

1-1-2013

The Economic Contest Between Coal Seam Gas Mining and Agriculture on Prime Farmland: It May Be Closer than We Thought

Cindy Chen
University of Sydney

Alan Randall
University of Sydney

Follow this and additional works at: <http://epubs.scu.edu.au/jesp>

 Part of the [Agricultural and Resource Economics Commons](#)

Recommended Citation

Chen, Cindy and Randall, Alan (2013) "The Economic Contest Between Coal Seam Gas Mining and Agriculture on Prime Farmland: It May Be Closer than We Thought," *Journal of Economic and Social Policy*: Vol. 15 : Iss. 3 , Article 5.
Available at: <http://epubs.scu.edu.au/jesp/vol15/iss3/5>

ePublications@SCU is an electronic repository administered by Southern Cross University Library. Its goal is to capture and preserve the intellectual output of Southern Cross University authors and researchers, and to increase visibility and impact through open access to researchers around the world. For further information please contact epubs@scu.edu.au.

The Economic Contest Between Coal Seam Gas Mining and Agriculture on Prime Farmland: It May Be Closer than We Thought

Abstract

There is substantial market impetus behind the expansion of coal seam gas (CSG) in Australia, driven by buoyant international demand for liquefied natural gas. The benefits of CSG development come in the first few decades, followed by a potentially long period in which the agricultural and environmental costs dominate. We identify the key drivers influencing the economic contest of CSG versus agriculture on prime farmland, and undertake a Darling Downs case study using evidence from primary and secondary sources. Despite the momentum driving CSG development, under some plausible scenarios, the long-term economic net benefits from agriculture-only exceed those from CSG-only and CSG-agriculture coexistence.

Keywords

Agriculture, coal seam gas, Darling Downs, rents, net benefits, environmental costs, external costs, co-existence

Cover Page Footnote

This article benefited from the data contributed by Cotton Australia and Friends of Felton.

Introduction

Coal seam gas (CSG) mining in Australia has grown rapidly since 1995, responding to buoyant international demand for liquefied natural gas (LNG), and encouraged by Australia's minerals exploration and extraction laws, which provide big rewards to those who find and extract these exhaustible resources. In several regions, notably the Liverpool Plains in New South Wales and the Darling Downs in Queensland, CSG comes into direct contact with agriculture. Our purpose in this article is to explore in economic terms, the relationship between CSG and agriculture on prime farmland.

In this introductory section we aim to provide a general sense of the trajectory of the industry and its impact on the Australian economy, and examine the nature and extent of its environmental impacts, insofar as they can be known and/or anticipated on the basis of reasoning and available evidence. In this context, to indicate that an impact might be present, or might be substantial, implies only that reasoning and/or evidence suggest such possibilities. At this stage in the industry's development, a definitive account of CSG's future economic and environmental impacts in Australia is impossible. Instead, our objective is to frame the potential and the uncertainties that attend this industry. In subsequent sections, our economic analysis confronts these uncertainties directly, by using best estimates of the essential quantities and relationships, and by conducting transparent sensitivity analyses for those quantities and relationships that entail the major uncertainties.

Demand, especially export demand

From a trivially small baseline in 1995, CSG is projected to provide about one-half of Australia's total gas output by the mid-2020s. Queensland is the state that led the way in terms of projects operating and committed, CSG production, and CSG reserves remaining (Figure 1). In 2010, Queensland was projected to have about 40,000 wells producing CSG by 2030 (Carlisle, 2012). Ongoing exploration may add to that number, but a modest contraction in export projections reflecting increased supply from competing exporters may have the opposite effect. Even at a relatively high rate of development, Australia is thought to have about 100 years of CSG reserves (Carlisle, 2012). Much of the output will be exported in several forms, perhaps the most prominent being LNG, with projected exports of 16 million tonnes by 2015 (Carlisle, 2012).

