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Food Bowl or Folly? The economics of irrigating Northern Australia

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Abstract

Australia's northern area has vast but largely undeveloped land that would be arable if irrigated. The prospect of a northern 'food bowl' has drawn political support for irrigation schemes from both major parties in the 2013 federal election. In this study we consider the net economic benefits of allocating northern Australia's divertible surface water to irrigation, a scheme that would require significant infrastructure costs in dam and canal construction. We estimate the benefits to northern Australia, using a Ricardian hedonic approach to forecast the economic value of constructing major new irrigation schemes that would be capitalised into agricultural land values. We use publicly available information from existing and potential Australian irrigation schemes to define the cost of constructing large water storages and distribution infrastructure, as well as on-farm irrigation infrastructure. We find that the costs of turning northern Australia into an irrigated food bowl are likely to exceed any benefits that would be capitalised into land prices by a multiple of between 1.1 and 3.2.

JEQ Classifications: Q15, R11 Keywords: irrigation, dams, agriculture, land value, benefit cost analysis

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Introduction

Over the past five years, Australian state and federal governments have spent in excess of \$500¹ million of public funding to support the expansion of the existing Ord River irrigation area in north-western Australia. Hatched in the 1940s, the Ord River irrigation scheme has a history of repeated and consistent failure, despite massive public subsidies that, in current dollar terms, total well over \$1 billion. This is not atypical of irrigation ventures in the north (see, for example, the ill-fated Cambellin irrigation scheme (Yuhun, 1989)). Nevertheless, during the 2013 Australian federal election campaign, both major parties recommitted to 'opening up' northern Australia to intensive agricultural development. In response to this, this study considers the following question: If we continue in the future to make additional large public investments in broad scale irrigation infrastructure in northern Australia, are the economic benefits likely to outweigh the costs?

To address this question, we use the most up to date publicly available information to define the cost of building vast new surface water storage dams and the hundreds of kilometres of distribution infrastructure required to move water through the landscape. On the benefits side, we undertake a Ricardian analysis, an application of hedonic price theory, to estimate the value of existing irrigated land under the assumption that past expenditure on irrigation infrastructure is fully capitalised into agricultural land values. Assuming that pricing practices do not change radically in the future such that they actually cover the full opportunity cost of public investment in irrigation infrastructure,

¹ All \$ figures refer to 2013 Australian dollars unless otherwise noted.

this measure provides an indicative value of the future benefits that will be capitalised into land values if construction of major new water storage and distribution infrastructure goes ahead.

We model the value of irrigated agriculture using a quasi-likelihood generalised estimating equation method. To maximize predictive performance of our econometric model we use a general-to-specific model selection framework based on Pan's (2001) quasi-likelihood information criteria. We subsequently use our model estimates to produce a heat map of the potential market value of irrigated land for all of northern Australia. We find that, even in the most optimistic scenario, the costs of constructing surface water irrigation schemes in northern Australia will exceed any benefits capitalised into land values. We project that the average value of irrigated land in northern Australia will be approximately \$6,200 per hectare while the costs of developing that land will be upwards of \$26,500 per hectare.

Issues that are not considered in this analysis, but which would need to be considered in a full cost benefit analysis, include: environmental regulations, of which there are many; native title issues; the impact on down stream industries, such as fisheries and tourism; and the practicalities and timing of converting a potentially large swathe of northern Australia over to irrigated farmland.

This paper proceeds as follows. First, we provide some background and economic context about the recent push to develop agriculture in northern Australia, including a discussion of the practicalities, the physical environment, and the outcomes from previous attempts to water the north. We then move on to discuss recent studies looking

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at the availability of land and water in northern Australia, and provide a summary of the likely costs involved in large scale development of irrigated land, including the cost of building water storages. Next we turn to the potential benefits, and describe our data, economic model and econometric estimation strategy. We then present our empirical results, including projected land values for irrigated agricultural land in northern Australia. We conclude with a discussion about the value of potential dam sites in northern Australia.

Background

A policy to develop the north of Australia is not new. It has been touted repeatedly by Australian politicians going back at least 100 years to Australia's second Prime Minister, Alfred Deakin.² So it was no surprise that, during the 2013 Federal election campaign, the Coalition of the Liberal and National parties committed to exploring ways to develop the economy of northern Australia. One proposal was to develop an agricultural 'food bowl' that would double Australia's agricultural output by 2030 (Mitchell, 2013). A similar commitment, albeit restricted to the Northern Territory,³ was also made by the then Labor Government during the same election campaign (Coorey, 2013; Wright, 2013). At least at first glance, it is clear why such proposals have been attractive.

² In his victory speech in 1906, Deakin spoke of his ambition to "people the unpeopled shores…connecting them with the south and ourselves with…trunk lines which will bind us together as one great whole" (Deakin, 1906).

³ The Northern Territory is a self-governed Territory of the Commonwealth of Australia. The term 'northern Australia' is a geographical area that encompasses approximately 120 million hectares that spans parts of the Northern Territory and the states of Western Australia and Queensland.





With reference to Figure 1, northern Australia is strategically located in the Asia-Pacific. If the north of Australia were developed into an agricultural food bowl, it would be strategically placed to access markets within the huge and growing economies of Southeast Asia as well as the world's second and third largest economies, China and Japan respectively (World Bank, 2014). The Asia-Pacific is home to a rapidly growing middle class (Barton, Chen & Jin, 2013) and in the midst of food safety concerns in the region, China in particular (Lubman, 2011; McDonald, 2012), demand for Australia's high quality produce is likely to drive export earnings into the future (Port Jackson Partners, 2012; Austrade, 2012). Darwin, Australia's northern most capital city, lies just four hours flight time from the Indonesian capital, Jakarta; a little less than six hours flight time from Hong Kong; and is home to a natural deep water port.

In addition to its strategic location, northern Australia hosts a large natural resource base. Of its total 120 million hectares between six and 17 million hectares is arable land⁴ – which World Bank (2013b) figures indicate constitutes between 11 and 38 per cent of Australia's current total arable land resource. Northern Australia also has vast water resources. Every year approximately one million Gigalitres (GL) of rain falls over northern Australia, generating approximately 200,000GL of surface water runoff (Cresswell et al, 2009). This represents approximately one third of Australia's total average rainfall and more than half of Australia's total average runoff (Bureau of Meteorology (BoM), 2013; Kollmorgen et al, 2007; Brouwer et al, 1985).

In 2011-12, Australia irrigated 2.14 million hectares of land with 8,170GL of water. This implies an average application rate of approximately 3.8 Megalitres (ML) or 0.0038GL per hectare (Australian Bureau of Statistics (ABS), 2013b). At this application rate, northern Australia would need between 22,800GL and 64,600GL of water per annum – which represents between approximately 11 and 32 per cent of its total annual runoff – to irrigate its entire stock of arable land. The potential value of this irrigated land is significant. Meyer (2005) suggests irrigated agriculture produces somewhere between 30 and 50 per cent of total agricultural profits in Australia on less than one per cent of total agricultural land.

Put simply, these profit estimates imply that irrigated agriculture is up to 100 times more valuable, per unit of land, than non-irrigated agriculture, implying that irrigated agriculture in the north has the potential to be highly profitable - particularly off-season cultivation of temperate annual crops including sorghum, rice, maize, soybean and

⁴ Defined as land suitable for cropping or improved pastures.

cotton. These types of crops tend to support higher yields in the relatively cool dry months in northern Australia; and water logging, insect and plant diseases - which can devastate crops in the wetter months - are much more manageable in the dry season (Chapman, Sturtz, Cogle, Mollah & Bateman, 1996).

Where's the catch?

