15% in the following years. Chart 6.1 outlines the loss in agriculture yield, in today's dollars that was modelled for this report.

Chart 6.1: Change in agriculture output (2012-13 dollars)



6.2 National economic impacts

The absence of paraquat is expected to initially have a modest impact on the national economy; however, the impact is expected to increase over time. The modelling estimates that Australia's gross domestic product (GDP) expected to decline by $72 million in 2015. GDP is expected to later fall by an estimated $362 million per annum (see Chart 6.2), once the 15 % yield loss has occurred, compared with the BAU scenario.

Against the loss in agricultural output, some industries increased their output in comparatively small amounts as factor markets (markets for land, labour and capital) adjust to industries with higher returns (see Table 6.2).

Chart 6.2: GDP impacts within Australia

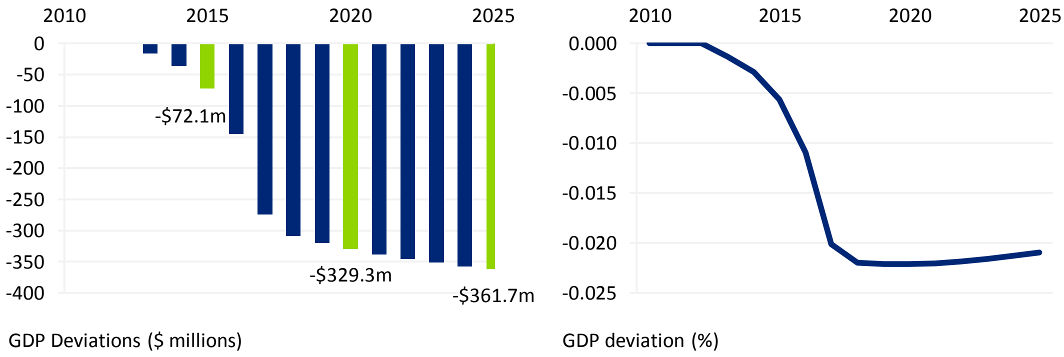


Table 6.1 shows the estimated impact of the absence of paraquat on key macroeconomic variables over different time periods.

The absence of paraquat is expected to have the largest impact in the latter half of the modelling period. Over the period of 2019 to 2025 inclusive, GDP is expected to decline in net present value terms by $1.2 billion, compared to $616 million from 2013 to 2018 inclusive. This reflects the accelerating reductions in output in the agriculture industry and flow-on effects across the whole economy.

Table 6.1: Economic impacts within Australia (cumulative deviations from BAU)

	2013 to 2018	2019 to 2025	2013 to 2025
GDP (NPV, $A)	-$616 m	-$1,225 m	-$1,841 m
Agricultural output (NPV, $A)	-$852 m	-$1,402 m	-$2,254 m
Exports (NPV, $A)	-$182 m	-$588 m	-$771 m
Employment (average over period)	-296 FTE	-553 FTE	-434 FTE
Wages (average over period)	-0.01%	-0.02%	-0.02%

Note: NPVs have been calculated using a discount rate of 7 per cent. All values are in real 2012-13 terms.

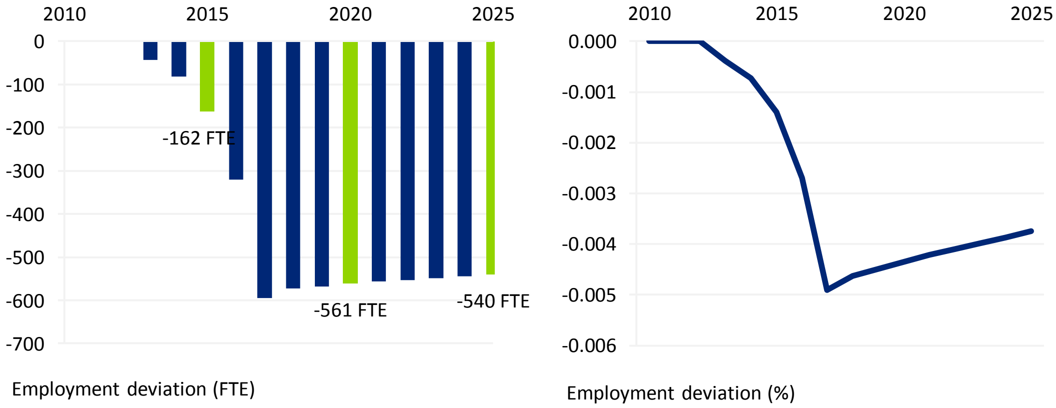
The absence of paraquat is expected to reduce Australian exports on average by $109 million per annum below the BAU by 2025, or $588 million cumulatively over the period 2019 to 2025 (in NPV terms, in 2012-13 dollars), driven by a combination of the aforementioned reductions in agricultural yields and reduced output in the processed food sector which is a major consumer of agricultural output. Other industries exports rise by comparatively small amounts over the period, but not enough to offset the fall from agriculture production and exports.