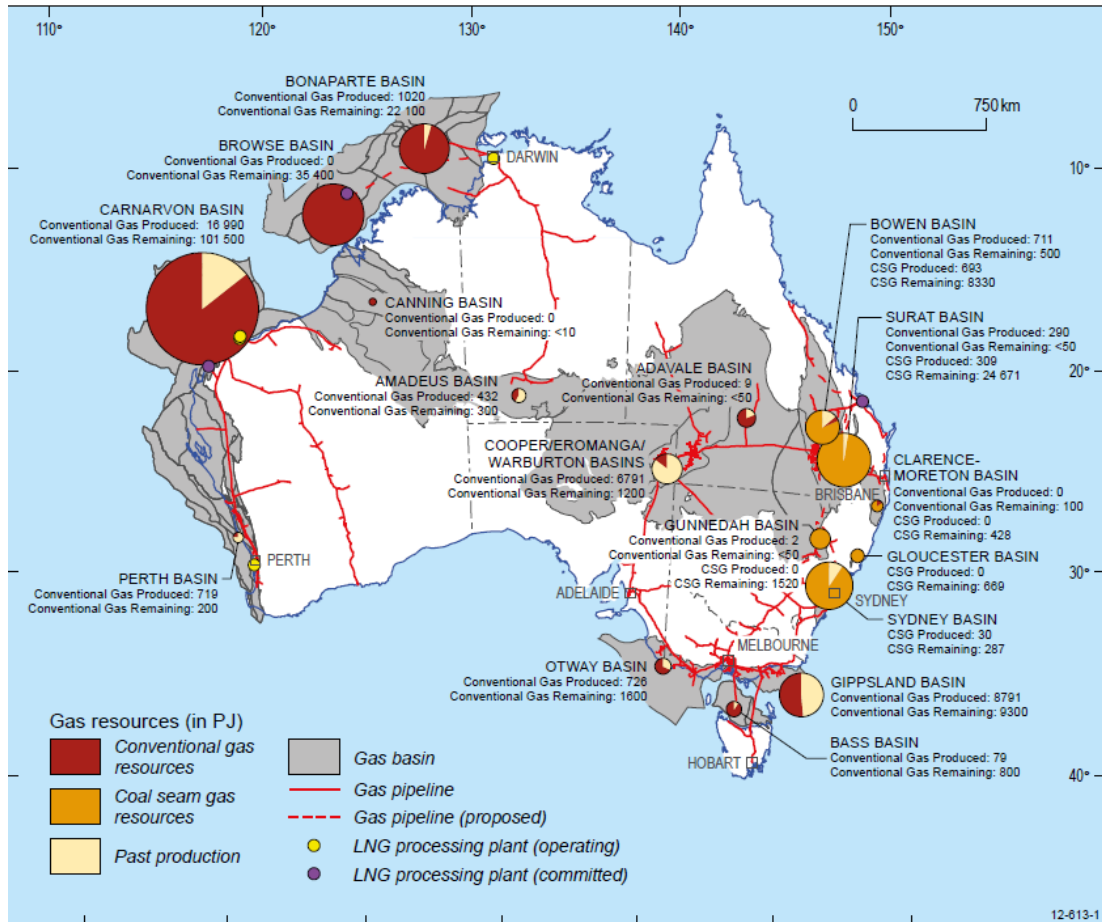


Figure 1: Location of Australia's gas resources and infrastructure

Source: Australian Gas Resources Assessment (BREE, 2012a).

Australian minerals rights and resource taxation policies encourage extraction

It is well known that minerals rights and taxation regimens influence the rates of extraction and the distribution of rewards therefrom (Schulze, 1974; Dasgupta, Heal and Stiglitz, 1980). Furthermore, minerals are exhaustible resources; once extracted they are gone, (as opposed to renewable resources such as timber, which is capable of regeneration if managed appropriately) and extraction is inherently unsustainable. However, an economy that extracts exhaustible resources may be able to sustain its standard of living so long as the economic rents (net economic

value) of extracted minerals are reinvested in productive capital (Solow, 1974; Hartwick, 1977). In addition to generating revenue for government and providing an instrument for managing the rate of extraction, it can be argued that minerals taxes should generate capital reserves for reinvestment in the national interest. Thus minerals rights and taxation policies are important considerations in any discussion of CSG mining and the national interest.

In Australia, subsurface rights are separated from surface rights and retained by the Crown (MCMPR, n.d. a). Surface rights come in several forms, predominantly long-term leases from governments, and freehold title. Subsurface rights are dominant to surface rights in the sense that protections for surface rights-holders who may be impacted by subsurface extraction are limited to those provided explicitly by statute law and regulations.