These high level statistics paint a positive picture of northern Australia's agricultural prospects and the possibility of giving life to the food bowl proposal. In fact, the north already has some well-established *extensive* agricultural industries, such as livestock production. But the success of extensive agriculture is based on extremely large farms earning relatively low profits per hectare. For example, the average cattle farm in the Northern Territory is 280,000 hectares – more than 20 times bigger than the Australian average – and can be as large as one million hectares. But average profit per hectare for cattle farms is a fraction of that earned on Australian cropping land (Australian Bureau of Agricultural and Resource Economics and Sciences, 2013a; Cook, 2009). Could northern agriculture move from farming primarily grazing land to radically more profitable cropping land?

This depends on whether key methods for cultivating cropping land - *intensive* dryland agriculture or irrigated agriculture - could be successfully implemented in the north. And this is where northern Australia's seemingly bright agricultural prospects begin to dim. Harsh environmental conditions in the north (compared to southern Australia) fundamentally constrain the development of intensive dryland agriculture (Chapman et al, 1996). The soils of northern Australia are ancient and infertile with low

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levels of nitrogen and phosphorous. Soil erosion rates are high even on relatively gentle slopes and the soil resource itself is often characterised by shallow depth and high acidity (Wilson et al, 2009). Soils have a tendency to form strong surface seals during both wetting and drying cycles and a low capacity to hold water (Chapman et al, 1996).

On average, northern Australia is wetter and hotter than the south. Mean rainfall in the north is higher on average than the south, but is offset by far higher seasonal variability and intensity in the north (Chapman et al, 1996). For example, the northern water resource is driven almost entirely by wet season rainfall, with 94 per cent of the rain falling in the six months to April (Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO), 2009). The wet season is characterised by extensive and prolonged flooding events in low-lying coastal areas that can penetrate many kilometres inland (CSIRO, 2009; Wilson et al, 2009). The subsequent six month long dry season is aptly named, with a majority of rivers in the north completely empty for two-thirds of the year (Cresswell et al, 2009).

Mean annual temperatures are typically above 24° C – as much as 10°C higher than in southern agricultural zones (BoM, 2013). Average maximum daytime temperatures are between 30°C and 33°C. This is much hotter than the south, and well above the yield maximising temperature even for tropical crops (Webster et al, 2009). So while the north does not suffer the yield limiting frosts of the south, for as much as ten months of the year, potential evapotranspiration exceeds precipitation - meaning the environment is severely water limited (Cresswell et al, 2009). This contrasts sharply with southern agricultural zones, where rainfall is much more evenly distributed. Taken together, these environmental characteristics – infertile soils, extreme heat, and highly variable and intense rainfall – suggest the north is not well suited to farming at all, let alone the temperate dryland cash crops like wheat and barley, which are grown predominantly during the southern winter and spring.

On its face, the vast water resources of northern Australia might imply positive prospects for irrigated agriculture. As already noted, the north receives more than one third of Australia's total average rainfall and more than half of Australia's total average runoff. But the same environmental conditions that hinder intensive dryland farming also make water storage – a necessary condition for irrigated agriculture – relatively difficult. The generally hot climate and high evaporation rates (as much as 50 per cent higher than southern Australia (BoM, 2013)) mean large, deep dams are required. But the relatively flat topography of northern Australia means such water storage options are limited – both in number and capacity.

In total, northern Australia has 11,170GL of water storage, 90 per cent of which is provided by a single reservoir, Lake Argyle, at 980 square kilometres (Webster et al, 2009; Australian National Committee On Large Dams Incorporated, 2012). This situation in the north contrasts with Australia's single biggest existing irrigation region, the Murray-Darling basin (MDB) in south-eastern Australia. According to the ABS (2013a; 2013b), the MDB produces approximately 40 per cent by value of total annual Australian agricultural output on 16 million hectares of arable land. In 2011-12, approximately 5.88GL of water was applied to 1.41 million hectares of irrigated land in the MDB and the value of irrigated output was \$6.7 billion and accounted for 49 per cent of total Australian gross value of irrigated agricultural production.

The MDB receives approximately 530,000GL of annual rainfall which produces just 23,609GL of surface water runoff – not much more than 10 per cent of the northern total (ABS, 2008; ABS, 2012a). Unlike in the north, however, the MDB has very well developed water storages and a sophisticated water trading system based on 25,000GL of public water storage capacity (Murray Darling Basin Authority, 2013) and another 5,000GL—10,000GL in private storage (Productivity Commission, 2010). In addition, much of the rainfall in the MDB occurs in the highland headwaters of the major river systems before running inland for thousands of kilometres, providing numerous opportunities for capture and storage, before reaching the sea. By contrast, in northern Australia much of the rain falls on the coast, well away from the headwaters of the region's rivers. This means runoff has relatively short distances to run to the sea, and, combined with the flat topography, leaves few opportunities for capture and storage (Cresswell et al, 2009).

Previous efforts to irrigate the north: a cautionary tale

As with political interest in developing the north, efforts to irrigate the north are not new. Born out of a Royal Commission in 1940 (Fyfe, 1940), irrigation in the north began with the construction of a \$6 million (\$83 million in 2013 dollars) diversion dam on the Ord River in Western Australia in 1963 and the creation of the Ord River Irrigation Scheme (Davidson & Graham-Taylor, 1982). The results were disappointing. Farmers failed to profitably produce any crops, despite a range of explicit subsidies and price supports. Nevertheless, in 1969 construction of the main dam and associated works proceeded, funded by an Australian Government grant of \$48 million (\$700 million in 2013 dollars). Given its capacity, the main dam potentially opened up more than 70,000 hectares of land to irrigation. But, again, by the early 1980s farmers had failed to profitably produce anything they planted and remained entirely dependent on subsidies (Davidson & Graham-Taylor, 1982). The cotton industry collapsed amid "pretty much total disaster" in 1974, unable to deal with insect pests (Lewis, 2004a); and, more generally, all crops produced in the Ord River were both more expensive to produce, due to cost of freighting in fertilisers and expensive labour, and less profitable than those produced by their southern counterparts (Chapman et al, 1996; Davidson & Graham Taylor, 1982).

The experience with sugar has been no different. In 1996, CSR constructed a sugar mill at Kunnunura, but sold it after six years to South Korea's biggest food producer, Cheil Jedang (Lewis, 2004b). The sugar mill, and the industry, subsequently folded in 2007 after plans to expand the irrigation region to support increased throughput in the mill stalled (Thompson, 2012). Despite this apparent tale of woe, since 2007, the Western Australian Government has invested \$311 million as part of the Ord Irrigation Expansion Project (the second stage of the original Ord River scheme) and the Australian Government has spent \$195 million on social infrastructure including housing, schools, a hospital and on expanding port facilities. The project has delivered 31 kilometres of new irrigation supply channel, as well as 40 kilometres of roads, to support the future development of 14,680 hectares of irrigated farming land (Barnett, 2012; Department of Regional Development and Land (DRDL), 2009). In late 2012, a 'lease and develop' agreement was signed by the Chinese owned company Kimberley Agricultural Investment (KAI) under an agreement with the Western Australian Government to develop 13,400 hectares of land for irrigation. KAI has reportedly committed to spend \$700 million developing the land with a goal of restarting sugar production to feed a new

\$450 million sugar mill (McConnon, 2013a). But with 13,400 hectares of land expected to yield just 500,000 tonnes of sugar cane – well short of the required 2 million tonnes required to make investment in sugar production profitable – the commitment appears to be conditional on getting access to significantly more land. The owner of KAI has publicly stated "We need more land and a bigger supply of sugar cane; we don't have enough yet" (Neales, 2012). So despite actual or committed expenditure since 2009 of well in excess of \$1 billion, no crops have been planted, the construction of the sugar mill remains dependent on the opening up of more land (and presumably more publicly funded infrastructure) and the success or otherwise of this latest investment in the Ord River remains to be seen (McConnon, 2013b).

What are the possibilities?