Employment

During the period from 2013 to 2017, the reduction in full time equivalent (FTE) employment is expected to grow as employment in industries adjusts throughout the economy. The loss of full time employment is expected to peak at 594 FTE in 2017. Industries that use agriculture as an intermediate input in its production process, such as the processed foods industry, are the main driver of the loss in FTE.

Beyond 2017 labour markets begins to readjust to some degree through a combination of agriculture requiring additional labour to produce a unit of yield (as a result of alternative weed control strategies being more labour intensive) and as industries respond to reduced wage pressures as shown in Table 6.1. The expected pattern of employment over 2013 to 2025 is shown in Chart 6.3.

Chart 6.3: Employment impacts within Australia



6.3 Industry impacts

Over the modelling period, the absence of paraquat has a number of positive and negative impacts on industries in Australia. Table 6.2 outlines the average expected deviation of industry output from 2013 to 2025.

Agricultural output is expected to decline by $390 million per annum by 2025 (in 2012-13 dollars). This decline is due to a combination of factors: a reduction in agricultural output from the proliferation of glyphosate-resistant weeds, and losses of land and labour productivity as farmers use less effective methods for weed control.

As agricultural products are used as intermediate inputs into other products, the loss of agricultural output also has indirect impacts on the production of other industries. The estimated reduction in agricultural output is expected to have the largest indirect impact on the processed foods industry with output reducing by $139 million by 2025 (in 2012-13 dollars).

Table 6.2: Average deviation in industry output from BAU (2013-2025)

Industry	Deviation in output
Agriculture	-0.35%
Coal	0.02%
Oil	0.03%
Gas	0.03%
Other minerals	0.01%
Processed Foods	-0.07%
Manufacturing	0.01%
Chemicals, Rubber and Plastic products	0.00%
Electricity	0.00%
Water and Waste	-0.01%
Construction Services	-0.03%
Trade	-0.01%
Transport	0.00%
Communications	-0.01%
Other Finance and Insurance	-0.01%
Other Business Services	-0.01%
Recreation	-0.01%
Other Services- Government	0.00%

Some industries, on the other hand, are expected to enjoy small increases in output over the modelling period. The increase in output occurs for two reasons.

Firstly, as a result of a reduction in production costs due to slightly reduced wage pressures, with the national wage rate reduced by an average 0.02% as shown in Table 6.1.

Secondly, due to a depreciation of the Australian dollar. The decline in agricultural output drives a reduction in agricultural and processed food exports with a corresponding reduction in the exchange rate, improving the competitiveness of exports from other industries.

These industries are expected to increase their output, over the BAU scenario, on average by 0.01 to 0.03 per cent over the modelling period.

7 Conclusion

In the absence of paraquat, it is understood that farmers would be likely to continue using glyphosate and face potential resistance development over time. While some farmers would turn to the use of other chemicals in their spray mix, there are not currently considered to be any viable chemical alternatives to paraquat, regardless of cost.

Other weed management strategies such as tillage are also unlikely to see resurgence in the absence of paraquat, given the costs of labour, farm machinery and environmental impacts that would be incurred. Estimation of the value of paraquat was supported by consultations with subject matter experts and industry stakeholders. Three methods of estimation were used.