Traditionally, federal, state and territory governments (the subsurface rights-holders in Australia), allocate exploration and production rights to private investors and collect a return for the public via a mix of arrangements, predominantly royalties and taxes (Hogan and McCallum, 2010). Commentators have described Australia's rights regime for minerals as effectively "finders keepers" (Bergstrom, 1984; Daintith, 2010). Exploration licenses are issued inexpensively and non-competitively, and license-holders are encouraged to explore actively. Licensed explorers who find potentially profitable deposits are awarded extraction leases, so that discoveries effectively belong to the finder. The states collect royalties, typically 10 percent *ad valorem* at the well-head for CSG (MCMPR n.d. b). Researchers have concluded that such regimes encourage extraction (Daintith, 2010; Taggart, 1998). Despite the dominant position of Australian governments as subsurface rights-holders, Hogan and McCallum (2010) argue that they have left a considerable proportion of the net benefits on the table, i.e. failed to collect a substantial portion of the economic value of the nation's mineral resources that have been depleted, a stance that is tilted toward excessively rewarding extraction.

Multinational operators and retention of resource net benefits in Australia

There are a number of obvious economic benefits from the robust expansion of CSG development, although some are more tenuous on closer examination. Projections call for 18,000 new jobs, directly and indirectly in Queensland, but the majority of those jobs will not continue beyond the construction phase (Carlisle, 2012). Billions of dollars in federal company taxes will be generated. For example, the Gladstone liquefied natural gas plant and associated gas fields will generate an estimated \$40 billion in federal taxes over their productive life,

according to the operators (Carlisle, 2012) and royalty returns of \$850 million per annum to the Queensland government beginning in 2014 (Queensland Government, 2010). As well as providing jobs and taxes, exports benefit the balance of payments. It is a standard result in economics that, in an economy that was already close to full employment, expansion of a particular economic sector occurs mostly by reallocating resources otherwise employed elsewhere in the economy; and it is reasonable to apply that result to CSG extraction and processing. It follows that the net economic gains attributable to CSG expansion equate to the difference between employment, income and taxes collected with and without expansion of CSG operations.

The potential profits from the industry are substantial but, because the industry is predominantly foreign-owned – consensus estimates suggest at least 80 percent foreign ownership in the minerals sector – many of the profits will leave Australia (Reserve Bank of Australia, 2011). If those profits include a substantial portion of the rents from extracting exhaustible resources, as well as the rewards to extraction and processing effort, it becomes much more difficult to assure Australia's economic sustainability by reinvesting the rents from extraction of exhaustible resources as suggested by Solow (1974) and Hartwick (1977).¹ It is not easy to be precise about the portion of the resource rents lost to Australia. For example, (i) apportioning profits into rewards for effort and resource rents is not an exact science, and (ii) Australians hold a portion of the stock in these multinational firms and thereby retain some of the rents. So, in the case study reported below, we apply sensitivity analysis to the proportion of rents retained in Australia.

With much of the profit from extraction shifted off-shore, the instruments available to Australian governments for rent collection are limited to royalties, severance taxes and other direct taxes on mineral extraction, thus the magnitude of revenue collected matters crucially to the nation. While the industry will pay substantial royalties to state governments, it remains an open question whether royalties and taxes on the industry are high enough to compensate Australians for the eventual exhaustion of a valuable resource and the potentially long-lived

¹ Because our argument is directed explicitly at the issue of retention and reinvestment of the rents from extraction of exhaustible resources, certain potential counter-arguments are ineffective. For example, we do not need to debate the benefits in general of foreign investment in Australia or concern ourselves with the relatively modest foreign investment in Australian farmland, a renewable resource; and the fact that multinational minerals operators invest in Australian mines and peripherals does not invalidate our point – these investments will generate resource rents and retention of those rents will still be at issue.

damage to land and water resources that results from the extraction process (Hogan and MacCallum, 2010).

Environmental impacts of CSG

CSG mining on a large scale is a highly intrusive process entailing a considerable catalogue of potential environmental risks and land use conflicts – diminished water supply and quality, methane leakage into the atmosphere, disturbance of subsurface aquifers and geological structure, fragmentation of landscape, and disruption of agricultural production (Carlisle, 2012; Healy, 2012; Randall, 2012). The magnitudes of these threats are not merely uncertain in the statistical sense; in some cases they are driven by complex systems that work in ways we do not fully understand, even conceptually. In the face of these uncertainties and unknowns, the above-mentioned separation of surface and subsurface rights limits the protections for landowners. Their protection, like that of the general public, is limited by the willingness and capacity of governments to implement adequate regulatory regimes.