But what if we could guarantee more land and, more importantly, the water to irrigate it? The most recent review of irrigation opportunities in northern Australia was the *Northern Australia Land and Water Science Review* (NALWSR). The NALWSR found that due to the lack of availability of surface water no more than 120,000 hectares, or less than 1 per cent of the 17 million hectares of potentially arable land, could be exploited for irrigation and that this would be sourced entirely from groundwater.⁵ The NALWSR largely dismisses the idea of additional surface water exploitation, let alone surface water storages, claiming "All water is fully in use…The water balance is closed" (Cresswell et al, 2009). They cite the biophysical difficulties – high evaporative losses, lack of suitable

⁵ Due to the low recharge rate in northern Australian aquifers, groundwater offers a very small irrigation multiplier. Specifically, Webster et al (2009) assume that the size of the groundwater recharge zone should be at least 3 orders of magnitude larger than the irrigated land it's required to support. The area of Northern Australia is 120 million hectares, hence a relatively paltry 120,000 hectare of land is available for groundwater fed irrigation.

sites – as well as the difficulty of navigating a host of environmental regulations (including RAMSAR wetlands and 'wild rivers' designations) and broader, somewhat nebulous, claims about society's unwillingness or inability to fund such an endeavour (Ross, 2009; Webster et al, 2009). While the former are certainly potentially difficult obstacles to overcome, on the purely practical question of the availability of water for irrigation, evidence suggests that significant sustainable sources of surface water have been investigated and do exist. The most recent assessment of divertible water resources was undertaken by the Australia Water Resources Council (AWRC) in 1985. The AWRC (1988: 14) defined a 'divertible water resource' as...

The average annual volume of water which, using current technology, could be removed from developed or potential surface water or groundwater sources on a sustained basis, without causing adverse effects or long term depletion of storages.

And with specific reference to major divertible surface water resources:

The volume of water which can be diverted on a sustained basis into conventional water supply systems or to substantial private users, utilising existing storages **and potential dam sites** [emphasis mine] *identified by investigation or indicated by preliminary reconnaissance.*

Using this definition, the AWRC found that northern Australia had around 35,200GL of divertible surface water resources of which just over 33,000 was not already being utilised. More recently, in 2009 the *Northern Australia Sustainable Yields* (NASY) study modelled streamflow estimates that they characterised as "the most comprehensive hydrological modelling ever attempted for the region" (Petheram, Rustomii & Vleeshouwer, 2009: iii). Although the NASY did not consider the potential for new surface water storages (i.e. dams), nor independently assess divertible yield, the study did provide a basis to update the 1985 figures (Petheram et al, 2009: 50). Specifically, taking the ratio of the AWRC divertible resource to the total AWRC assessed resource and multiplying by the NASY streamflow volume, gives an updated estimate of the divertible

yield. The implied NASY divertible surface water estimates return a range of between approximately 32,000GL and 56,000GL for mainland northern Australia. As noted above, even at the low end, this quantum of stored water is at least as much as is available in the entire MDB.

How much land is available?

The NALWSR (Wilson et al, 2009) included a land suitability report of northern Australia's soil resources designed to assess the region's ability to support a variety of crop types. The crop types assessed were: (i) annual crops (e.g. wheat, peanuts and cotton); (ii) perennial crops (shrub, vine and tree crops); (iii) rice; (iv) forestry; and, (v) improved pastures. The suitability report found that between 30 and 41 per cent (or 36 million and 50 million hectares respectively) of northern Australia was moderately suitable for annual and perennial cropping, and as much as 60 per cent, or 72 million hectares, for improved pastures. At least 14 per cent (and as much as 19 per cent), or 17 million hectares, of the land was deemed to be high quality arable land. That is, it presented no, or only minor, limitations for a combination of annual or perennial cropping and improved pastures. As the NALWSR (Wilson et al 2009: 5) acknowledges, this quantum of arable land "represents a potential significant addition to the national agricultural resource base."

How much land can we irrigate?

As illustrated in Table 1, the average application rate per hectare for irrigated land in Australia in 2011/12 was 3.8ML per hectare. If we fully allocated 56,000GL (the upper range of the divertible surface water estimates for northern Australia derived above) of

water at this rate, we could irrigate approximately 14.7 million hectares, or 87 per cent, of the total 17 million hectares of potentially arable land in northern Australia. But there are two additional water use constraints that need to be considered.

Year	Australia	NSW	QLD	VIC	SA	WA	NT	TAS	Kimberley
2002-03	4.4	4.6	4.3	4.2	4.9	6.5	4.7	2.4	14.5
2003-04	4.3	4.4	4.3	4.1	5.2	5.7	3.8	2.6	11.3
2004-05	4.2	4.1	4.8	3.7	4.8	4.8	4.0	2.7	12.1
2005-06	4.2	4.6	4.3	3.8	4.1	5.1	3.1	2.5	10.6
2006-07	4.0	3.8	4.0	3.8	4.8	5.5	3.2	3.0	9.4
2007-08	3.4	3.2	3.6	3.1	3.9	4.5	3.2	2.8	9.1
2008-09	3.7	3.8	3.8	3.2	4.2	4.7	3.6	3.0	6.3
2009-10	3.6	3.6	4.0	3.4	3.8	5.0	3.7	2.7	8
2010-11	3.4	4.1	3.6	2.3	3.4	4.6	3.7	2.1	7.2
2011-12	3.8	4.5	3.8	2.9	4.0	4.9	3.9	2.3	8.1
Average	3.9	4.1	4.1	3.5	4.3	5.1	3.7	2.6	9.7

Table 1 - Irrigation application rates in Megalitres per hectare (2002-2012)

Source: ABS (2005-2013).

First, the average application rate ignores distribution losses involved in conveying water from the reservoir to the crop. In open channel irrigation systems that typify much of the Australian irrigation network, these losses can run as high as 30 per cent (Irrigation Review Steering Committee, 2005). In fact, over the last decade, approximately 25 per cent of total water delivered by irrigation water suppliers across Australia was lost prior to reaching the crop (ABS, 2004-2013).

Second, as described in the Background section of this paper and illustrated in Figure 2, northern Australia is considerably hotter and drier than the south of Australia. For example, regions within northern Australia experience evaporation rates exceeding 3,200mm or 3.2m per year meaning that on average, crops grown in the north have relatively high transpiration rates and hence higher water requirements.⁶

⁶ Plants require water as a cooling mechanism, a transport medium for nutrients and as an input to photosynthesis. The mechanism by which water is obtained and cycled through the plant is known as transpiration. Transpiration is driven by the evaporation of water into the surrounding atmosphere via openings in the leaf called stomata. Loss of water causes a decrease in hydrostatic water pressure within



Figure 2 - Average annual evaporation (mm) – 1975-2005 Evaporation rates in northern Australia can be two or three times as high as southern Australia.

Source: Bureau of Meteorology (2013).

Although the Northern Territory achieved an application rate of just 3.7ML per hectare on average over the last decade – consistently below the national average – the Kimberley statistical division, which encompasses the Ord River irrigation region, requires much more water to produce any given crop. Over the past decade, irrigation application rates in the Kimberley have averaged approximately 10ML per hectare with a

the leaf and this pressure imbalance forces water (and nutrients contained in the soil) to be drawn up from the soil through the roots via osmosis. When the stomata are open CO_2 enters. Hence the importance of an adequate source of water: if water is unavailable, transpiration must proceed at a relatively slower rate which in turn will limit the rate of photosynthesis, the rate of nutrient uptake and the ability of the plant to remain cool (Reece et al, 2011). All these factors in turn will conspire to limit crop yield (Tennant, 2000).

range from 6.3ML per hectare to 14.5ML per hectare – anywhere from 1.5 to 3.5 times higher than the national average over the same period (ABS 2005-2013).⁷

When we take these two constraints into consideration (i.e., we assume distribution losses of 25 per cent and an average application rate of 10ML per hectare), rather than being able to irrigate 14.7 million hectares, fully allocating between 32,000GL and 56,000GL of water would only irrigate between 2.4 million and 4.2 million hectares, or almost ¼ of the total arable land in northern Australia. This is still an extremely large amount of irrigated land: at its maximum extent, approximately 2.5 million hectares of land was irrigated in a single year in Australia (ABS, 2012b). Therefore, under the assumptions outlined above, in full production, northern Australia's irrigated land resource would almost double Australia's total irrigated land.