Together, these three methods of estimating the value of paraquat build up a picture of its contribution to agriculture. Direct expenditure is the smallest estimate of the value of paraquat, as it must be worth at least what is spent on it, in order for rational farmers to purchase it in the first place. The net present value of this weed control cost is estimated at $570 million over a 10 year period.

Consideration of the pro-rata impact of paraquat provides a larger estimate of its value. This method attributes a proportion of the gross value added of agricultural output attributed to paraquat as a share of all herbicides (a straight pro-rata share without allowing for interaction with glyphosate). This takes into account its contribution as a herbicide, inclusive of what is spent to purchase and apply it. This measure of the value of paraquat is estimated at $1.3 billion over a 10 year period.

Finally, the yield loss interaction method considers what would happen in the absence of paraquat, with glyphosate resistance increasing exponentially before plateauing. This leads to an increasing yield loss over 10 years and accounts for paraquat's contribution to production but also its contribution to crop protection more broadly. The resistance management role of paraquat in supporting the ongoing use of glyphosate is a further measure of its value considered in this method, resulting in a higher estimate of its value. Over a 10 year period, the net present value of this yield lost (less the cost of purchasing) is estimated at $1.8 billion. This only includes agricultural yield impacts.

The economy-wide impacts on the Australian economy and industry over the period of 2013-2025 were estimated using Computable General Equilibrium (CGE) modelling. The impact on GDP is estimated at $362 million per annum by 2025. The absence of paraquat is expected to reduce Australian exports on average by $109 million per annum below the business as usual case. The loss of full time employment is expected to peak at 594 FTE in 2017. Agricultural output is expected to decline by $390 million by 2025 (2012-13 dollars).

These estimates suggest that paraquat has a significant role in the weed management mix, and in the absence of paraquat there would be no ready alternatives to manage glyphosate resistance, or other situations where glyphosate is less than fully effective, resulting in a cost to the economy.

Appendix A – References

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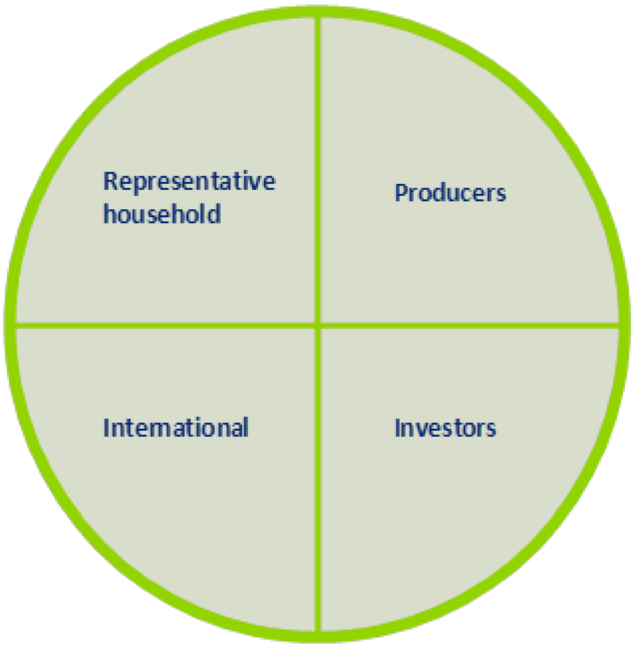
Appendix B – CGE Modelling

The Deloitte Access Economics – Regional General Equilibrium Model (DAE-RGEM) is a large scale, dynamic, multi-region, multi-commodity computable general equilibrium model of the world economy. The model allows policy analysis in a single, robust, integrated economic framework. This model projects changes in macroeconomic aggregates such as GDP, employment, export volumes, investment and private consumption. At the sectoral level, detailed results such as output, exports, imports and employment are also produced.

The model is based upon a set of key underlying relationships between the various components of the model, each which represent a different group of agents in the economy. These relationships are solved simultaneously, and so there is no logical start or end point for describing how the model actually works.