Water usage

Water is extracted from the coal seams to release the gas. At the site and project levels, farmers and settlements using artesian water worry that water pressures and levels will fall, and wells and bores will need to be drilled deeper and may dry up completely. The Queensland government has insisted on ‘make good’ provisions requiring operators to provide water to users facing reduced and more expensive groundwater supplies as a result of CSG activity (Swayne, 2012). ‘Making good’ is intended to compensate in-kind for any harm that may arise from extracting water to release the gas, but three kinds of operational difficulties are obvious: establishing the cause-and-effect relationship with CSG extraction; the increasing infeasibility of making good as the cumulative impacts of CSG extraction grow larger with the increasing number of wells across the landscape; and reconciling the long-term impacts on aquifers, which are likely to play out on a time-scale of many decades and perhaps centuries, with the much shorter time-scale of CSG extraction.

Because so much of the CSG action will be concentrated in the Great Artesian Basin (GAB), basin-level analysis is essential. According to the National Water Commission (2011), planned CSG development will, at full operation, withdraw more than 300 gigalitres of groundwater annually from the GAB, i.e. more than 60 percent of total allowable withdrawals. This 60 percent for CSG implies some combination of displacing existing uses and pushing total withdrawals well above

sustainable levels. The National Water Commission estimate is thought to be relatively conservative; industry sources offer a somewhat lower projection, but the federal government's "Water Group" suggests, based on its case studies of the Surat and Bowen sub-basins, that GAB-wide withdrawals may considerably exceed the National Water Commission estimate (Department of Sustainability, Environment, Water, Population and Communities, 2010).

The theory of complex systems suggests that it is near-impossible to predict the cumulative impacts on groundwater over several centuries, because the GAB hydrological system is much too complex and the cumulative shock to the system from CSG development will be much too large to be characterised with standard groundwater models and modeling methods (Randall, 2011; Randall, 2012).

Waste water

The water co-produced in CSG extraction is briny to varying degrees and contains a range of chemicals naturally present in and around the coal seam. Depending on site conditions, toxic and radioactive substances may be present. The process of hydro-fracturing (fracking), where used, may add to the chemicals in waste water – while the industry insists it is not presently using them, BTEX (benzene and similar organic chemicals thought carcinogenic) chemicals have in the past been added to the water.²

Recycling the waste water represents the only conceivable way to compensate for the huge volume of groundwater to be extracted by the industry. Treatment and recycling are processes that separate the waste water into two components, a treated/recycled component that, depending on the level of treatment, is safe for certain uses, and a solid and/or liquid component (sludge) in which salt and chemical contaminants are concentrated. The simplest and cheapest treatment methods, evaporation ponds, contribute nothing to recycling, whereas reverse osmosis (basically desalination) is very expensive (GHD, 2003). In addition to the costs of recycling plants, recycling at scale requires an extensive network of pipes to bring waste water from spatially dispersed sites to a central recycling plant. If recycling waste water becomes the norm, recycled water will be produced in such volumes that the environmental impacts of returning it to the environment will raise issues: releasing recycled water into surface streams may produce sustained

² In Queensland, a conservative rule of thumb is that fracking can be expected to occur in about 10 percent of new wells (more in some locations), increasing to 40 percent as wells approach the end of their productive life (Queensland Government, <http://www.ehp.qld.gov.au/factsheets/pdf/csg/csg8.pdf>, viewed 20 March 2013).

flows where ecosystems demand episodic flows; and successfully re-injecting it into depressurised aquifers in order to recharge the groundwater may over-tax our technical capacity and our understanding of complex aquifer systems in the coalfields (National Water Commission, 2011).

The Australian Broadcasting Corporation reports cases where cognisant governments have permitted discharges into streams of co-produced water that, despite treatment, contains a variety of chemicals at concentrations above guidelines for aquatic ecosystems and in some cases at toxic levels (Carlisle, 2012).