What would it cost?

At a minimum, irrigation requires three things: a water source; a distribution system; and improved farm land.⁸ All three of these improvements are capitalised into the market value of land. For the purposes of analysing the net economic benefits accruing to the northern Australia scheme, we need to know how these elements are incorporated into the current market price of land. For example, if irrigators pay a fee for access to bulk infrastructure, such as dams and distribution canals, and that fee covers the full

⁷ Sugar cane, KAI's preferred crop, is particularly water intensive. The Ord River achieved water application 'efficiencies' of 20ML per hectare in the early 2000s. By contrast, in Queensland the vast majority of the Australian sugar crop is produced with application rates of 5ML per hectare (ABS, 2005). ⁸ We ignore for brevity the issue of roads and power supply infrastructure. The construction and maintenance of local roads are nominally borne by local government, which raises funds via the levying of annual rates. However, perusal of annual accounting reports shows that road construction and maintenance are often heavily subsidised by State and Federal government grants (See for example, Shire of Wyndham East Kimberley, 2006-2013).

opportunity cost of the investment, it will be capitalised into current market prices. That is, the current sale price of the land incorporates the net present value of the fee, or in other words, the cost of building infrastructure in northern Australia, assuming cost equivalence, is built into the market price. On the other hand if irrigators pay something less than the full opportunity cost of the infrastructure, which the evidence suggests they do (Parker & Speed, 2010), they are effectively being subsidised. The value of the subsidy – in this case some proportion of the cost of constructing the infrastructure in northern Australia – needs to be netted off the current market value of land.

In 2008 (the most recent observation in our dataset) fees for access to irrigation infrastructure did not cover the opportunity cost of bulk irrigation supply infrastructure. In fact fees were levied in line with a 'lower bound' cost designed to cover asset depreciation, but specifically did not "make provision for the cost of asset consumption and cost of capital" (Department of the Environment, Water, Heritage and the Arts, 2010). Prior to that time, costs levied on irrigators did not even cover this lower bound (Queensland Competition Authority, 2010). In effect, under this type of a pricing regime, the asset is provided free to irrigators – meaning that the full construction cost needs to be netted off the market value of irrigated land derived below.

Cost of a water source

Assuming that bulk quantities of water for irrigation cannot be extracted with any reliability from existing river systems, new water storages will need to be constructed. To estimate the cost of building these storages we can look at the cost of recent irrigation dams built in Australia and current replacement costs of existing infrastructure. In the

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last 20 years, three large dams with capacity in excess of 50GL have been built for the purpose of supplying water for irrigation. These are listed in the first 3 rows of Table 2. In addition, estimates are available for the cost of replacing water storages in a number of Queensland irrigation schemes and these are listed in rows 4-6 of Table 2. The average cost per ML of water stored in these dams is approximately \$670 in 2013 dollars.

Table 2 - The cost of storing water for imgation in Australia.									
Dam (year completed)	Cost - 2013 (\$millions)	Capacity (GL)	Cost per ML (Stored)	Area currently Supplied (ha)	Cost per Ha				
Teemburra Dam (1996)	65.5	147.5	\$444	not available	not available				
New Harvey Dam (2002)	76.4	59	\$1,295	not available	not available				
Burnett River Dam (2005)	246.9	300	\$823	40,000	\$6,172				
Burdekin Falls Dam (1987)	820.4	1860	\$441	45,000	\$18,232				
Tinaroo falls dam (1958)	244.2	439	\$556	17,000	\$14,364				
Borumba Dam (1964)	21.1	46	\$458	3,500	\$6,019				
Average	-	-	\$670		\$11,196				

Table 2 - The cost of storing water for irrigation in Australia.

Source: The Australian National Committee on Large Dams Incorporated 2012; Network Economics Consulting Group 2001; Queensland Competition Authority 2010, 2011; Water Corporation 2001.

But water stored is not water applied to the crop. We need to know how much water a dam can reliably supply for irrigation per year and how much water is required for each crop. For example, if a dam yields 50 per cent of its storage capacity per year – broadly in line with a number of existing irrigation dams in Queensland – and that water is delivered to the farm gate with 25 per cent losses, then for one ML delivered to the farm 2.67ML needs to be stored.⁹ We know that the average farm uses 3.8ML per hectare per year, implying that the average farm requires about 10ML of storage capacity. At \$670 per ML this equates to \$6,700 per hectare which is broadly comparable with the lower end of the costs presented in column 6 in Table 2. As outlined above, water requirements in the driest parts of northern Australia are likely to be more like 10ML per hectare on

⁹ For example, a dam with 2.67ML total storage supplies 1.33ML or 50 per cent of its capacity annually. During distribution to the farm, 25 per cent (.33ML) of water is lost, and 1ML is delivered to the farm.

average or higher;¹⁰ and growing sugar in northern Australia is likely to require as much as 20ML per hectare, which equates to between \$18,000 and \$36,000 per hectare using the same assumptions as outlined above.

Unless a relatively inexpensive (per ML) water storage can be found, the cost of delivering large amounts of water to a farm can be extremely expensive. These storages do exist, and the Ord River dam is one such example, with the inflation-adjusted cost of the dam of \$305 million equating to a cost per ML of storage of just \$53. However, given the relatively low annual yield of water for irrigation from Lake Kununurra, at around 13-19 per cent of total storage,¹¹ due to high environmental water requirements and evaporation, these cost savings become an economic imperative. That is, at 13 per cent yield and 25 per cent distribution losses, 10.25ML is required for each ML delivered to the farm; and as outlined above, with the average water use by a farm in the Kimberley region of around 10ML per hectare, this amounts to more than 100ML of water in storage per farm. At \$53 per ML of water stored, this equates to a cost of approximately \$5,433 per farm.

With respect to bringing substantial new irrigation regions into production, including the construction of heavy infrastructure, the ongoing expansion of the Ord River irrigation area that began in the late 2000s provides a potential upper bound estimate of the likely costs involved. The WA Government spent \$311 million constructing 31 kilometres of

¹⁰ The land release information released by the Western Australian Government in 2011 (Landcorp, 2011) for the Ord irrigation area expansion project notes that "combined crop needs are not expected to exceed 12ML per hectare" on average.

¹¹ This figure is based on the original dam capacity of 5,800GL prior to the dam wall being raised primarily to support the production of hyrdroelectricity. The current Ord River water management plan allows for 750GL of water for irrigation and alludes to a maximum around 1,100GL being available (Department of Water 2006, 2013).

bulk distribution channels¹² to supply approximately 15,000 hectares of land, as well as constructing 40 kilometres of sealed public roads (DRDL, 2009). This equates to approximately \$21,000 per hectare, although there is no cost split that separates the cost of the roads from the distribution infrastructure. Table 3 provides a summary of the replacement costs for shared distribution infrastructure in a number of Queensland irrigation schemes. The average cost per hectare of land currently supplied in those schemes, for the construction of pump stations and main irrigation channels, is about \$5,000.