Figure A.1 shows the key components of the model for an individual region. The components include a representative household, producers, investors and international (or linkages with the other regions in the model, including other Australian States and foreign regions). Below is a description of each component of the model and key linkages between components. Some additional, somewhat technical, detail is also provided.

Figure B.1: Key components of DAE-RGEM



DAE-RGEM is based on a substantial body of accepted microeconomic theory. Key assumptions underpinning the model are:

- The model contains a ‘regional consumer’ that receives all income from factor payments (labour, capital, land and natural resources), taxes and net foreign income from borrowing (lending).
- Income is allocated across household consumption, government consumption and savings so as to maximise a Cobb-Douglas (C-D) utility function.

- Household consumption for composite goods is determined by minimising expenditure via a CDE (Constant Differences of Elasticities) expenditure function. For most regions, households can source consumption goods only from domestic and imported sources. In the Australian regions, households can also source goods from interstate. In all cases, the choice of commodities by source is determined by a CRESH (Constant Ratios of Elasticities Substitution, Homothetic) utility function.
- Government consumption for composite goods, and goods from different sources (domestic, imported and interstate), is determined by maximising utility via a C-D utility function.
- All savings generated in each region are used to purchase bonds whose price movements reflect movements in the price of creating capital.
- Producers supply goods by combining aggregate intermediate inputs and primary factors in fixed proportions (the Leontief assumption). Composite intermediate inputs are also combined in fixed proportions, whereas individual primary factors are combined using a CES production function.
- Producers are cost minimisers, and in doing so, choose between domestic, imported and interstate intermediate inputs via a CRESH production function.
- The model contains a more detailed treatment of the electricity sector that is based on the 'technology bundle' approach for general equilibrium modelling developed by ABARE (1996).
- The supply of labour is positively influenced by movements in the real wage rate governed by an elasticity of supply.
- Investment takes place in a global market and allows for different regions to have different rates of return that reflect different risk profiles and policy impediments to investment. A global investor ranks countries as investment destinations based on two factors: global investment and rates of return in a given region compared with global rates of return. Once the aggregate investment has been determined for Australia, aggregate investment in each Australian sub-region is determined by an Australian investor based on: Australian investment and rates of return in a given sub-region compared with the national rate of return.
- Once aggregate investment is determined in each region, the regional investor constructs capital goods by combining composite investment goods in fixed proportions, and minimises costs by choosing between domestic, imported and interstate sources for these goods via a CRESH production function.
- Prices are determined via market-clearing conditions that require sectoral output (supply) to equal the amount sold (demand) to final users (households and government), intermediate users (firms and investors), foreigners (international exports), and other Australian regions (interstate exports).
- For internationally-traded goods (imports and exports), the Armington assumption is applied whereby the same goods produced in different countries are treated as imperfect substitutes. But, in relative terms, imported goods from different regions are treated as closer substitutes than domestically-produced goods and imported composites. Goods traded interstate within the Australian regions are assumed to be closer substitutes again.
- The model accounts for greenhouse gas emissions from fossil fuel combustion. Taxes can be applied to emissions, which are converted to good-specific sales taxes that impact on demand. Emission quotas can be set by region and these can be traded, at

a value equal to the carbon tax avoided, where a region’s emissions fall below or exceed their quota.

Households

Each region in the model has a so-called representative household that receives and spends all income. The representative household allocates income across three different expenditure areas: private household consumption; government consumption; and savings.

Going clockwise around Figure B.1, the representative household interacts with producers in two ways. First, in allocating expenditure across household and government consumption, this sustains demand for production. Second, the representative household owns and receives all income from factor payments (labour, capital, land and natural resources) as well as net taxes. Factors of production are used by producers as inputs into production along with intermediate inputs. The level of production, as well as supply of factors, determines the amount of income generated in each region.

The representative household’s relationship with investors is through the supply of investable funds – savings. The relationship between the representative household and the international sector is twofold. First, importers compete with domestic producers in consumption markets. Second, other regions in the model can lend (borrow) money from each other.

- The representative household allocates income across three different expenditure areas – private household consumption; government consumption; and savings – to maximise a Cobb-Douglas utility function.
- Private household consumption on composite goods is determined by minimising a CDE (Constant Differences of Elasticities) expenditure function. Private household consumption on composite goods from different sources is determined is determined by a CRESH (Constant Ratios of Elasticities Substitution, Homothetic) utility function.
- Government consumption on composite goods, and composite goods from different sources, is determined by maximising a Cobb-Douglas utility function.
- All savings generated in each region is used to purchase bonds whose price movements reflect movements in the price of generating capital.

Producers

Apart from selling goods and services to households and government, producers sell products to each other (intermediate usage) and to investors. Intermediate usage is where one producer supplies inputs to another’s production. For example, coal producers supply inputs to the electricity sector.

Capital is an input into production. Investors react to the conditions facing producers in a region to determine the amount of investment. Generally, increases in production are accompanied by increased investment. In addition, the production of machinery, construction of buildings and the like that forms the basis of a region’s capital stock, is undertaken by producers. In other words, investment demand adds to household and government expenditure from the representative household, to determine the demand for goods and services in a region.

Producers interact with international markets in two main ways. First, they compete with producers in overseas regions for export markets, as well as in their own region. Second, they use inputs from overseas in their production.

- Sectoral output equals the amount demanded by consumers (households and government) and intermediate users (firms and investors) as well as exports.
- Intermediate inputs are assumed to be combined in fixed proportions at the composite level. As mentioned above, the exception to this is the electricity sector that is able to substitute different technologies (brown coal, black coal, oil, gas, hydropower and other renewables) using the 'technology bundle' approach developed by ABARE (1996).
- To minimise costs, producers substitute between domestic and imported intermediate inputs is governed by the Armington assumption as well as between primary factors of production (through a CES aggregator). Substitution between skilled and unskilled labour is also allowed (again via a CES function).
- The supply of labour is positively influenced by movements in the wage rate governed by an elasticity of supply is (assumed to be 0.2). This implies that changes influencing the demand for labour, positively or negatively, will impact both the level of employment and the wage rate. This is a typical labour market specification for a dynamic model such as DAE-RGEM. There are other labour market 'settings' that can be used. First, the labour market could take on long-run characteristics with aggregate employment being fixed and any changes to labour demand changes being absorbed through movements in the wage rate. Second, the labour market could take on short-run characteristics with fixed wages and flexible employment levels.

Investors

Investment takes place in a global market and allows for different regions to have different rates of return that reflect different risk profiles and policy impediments to investment. The global investor ranks countries as investment destination based on two factors: current economic growth and rates of return in a given region compared with global rates of return.

- Once aggregate investment is determined in each region, the regional investor constructs capital goods by combining composite investment goods in fixed proportions, and minimises costs by choosing between domestic, imported and interstate sources for these goods via a CRESH production function.

International

Each of the components outlined above operate simultaneously in each region of the model. That is, for any simulation the model forecasts changes to trade and investment flows within, and between, regions subject to optimising behaviour by producers, consumers and investors. Of course, this implies some global conditions that must be met, such as global exports and global imports, are the same and that global debt repayment equals global debt receipts each year.