Table 5. Distribution costs for infigation schemes in Queenstand.								
Distribution system	Cost - 2013 (\$millions)	Area currently Supplied (ha)	Cost per Ha					
Burdekin Haughtin	165.9	45,000	\$3,687					
Mareeba Dimbullah	131.0	17,000	\$7,709					
Bundaberg	91.6	40,000	\$2,289					
Lower Mary	19.7	3,500	\$5,621					

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Table 3: Distribution costs for irrigation schemes in Queensland

Average Source: Queensland Competition Authority, 2010.

At the farm level, assuming that existing land is effectively in its native state, it will need to be cleared and access points and fencing constructed. In addition, land for irrigation would need to be laser levelled, and a system to deliver water to the plants would need to be installed. Of the total money publicly committed by KAI to its Ord river project, around \$200 million has been earmarked to develop 13,400 hectares of land into irrigated farms (McConnen, 2013a). This equates to a per hectare cost of approximately \$15,000. Alternatively, adjusting for inflation, the Irrigation of Sugar Cane Manual (Holden & McGuire, 2010) suggests that preparation of land and installation of furrow irrigation

\$4,826

¹² The original cost for the expansion project was \$220 million. The cost over run was blamed on a 'strategic decision' to expand the capacity of the irrigation channel to anticipate future demand from the Northern Territory to supply an additional 14,000Ha of irrigated land (Spooner, 2012). The original project documentation, however, clearly anticipates this demand and specifically makes allowance for it in the additional water allocation for the expansion project (DRDL, 2009).

would cost approximately \$2,350 per hectare, while a drip irrigation system would cost around \$5,000 per hectare. A centre pivot system is likely to cost around \$3,500 per hectare (Qureshi, Wegener, Harrison & Bristow, 2001).

In summary, the per hectare cost of constructing from scratch a new irrigation district in northern Australia can be broken down by the cost of building a water storage, the distribution infrastructure, and on-farm capital. The cost of a dam is highly dependent on the yield from storage. Assuming average dam costs of \$670 per ML stored and a 10ML per hectare crop requirement, the cost per hectare will range from a high of \$68,720 per hectare down to \$17,900 per hectare for a yield of 13 per cent and 50 per cent, respectively, after accounting for distribution losses of 25 per cent. The cost per hectare of distribution infrastructure is likely to be around \$5,000 per hectare, while on-farm infrastructure will cost \$3,600 per hectare on average. In total, the per hectare cost of developing irrigated farmland will be between \$26,500 and \$77,320.

What are the benefits?

The primary purpose of constructing water storage and distribution infrastructure is to open up land to irrigated farming. Therefore, one would expect the benefits to accrue primarily to farmers, via their ownership of land serviced by the irrigation infrastructure.¹³ But how much are farmers willing to pay for this new opportunity? Like any other productive asset, the value of farmland – its market price – is equal to the discounted stream of expected future profits that it can produce. This in turn is a function

¹³ If a significant labor force existed in the north, they might also accrue benefits through increased wages. However, population densities are very low, and the general equilibrium effects on wages from labor migration to northern Australia would presumably be low, given that the low labor intensity of the irrigated agriculture sector would imply a very small difference in overall demand for labor in Australia.

of the willingness to pay of people (in Australia and, in the case of food exports, the world) for the output from those farms. Assuming broadly competitive markets, a good indicator of the willingness to pay for additional irrigated land is, ceteris paribus, the price that farmers currently pay for irrigated land elsewhere in Australia.

In the following section we describe a framework for modelling farmland value using Ricardian price theory. The aim is to produce a robust specification with which we can predict the value of irrigated land in northern Australia.

A Ricardian model of farm land value

Farmland is a composite good consisting of a bundle of productive attributes such as rainfall, soil nutrients, topography, as well as spatial characteristics such as distance to population centres. The value of land in agricultural production is a function of these various intrinsic productive characteristics, combined with inputs and management decisions from the farmer. Given the assumption that farmers maximize profits, it is not necessary to explicitly model farmer input and management choices. Instead, Ricardian price theory provides a framework for modelling the value of property in terms of intrinsic productive attributes of the property (Mendelsohn, Nordhaus & Shaw, 1992, 1994).

We assume that all farmland in northern Australia (bounded by all farmland north of the Tropic of Capricorn – see below) is broadly substitutable such that the area is a single, large market within which farmers are free to move in line with their preferences. We assume markets are competitive and, in particular, that no single farmer has proprietary

knowledge about any given plot of land. In addition, as per all partial equilibrium approaches, we assume that prices remain constant.

A model of farm profit

The profit of the *i*th farm in the *j*th landuse (irrigation or dryland) is

$$\pi_{i,j} = \pi_j \left(p_i^0, p_i^I, z_i \right) - C_{i,j}$$
(1)

Where p_j^0 is the price associated with the output from landuse j, p_i^I is the input price for farm i, z_i is a set of exogenous environmental inputs (e.g., soil, and average temperature and rainfall) and $C_{i,j}$ is the cost minimising fixed cost of production which varies by farm and landuse. The market price of the *i*th farm is the discounted sum of future profits such that $V_{i,j} = \omega \pi_{i,j}$ where ω is a common market discount factor.

For irrigated farmland, water, an exogenous factor that appears in *z* as average rainfall for dryland farms, also appears in the cost function, $C_{i,j}$ (for dryland farms, water falling on the farm is free). This reduces the connection between climate and profit on irrigated farmland and implies that dryland and irrigated profit functions should be estimated separately to produce consistent estimates (Schlenker, Hanemann & Fisher, 2005). We describe our econometric specification and estimation strategy below, after describing the dataset.

Data

The dependent variable in the preceding Ricardian model is per hectare farm price from the period 1990-2008. We concentrate our analysis on those properties with similar climatic conditions to northern Australia by confining our sales data to those located north of the Tropic of Capricorn (Latitude 23.5°S). All our sales events have boundary geocoding and each of the data sources discussed below was obtained in the form of continuous mappings, grids or individual points in space. This allows for a high level of precision when it comes to attributing geo-physical and economic characteristics by simply overlaying the property boundary from each sales event and taking the mean of the variable across the intersected space.

Where previous Ricardian analyses are based on lumping all agricultural land into a single class, regardless of its primary use (e.g., cropping or grazing land), our model requires that we separately estimate a dryland and irrigated model of farm profit. We obtained geocoded digital landuse data in the form of continuous mapping across Australia from the Australian Collaborative Land Use Mapping Programme covering landuse across the period 1992-2002. We proportionally assign each sales event into irrigated and non-irrigated land using a simple geographical overlay.

Soil data is based on the digital Atlas of Australian soils (Northcote, 1979; McKenzie and Hook, 1992) and includes categorical indicators for nutrient status, permeability (a measure of how fast water moves through soil) and texture. The soil variables are treated as ordinal data and constructed as step variables to maximise the flexibility of the model selection process. For example, we have categories p1 through p4 for soil permeability, the interpretation of the coefficient on p3, is the incremental effect compared to p2. Thus the total value of p4 is the sum of the coefficients on the preceding two classifications (p1 is the base case and hence is not explicitly estimated).

We specify land value as a quadratic function of climate, which captures the basic agronomic relationship between land value and plant productivity (e.g., warmer temperatures support higher plant productivity up to a point, beyond which increasing temperatures become yield limiting, holding other factors fixed (Agricultural Production Systems Simulator, n.d; Reece et al, 2011)). Climate variables include the daily average temperature and the average of daily temperature squared and the average annual growing season rainfall and the average annual growing season rainfall and the average annual growing season rainfall squared. We define climate variables for both the winter (April to October) and summer growing seasons (November to March). The climate data was fitted to the properties using a climate grid for Australia based on more than 950 independent temperature stations and over 6,000 rainfall stations for the 30-year period from 1977 to 2006 (Bureau of Meteorology, 2007).