Appendix C – Paraquat products registered with the APVMA

Table C.1: Paraquat products

Product number	Product category	Product name
42635	Herbicide	FARMOZ SPRAYTOP HERBICIDE
46516	Herbicide	SPRAY.SEED 250 HERBICIDE
46531	Herbicide	GRAMOXONE® 250 HERBICIDE
48760	Herbicide	UNIQUAT 250 HERBICIDE
51958	Herbicide	COUNTRY PARAQUAT 250 HERBICIDE
52141	Herbicide	KENDON SPRAYQUAT 250 HERBICIDE
53221	Herbicide	NUFARM NUQUAT 250 NON-RESIDUAL KNOCKDOWN HERBICIDE
53381	Herbicide	IMTRADE PARAQUAT 250 HERBICIDE
53919	Herbicide	SHIRQUAT 250 HERBICIDE
54520	Herbicide	HALLEY PARAQUAT 250 HERBICIDE
54522	Herbicide	FARMOZ SPRAYTOP 250 SL HERBICIDE
56102	Herbicide	KENSO AGCARE PARA-KEN 250 HERBICIDE
57817	Herbicide	CONQUEST EXPLODE 250 HERBICIDE
58075	Herbicide	RAVENSDOWN PARAQUAT 250 HERBICIDE
58336	Herbicide	HALLEY PREMIER 250 HERBICIDE
58412	Herbicide	IMTRADE SPRAYKILL 250 HERBICIDE
58470	Herbicide	CONQUEST SCORCHER 250 HERBICIDE
58728	Herbicide	MACPHERSONS PARADYM 250 HERBICIDE
58733	Herbicide	4FARMERS BROWN OUT 250 HERBICIDE
58734	Herbicide	4FARMERS PARAQUAT 250 HERBICIDE
58841	Herbicide	GENFARM PARAQUAT 250 HERBICIDE
58908	Herbicide	RYGEL PRE-SEED 250 HERBICIDE
58992	Herbicide	SINMOSA 250 HERBICIDE
59078	Herbicide	RYGEL PARAQUAT 250 HERBICIDE
59098	Herbicide	SPRAY-PLANT 250 HERBICIDE
59287	Herbicide	FARMCOCHEM PARAQUAT 250 HERBICIDE
59311	Herbicide	NUFARM REVOLVER HERBICIDE
59333	Herbicide	KENSO AGCARE SPEEDY 250 HERBICIDE
59419	Herbicide	INFERNO HERBICIDE
59878	Herbicide	GENFARM DI-PAR 250 HERBICIDE
59879	Herbicide	FARMOZ SPRAY & SOW HERBICIDE
60287	Herbicide	COMBIK 250 HERBICIDE
60444	Herbicide	FORWARD PARAQUAT 250 HERBICIDE
60473	Herbicide	OSPRAY PARAQUAT 250 SL HERBICIDE
60991	Herbicide	OSPRAY SPRAY-OUT 250 HERBICIDE
61138	Herbicide	RAVENSDOWN WILDFIRE 250 HERBICIDE
61254	Herbicide	BIOTIS PARAQUAT 250 HERBICIDE
61460	Herbicide	ALARM HERBICIDE
61860	Herbicide	TITAN EOS HERBICIDE
61869	Herbicide	TITAN PARAQUAT 250 HERBICIDE
62042	Herbicide	CROP CARE ALLIANCE HERBICIDE
62096	Herbicide	CHOICE PARAQUAT 250 HERBICIDE

62495	Herbicide	SANONDA PARAQUAT/DIQUAT HERBICIDE
62540	Herbicide	CHEMFORCE PARAQUAT 250 HERBICIDE
62631	Herbicide	COUNTRY PARAQUAT/DIQUAT 250 HERBICIDE
63090	Herbicide	OZCROP PARAQUAT 250 HERBICIDE
63274	Herbicide	UNI-SPRAY 250 HERBICIDE
63521	Herbicide	SPECTRA PARAQUAT 250 HERBICIDE
63565	Herbicide	OZCROP BLOWOUT HERBICIDE
63617	Herbicide	QUASH 250 HERBICIDE
64169	Herbicide	AGCP PARAQUAT-DIQUAT 250 HERBICIDE
64173	Herbicide	AGROREG BLOWOUT HERBICIDE
64281	Herbicide	FARMALINX PARQUAT 250 HERBICIDE
64325	Herbicide	FARMALINX PARADAT HERBICIDE
64430	Herbicide	KENSO AGCARE PARA-KEN 334 HERBICIDE
64549	Herbicide	NAADCO PARAQUAT DIQUAT 250 HERBICIDE
64588	Herbicide	SMART PARAQUAT 250 HERBICIDE
64651	Herbicide	RC PARAQUAT 250 HERBICIDE
64704	Herbicide	FOSTERRA PARAQUAT / DIQUAT HERBICIDE
64706	Herbicide	FOSTERRA PARAQUAT 250 HERBICIDE
64731	Herbicide	AGRO-ESSENCE PARAQUAT 250SL
64737	Herbicide	TOMBSTONE HERBICIDE
64802	Herbicide	KWICKNOCK 250 HERBICIDE
65148	Herbicide	TRIO PARAQUAT 250 HERBICIDE
65149	Herbicide	PRO PARAQUAT 250 HERBICIDE
65295	Herbicide	RAINBOW DIQU-PARA 250 HERBICIDE
65524	Herbicide	PROTERRA PARAQUAT 250 HERBICIDE
65537	Herbicide	SANONDA HERBICIDE PARAQUAT 250SL
65694	Herbicide	RAINBOW PARAQUAT 250 SL HERBICIDE
65708	Herbicide	PACIFIC DIQUAT/PARAQUAT 250 HERBICIDE
65713	Herbicide	PACIFIC PARAQUAT 250 HERBICIDE
65839	Herbicide	MACPHERSONS PARAQUAT 250 HERBICIDE
66103	Herbicide	APPARENT PARAQUAT 250 HERBICIDE
66197	Herbicide	UNITED PHOSPHORUS UNISPRAY 250 HERBICIDE
66249	Herbicide	AW PUTOUT 250 HERBICIDE
66309	Herbicide	AGSPRAY PARAQUAT 250 HERBICIDE
66327	Herbicide	AW DISMANTLE HERBICIDE
66531	Herbicide	ACP PARAQUAT 250 HERBICIDE
66548	Herbicide	ECHEM PARAQUAT 250 HERBICIDE
66788	Herbicide	AGRO-ESSENCE PARAQUAT+DIQUAT 250 HERBICIDE
66809	Herbicide	KEY PARAQUAT 250 HERBICIDE
66852	Herbicide	MISSION PARA-DIQUAT 250 SC HERBICIDE
66853	Herbicide	MISSION PARAQUAT 250 HERBICIDE
67163	Herbicide	NOVA AGRO PARAQUAT 250 SL HERBICIDE
67307	Herbicide	AC PISTON 250 HERBICIDE
67323	Herbicide	FORWARD PARAQUAT + DIQUAT HERBICIDE
67399	Herbicide	NOVA AGRO PARAQUAT-DIQUAT 250 HERBICIDE
67437	Herbicide	AGROQUAT 250 HERBICIDE
67465	Herbicide	AGRIMART PARAQUAT 250 HERBICIDE
67562	Herbicide	FMC PARAQUAT + DIQUAT HERBICIDE
67563	Herbicide	FMC PARAQUAT 250 HERBICIDE
67627	Herbicide	APPARENT PARAQUAT 135 + DIQUAT 115 HERBICIDE
67650	Herbicide	AUSAGRI PARAQUAT 250 HERBICIDE
67707	Herbicide	SMART COMBINATION 250 HERBICIDE
67888	Herbicide	SPALDING PARAQUAT 250 HERBICIDE
67891	Herbicide	SPALDING EXOCET 250 HERBICIDE

67977	Herbicide	EZYCROP PARAQUAT 250 SL HERBICIDE
68075	Herbicide	EZYCROP PARAQUAT-DIQUAT 250 HERBICIDE
68112	Herbicide	CROPPRO PARAQUAT 250 SL HERBICIDE
68125	Herbicide	DIBROMQUAT 250 HERBICIDE
68196	Herbicide	NOVAGUARD PARAQUAT 250 SL HERBICIDE
68202	Herbicide	NOVAGUARD PARAQUAT-DIQUAT 250 HERBICIDE
68479	Herbicide	AGMATE PARAQUAT & DIQUAT 250 SL HERBICIDE
44249	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
44387	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
47747	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
48272	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
51041	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
51678	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
52712	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
53214	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
54043	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
54131	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
55327	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
55682	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
55966	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
56809	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
58230	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
59171	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
64565	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE
64765	Active constituent	PARAQUAT DICHLORIDE MANUFACTURING CONCENTRATE

Source: PUBCRIS, accessed 12 April 2013

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