We also employ a comprehensive set of control variables similar to those included in previous Ricardian analyses (e.g., Mendelsohn et al, 1994, Schlenker, Hanemann & Fisher, 2006) including a full set of year indicators (defined as step variables) and a time trend; a set of biophysical and built indicators of farm value, including distance to roads, rivers, the coast and irrigation infrastructure; as well as population density and terrain variability. The latter is a measure of the variation in height across a property based on a digital elevation map for Australia (Hutchinson et al, 2008).

To provide a further level of rigour, we ground truth a significant proportion of the data by overlaying our fitted maps on satellite imagery. Where land was clearly misclassified, for example due to the coarseness of the landuse data, we reclassified it as necessary. In

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some cases we purged data entirely where it was deemed that the land value was skewed by the presence of significant commercial structures such as processing plants or mines.

1			1	1		,
Variable	Mean	Min	Max	Std. Dev.	Soil Variables	Proportion of farms
Price per hectare (\$)	1,904	0.06	21,582	3,175	Texture	
Irrigated land	7,884	569	19,918	5,037	Uniform Coarse	8%
Non-irrigated land	985	0	13,832	1,689	Medium	6%
Winter rainfall (mm)	254.4	47.2	920.5	182.0	Fine	1%
Winter temperature (°C)	21.5	18.8	26.5	1.7	Cracking	31%
Summer rainfall (mm)	618.1	104.7	1663.5	340.4	Calcareous	0%
Summer temperature (°C)	27.8	24.7	31.5	1.5	Gradational	21%
Distance to primary roads(km)	16	0	405	34	Duplex	33%
Distance to coast (km)	134	0	583	140	Permeability	
Distance perrenial river (km)	93	0	455	104	Very Slow	21%
Variation in height (m)	5.0	0.1	52.0	6.4	Slow	36%
Population density (per square km)	1.1	0.01	7.4	1.7	Moderate	16%
					Fast	27%
					Nutrient Status	
					Low	9%
					Medium	64%
					high	27%

Table 4. Descriptive statistics for farms north of the Tropic of Capricorn (Latitude 23.5°S).

Econometric specification

Previous Ricardian analyses typically employ a linear or log-linear specification (i.e., f(V)= V or ln(V) respectively, where f is a transformation of the *dependent* variable). The latter is well suited to modelling data generating processes characterised by non-negative outcomes (e.g., land values) and heteroscedasticity, and it implicitly allows for non-linear interactions amongst the independent variables. An inconvenience associated with a loglinear specification is that it models the expectation of the logged variable of interest, V, when what we are actually interested in is the expectation of V. To back out predictions of V using the log-linear specification requires a correction to the predicted values (typically $e^{(\sigma^2/2)}$). An alternative approach that does not require transformation of *V*, but provides the same favourable properties as the log-linear specification is to use a Generalised Linear Model (GLM) with a log link function and variance proportional to the mean squared (see McCullagh & Nelder (1989) for a detailed exposition of GLMs).¹⁴ This specification follows naturally from a log-linear model. That is, if the model is taken to be $V = e^{X\beta}\varepsilon$ where ε is a homoscedastic error term, with some simple algebraic manipulation it follows directly that the variance is proportional to the mean squared (Manning & Mullahy, 2001). However, because our data is characterised by spatial correlation, it is not reasonable to assume that the error term, ε , is i.i.d. Therefore we estimate our model using the method of quasi-likelihoods (Wedderburn, 1974) and generalised estimating equations (Liang & Zeger, 1986), which implies GLM with clustered standard errors.

Estimation strategy

We are primarily interested in predicting the value of agricultural land in northern Australia. Therefore, good predictive performance is an essential objective for the purposes of this study. To this end, it is important that our model parsimoniously represents the underlying specification without unnecessarily overfitting the peculiarities of the dataset or underfitting characteristics that are otherwise common to the population – situations that lead to generally poor predictive performance under, for example, a mean-squared error criterion.

¹⁴ More formally we specify *V* to be gamma distributed with variance proportional to the mean-squared and a log link that transforms the expectation of *V* to the linear predictor, *X* β . In symbols: the mean, $\mu = e^{X\beta}$ and the variance $\sigma^2 = \theta \mu^2$ for some factor of proportionality, θ .

We use model selection, as opposed to ad-hoc techniques such as stepwise procedures based on hypothesis testing or goodness-of-fit tests, to help pin down a specification as Granger, Maxwell & White (1995) recommend. They argue that "...testing favors the null hypothesis, typically uses an arbitrary choice of significance level, and researchers using the same data can end up with different final models".

A powerful technique for model selection that performs well against the requirements outlined above is the Akaike (1973) Information Criteria (AIC). The AIC is an information-theoretic approach to model selection based on ranking competing models according to their expected, relative Kullback—Leibler distance (see Burnham & Anderson (2002) for a comprehensive treatment of the information-theoretic approach to model selection).

Other common model selection techniques include (i) cross-validation using partitioned samples (i.e., a model testing sample and a validation sample) which Xu & Huang (2012) show, at least in some contexts, asymptotically minimizes mean squared prediction error and (ii) the Bayesian Information Criterion (BIC)(Schwartz, 1978). Compared to cross-validation and BIC, an information-theoretic based criterion such as the AIC is less computationally demanding (Burnham & Anderson, 2002) and, as Stone (1977) showed, cross-validation and AIC are asymptotically equivalent. Compared to BIC, which converges asymptotically to the true model with probability = 1 for a fixed model, AIC is consistent as the complexity of the model increases with the number of observations.

(George, 2000).¹⁵ In other words, AIC is relatively conservative compared to BIC in that it will tend to under penalise complex models.

Because the AIC is a likelihood-based approach that presumes independence of the observations and, as stated above, we believe our errors are likely correlated, the AIC is unsuitable. Instead, we use a quasi-likelihood estimation method and employ a modified AIC for use with general estimating equations and correlated data known as the quasi-likelihood information criteria (QIC) (Pan, 2001) for model selection.¹⁶

Due to the large size of the search space, we combine the QIC selection criteria with a greedy search algorithm across the full model specification. We use this approach to pin down a final model specification.

The approach described in this section is a type of general-to-specific model selection framework designed to maximise model predictive performance. Hoover and Perez (1999, and see Campos et al (2005) for a detailed overview) and others have shown that a general-to-specific approach guided by both theory and model performance as well as model congruence (for example, constraints like no quadratic terms without the accompanying level term) performs very well in Monte Carlo simulations.¹⁷

¹⁵ For a discussion about the asymptotic properties of AIC and BIC, see Stone (1979), who argues that keeping the true model fixed as n becomes large is unrealistic and, in practice, the model would be refined (i.e., by incorporating more complexity) as the sample size increases.

¹⁶ Relative to the AIC, the QIC penalty function is twice the trace of the inverse of the covariance estimator based on a working model of independent observations multiplied by the sandwich covariance estimator such as a cluster correction. When the models are independent, this reduces to 2p, which is the AIC.

¹⁷ We tested the stability of the heuristic described above (i.e., QIC with a greedy search algorithm) on a simple pooled model by a Monte Carlo procedure with a known true model that was designed to mimic the key features of our dataset, including spatial correlation. Using the artificial data, the heuristic repeatedly chose the same or very similar specifications with consistent sign patterns.

Results

Table 5 presents the results of two GLM regressions. Column 1 presents the results of a pooled land use regression using the full set of available regressors, with an indicator variable for the proportion of land in a given farm that is irrigated. The most striking result from this regression is that *none* of the eight climate coefficients are statistically different to zero.

Variable	Pooled GLM			GLM - t	y landuse	
			Irrigated		Dryland	
Irrigation indicator	2.00866*	(9.249)	6.59531*	(13.430)		
Winter temperature	0.02624	(0.071)				
Winter temperature squared	0.00232	(0.174)				
Winter rainfall	0.00286	(1.200)			0.01006*	(11.165)
Winter rainfall squared	-7.41E-07	(0.637)				
Summer temperature	0.13816	(0.666)				
Summer temperature squared	-0.00343	(0.676)				
Summer rainfall	0.00179	(0.683)			0.00600*	(9.261)
Summer rainfall squared	-4.45E-07	(0.390)			-3.54E-06*	(16.862)
Distance perrenial river (metres)	-8.57E-07	(0.382)				
Within 1km of irrigation	-0.00966	(0.101)				
Distance to coast	-0.00400	(1.787)				
Distance to primary roads	-0.01318*	(6.394)			-0.01015*	(5.320)
Farmer density	240.78971*	(5.070)			238.35393*	(4.942)
Surface roughness	-0.02078*	(2.295)	-0.05777*	(5.761)	-0.02823*	(2.671)
Soil						
nutrient (medium)	0.89951*	(3.123)	0.81816*	(8.269)	1.10895*	(2.967)
nutrient (high)	-0.05743	(0.475)				
permeability (slow)	-0.75541*	(3.959)				
permeability (moderate)	0.59339	(1.686)				
permeability (fast)	0.45339*	(2.135)	0.62854*	(3.014)	0.43459*	(2.781)
texture (medium)	1.17597*	(3.488)	0.97031*	(4.271)	1.17653*	(2.784)
texture (fine)	-1.24570	(1.841)				
texture (cracking)	2.25779*	(3.984)				
texture (calcareous)	-6.97817*	(3.117)			-0.38248*	(3.201)
texture (gradational)	5.77941*	(2.511)				
texture (duplex)	-0.17195	(0.813)				
latitude	-0.17547	(1.671)				
Constant	-48.14510*	(4.341)	2.27354*	(2.433)	2.27354*	(2.433)
Number of observations	146	6	14	2	1118	3

Table 5 – GLM regression results explaining farmland value per hectare.

Note: The table lists coefficient estimates and t-values in parentheses (* indicates statistical significance at 1%). For expositional purposes the year indicators are omitted from the table.

As discussed in the model of farm profit section, one should allow climate impacts to vary by irrigated and dryland agriculture. Accordingly, columns 2 and 3 present the results from GLM regression where the model for each landuse is selected using the QIC selection criteria and the slope coefficients are allowed to vary according to land use. Compared to the pooled results, the best performing specification as selected by the QIC criterion includes only 11 of 27 available regressors (excluding the year indicators and the constant) and of those, just five are common to both land uses. This indicates that the pooled model is likely significantly overfitted - an important finding given that the primary aim of this analysis is to accurately predict the value of irrigated land in northern Australia.

Interestingly, the QIC-selected model included no climate variables for irrigated land. Only soil variables and the surface roughness indicator were selected. This is not unreasonable given a small sample size and that the value of irrigation is its ability to provide a buffer mitigating the impacts of undesirable climatic conditions, such as low rainfall or high temperatures. A model with various climate parameters performed only modestly worse than the preferred model on model selection criteria. However, given irrigation properties tend to be clustered and the relative dearth of data for irrigated properties, there is limited independent variability in the climatic variables compared to the dryland properties. On predictive grounds, one would anticipate that very different climates would lead to poor predictive performance. Indeed, this proved to be the case, with the alternative model predicting land values well outside the plausible range defined in Table 4. For dryland, the climate specification was stable and repeatedly converged on the same subset of regressors. The signs on the variables are intuitive: more rainfall is unambiguously good in the typically dry northern winter and summer rainfall has diminishing marginal value, perhaps due to the increased likelihood of flooding. Compared to the pooled GLM, the climate variables are highly statistically significant and although the signs are identical, the coefficients and the implied marginal impacts are quite different. The winter rainfall coefficient from the dryland GLM is approximately $3\frac{1}{2}$ times larger than in the pooled GLM, and, whereas the marginal benefit from increased summer rainfall begins to decrease beyond about 850mm, under the pooled GLM increasing summer rainfall is beneficial across the entire range of the data and beyond the observed maximum of 1,645mm.

With respect to the variables in common across both dryland and irrigated land, only the surface roughness indicator is statistically distinct with less even terrain penalised more heavily by a factor of 2:1 on irrigated land compared to dryland. Of the remaining common coefficients, the interpretation is intuitive: medium and high nutrient soils are worth relatively more than low nutrient soils; and, similarly, more permeable soils are more valuable.

Selectivity

Selectivity is an endemic issue in applied economic work where the value of the variable of interest depends on some dichotomous choice. In this example, the choice is whether to irrigate land or not. Assuming that the option to irrigate is available (i.e., a ground or surface water supply can be tapped), the choice to irrigate will be based on the costs and benefits of doing so. Specifically, with respect to equation (1) above, a farmer will choose irrigation if $\pi_{I} > \pi_{D}$ or, in an econometric context, where $X(\beta_{I} - \beta_{D}) > (\varepsilon_{I} - \varepsilon_{D})$. The correlation that may be induced within a selected sample (as implied by this inequality) is the classic selectivity problem which can lead to inconsistent estimates.

We use a Heckman (1976) two-step procedure to test for selectivity. We use the average area irrigated in each river basin as an instrument on the grounds that it is both relevant, and satisfies an exclusion restriction without which, identification would rely on functional form alone (Bushway, Johnson & Slocum, 2007). That is, the instrument clearly predicts the likelihood of a given piece of land in the basin being irrigated (relevance), but conditional on that outcome (i.e., a piece of land being irrigated), the instrument is unlikely to be correlated with the value of that piece of land (satisfies exclusion restriction), which itself is a function of the overall demand for agricultural products. We estimate the selection model using all of the variables in the dryland and irrigated GLM models in Table 5. We subsequently include the inverse mills ratio in the landuse GLM regressions presented in Table 5. We cannot reject the null that the inverse mills ratio is 0 for irrigated land (p-value = 0.27) and dryland (p-value = 0.33), indicating that our estimates are unlikely to be affected by selectivity.

How much is irrigated land worth?

Figure 3 shows the projected value of irrigated land in northern Australia using the irrigated GLM estimates and eliminating areas that are currently protected (e.g., within national parks). The average value of irrigated land in northern Australia is projected to be approximately \$6,230 per hectare. By contrast, according to the dryland GLM

estimates, the average value of dryland agriculture in northern Australia is about \$120 per hectare, meaning the land has a relatively low opportunity cost.

Above (see 'How much land can we irrigate?') we estimated that if we fully allocated 56,000GL of water we could irrigate up to 4.2 million hectares, or about 3 per cent of the total land in northern Australia. If we allocate the water by simply cherry picking the most valuable land regardless of its location or potential isolation, the most valuable land would be worth between \$12,870 and \$24,220 per hectare and approximately \$18,800 per hectare on average. The most valuable 2.4 million hectares of land is worth approximately \$21,520 per hectare on average if irrigated. These areas are represented by the darker shades in Figure 3.

To control for the possibility that the land we have picked is for some reason unlikely to ever be irrigated (e.g., because it lies on the top of a hill or the edge of a cliff) we use the land suitability mapping undertaken as part of the NALWSR (Wilson et al, 2009) project to limit the possible choices. Specifically, we take all land classified as at least moderately suitable for irrigated perennial agriculture and overlay that on our land value predictions.¹⁸ Using this restriction we find that the average value of irrigated agriculture is \$15,750 over 4.2 million hectares, and \$17,800 per hectare on the most valuable 2.4 million hectares, with a slightly reduced maximum of \$24,190.

¹⁸ We confine our analysis to irrigated annuals, but the NALWSR also produced suitability maps for irrigated perennials, rice, forestry and improved pastures. Although we have not for this analysis, we could create a composite of all available suitability maps, which could potentially support higher values than those reported above.





Note: White areas are protected park land, blue squares are potential dam sites.

What are the prospects for irrigated agriculture in the north?

We estimate that developing irrigated agriculture in northern Australia is likely to cost anywhere from \$26,500 to \$77,320 per hectare. But in the most optimistic circumstances this will only support land values up to a maximum of \$24,220 per hectare. This implies a cost to benefit ratio of between 1.1 and 3.2, assuming that dams are built and brought on line immediately (which they will not be), and that the most valuable land is accessible such that average costs prevail.

To provide a sanity check on these cost to benefit ratios, we can look at publicly available costs of some potential dam sites mentioned in the Coalition Government's policy paper on northern Australia (Mitchell, 2013). Two sites in Queensland, on the Flinders River near Richmond and on the Gilbert River near Georgetown, provide for short case studies enabling a rudimentary cost and benefit analysis. The dam sites are labelled in Figure 3.

The Gilbert River dam

The cost of developing the potential dam site on the Gilbert River will likely be upwards of \$300 million to construct a 300GL storage designed to provide 100,000ML annually to irrigate up to 13,800 hectares (Queensland Department of Environment and Resource Management (QDERM), 2012; Gulf Savannah Development, 2009). This equates to a per hectare cost for storage of about \$22,000. Allowing for distribution works and onfarm development of around \$8,600 per hectare (see Appendix A: Key assumptions), the cost of this proposal is likely to be in excess of \$30,000 per hectare.¹⁹ On the benefits side, land within 10 kilometres of the proposed dam site is projected to be worth less than \$4,000 per hectare on average if irrigated. Casting the net further afield, within 20 kilometres of the dam site, but outside the Gilbert River catchment (and therefore requiring potentially large pumping and related distribution costs) there is about 5,000 hectares of land projected to be worth up to \$20,000 per hectare if irrigated. But even this implied return will not cover the cost of constructing the infrastructure. The implied cost to benefit ratio in this case is around 7.5:1 using average land values and 1.5:1 in a best-case scenario.

The Flinders River water storage

On the Flinders River near Richmond, our projections suggest that more than 1 million hectares within 60 kilometres of the proposed dam site could be worth almost \$12,000 per hectare on average if irrigated. The cost of building water storage infrastructure at this site is estimated at approximately \$225 million to construct two storages on O'Connell Creek and at Mount Beckford with a combined capacity of 302GL and a yield of 121,500ML (Richmond Shire Council, 2009; Cummings, 2008). Approximately 10,500 hectares of irrigated farmland could be supplied using this water storage, implying an average cost per hectare of \$21,400. According to the Queensland Department of Environment and Resource Management (QDERM, 2012), it would cost in excess of \$15,000 per hectare to construct channels for water delivery, access roads to the irrigation farms and drainage of excess water for this scheme (QDERM, 2012). This takes the total

¹⁹ We note that the estimated cost in 2009 of upgrading the road infrastructure in this area to facilitate moving agricultural produce to markets was \$50 million or \$3,600 per hectare (Gulf Savannah Development, 2009).

cost of development to almost \$40,000 per hectare after factoring in on-farm infrastructure, implying a cost to benefit ratio of approximately 3.3:1.

What about taxes?

The land value estimates derived in this paper are private benefits accruing to owners of irrigated farmland, net of taxes. This ignores government taxes levied on the income produced by the farmland which needs to be added to the benefit estimates. However, on the other hand the dead weight loss associated with raising revenue via taxation to fund government spending needs to be added to the cost estimates. To incorporate these two effects we can derive a cost inflation rate that reflects the effective tax rate for agriculture and the deadweight loss from taxation.

What is the effective tax rate for the agricultural sector?

According to the Government's Agricultural Competitiveness Green Paper (2014), the agriculture sector paid approximately \$500 million in taxes on average over the 4 financial years to June 2012. However, they also received almost \$400 million in industry assistance over the same period of time. That is, for each tax dollar levied, the agricultural sector paid approximately 20 cents or $1/5^{\text{th}}$ of a dollar. It follows that, based on the Australian corporate tax rate of 30 per cent (levied on profits), the effective tax rate on agriculture is around 6 per cent ($1/5^{\text{th}}$ of 30 per cent).²⁰ Therefore to incorporate the tax benefits in our estimates we could inflate the private estimates by a factor of 1.06.

 $^{^{20}}$ This compares to an effective corporate tax rate of about 29 per cent respectively for the mining and manufacturing sectors.

What are the deadweight losses associated with tax?

When a government levies a tax with the intent of redistributing the income, there is an attendant 'deadweight loss' or excess burden caused by the price distortion. Estimates for Australia of the marginal deadweight loss from raising tax – defined as the ratio of the incremental cost of raising a tax to the incremental change in revenue raised – range from between 20c to 65c for each tax dollar collected (Robson, 2005).²¹ This implies that the marginal cost of raising public funds in Australia (the 'MPF' which is equivalent to 1 + the marginal deadweight loss) is between \$1.20 and \$1.65 for every \$1 collected. The MPF acts as a simple investment rule for government expenditure. That is, the Government's subsequent investment should be at least as high as the MPF to justify the imposition of the tax.

In this paper (summarised in Appendix A), we calculate that the cost of dam building and distribution, typically borne entirely by the Government, is approximately 67-90 per cent of the total project cost. Using an MPF of between 1.2 and 1.65, this implies that the total cost estimates should be inflated by a factor of between 1.13 and 1.59.

If we net out the benefit from taxation of agricultural returns (6 per cent), we get a cost inflation rate of between 1.07 and 1.53. That is, if we incorporate the distortionary effects associated with taxation into our cost to benefit ratios irrigation projects become less economic.

²¹ Estimates for the US economy suggest that it may be as high as 100 per cent (Feldstein, 1999).

Conclusion

Using a Ricardian analysis of the value of irrigated farmland and publicly available information about the cost of irrigation infrastructure, this analysis has shown that large-scale investment in new irrigation schemes in northern Australia is a poor investment that will not provide an economic return. In the most optimistic circumstances, assuming that you could easily cherry pick the most valuable land, it would be worth a maximum of \$24,220 per hectare if irrigated. But even then the implication is that for every \$1 of economic benefit created, between \$1.10 and \$3.20 would need to be spent constructing irrigation infrastructure. We also show, using project specific estimates, that the costs of developing two potential dam sites in Queensland for irrigated agriculture would far outweigh the projected benefits.

It is worth noting that we do not factor in the loss of amenity value associated with damming rivers, nor do we factor in the potential effect on downstream industries such as fisheries or tourism that may well increase the costs of these proposals. We also show that given the low effective tax rate on agricultural output, any tax benefits from irrigation projects will likely be swamped by the distortionary effects of taxation.

Irrigation requires hugely expensive infrastructure, including water storage and distribution works and these are almost exclusively publicly funded and their use is typically priced well below the full opportunity cost (Parker & Speed, 2010). When these costs are sunk, irrigation can be highly profitable. But clearly, the implication of this analysis is that Australians on average would receive no net benefit from the construction of major new water storages in northern Australia; and the construction of such dams and

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distribution systems, if built, will by definition represent a significant transfer of wealth from taxpayers to private irrigators with the Ord River irrigation scheme a clear case in point.

Appendix A: Key assumptions

Per hectare cost of constructing irrigation scheme = $Dam \cos t + Distr$. Infrastructure $\cos t + On$ -farm infrastructure $\cos t = $26,500$ to \$77,320:

- Dam cost = \$17,900 (50 per cent yield) to \$68,720 per hectare (13 per cent yield)
 - \circ Water storage costs = \$670 per ML stored
 - \circ Distribution losses = 25 per cent.
 - \circ Per hectare crop requirement = 10ML

Dam cost = (*Per/ha* crop requirement)*[*Water* storage cost/(1-Distribution losses)]/yield

- Distribution infrastructure cost = \$5,000 per hectare
- On-farm infrastructure = \$3,600 per hectare

Refer to Tables 1, 2 and 3 for details.

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