Regardless of treatment method, by-products include salt in vast volumes and contaminated sludge in quantities and kinds that depend on local conditions and extraction and treatment practices. Until better solutions are discovered, most of the contaminated waste will be stored in brine ponds and salt pits on the gas fields (see for example the position of Santos, a major CSG operator; Santos, 2012).

The atmosphere

CSG burns much more cleanly than coal – typical carbon emissions per unit of electricity generated from burning coal range from 43 percent to 87 percent greater than from CSG-LNG (Clark et al., 2011) – and, if emissions were restricted to those from burning fuel, widespread substitution of CSG for coal would bring big reductions in Australia's carbon footprint. More comprehensive accounts suggest a more nuanced picture – when the energy used in extraction, the methane and carbon dioxide that will inevitably escape from CSG wells and gas fields, energy used and emissions in processing, etc., are counted, the greenhouse gas reduction benefit of CSG becomes more tenuous and specific to individual CSG operations (Department of Climate Change and Energy Efficiency, n.d.).

The cognisant federal agency has recognised the policy and regulatory problem posed by large quantities of methane and carbon gases likely to be released directly into the atmosphere from the gas fields and liquefaction plants (DIICCSRTE, 2013).

It has been estimated that approved CSG and LNG projects, including associated infrastructure, could generate 39 million tonnes of carbon dioxide equivalent each year (Carlisle, 2012). Modeling suggests that the CSG industry eventually could produce as much greenhouse gas as all the cars on the road in Australia (Carlisle, 2012).

Impacts on subsurface geology and hydrology

Subsurface geology and hydrology can be disturbed by CSG mining in two distinct ways: withdrawal of large quantities of water, which is endemic to CSG operations; and fracking, which fractures the coal seam and surrounding soil and rock layers to release the gas, and is used in some CSG operations. Gas extraction and the lowering of water tables create voids that may lead to land subsidence. Fracking may lead to disturbance and irreparable damage to aquifers, migration of methane and contaminants, and increased seismic activity (Healy, 2012).

Fragmentation of the landscape: ecosystems, agriculture, rural communities and society

CSG extraction is a spatially dispersed industry with a much greater footprint on landscape and environment than the fairly modest surface area devoted to well-heads would suggest. The networks of pipes for fracking water, gas, and waste water, along with the processing, waste storage, and treatment facilities, and the network of roads to tend the wells and transportation upgrades to get the CSG products to market all contribute to landscape fragmentation with negative impacts on agriculture and ecosystems.

Regarding ecosystem impacts, the Australian Broadcasting Corporation reports instances in which the federal government has granted major CSG operators permission to clear land containing species and ecosystems protected under federal threatened species legislation (Carlisle, 2012).

Landscape fragmentation associated with CSG development reduces agricultural productivity and increases farmers' costs. Despite the major operators' commitment to good neighbor policies, the dominance of subsurface rights disadvantages surface rights-holders by weakening their bargaining position. In regions with active or potential CSG operations, organisations have arisen to express concerns about the potential impacts of a weakened agriculture on rural and community ways of life (Lock the Gate Alliance, n.d.). Conflicts between agriculture and CSG strike with particular force in some of Australia's most productive farming areas, including the Darling Downs and the Liverpool Plains, where the national interest in prime farmland (quite scarce in Australia) comes into play, in addition to local concerns.

Some would argue that there is a national interest in preserving the very best farmland for agriculture, even if the economic argument for CSG development is strong (Dart, 2011). However, the possibility might be considered that, for the

best land, the economic advantage of CSG is not so compelling. CSG offers the prospect of several decades of lucrative extraction but it is reasonable to expect environmental costs, some of them potentially substantial in cumulative effect, to continue perhaps for long after the gas is gone. Furthermore, the economic benefits of CSG are not assured: while current projections are for high and stable commodities prices for the life of the planned projects, the extractive industries historically have experienced cycles of boom and bust (Rosenau-Tornow, Buchholz, Riemann, and Wagner, 2009; Jacks, 2013). At best, CSG is a transition energy technology and we do not know how long its window of opportunity will be.

The remainder of this article frames the issues in the contest between CSG and agriculture on prime farmland, assembles and interprets economic evidence from primary and secondary sources, identifies the key economic drivers of the CSG versus agriculture decision and, for a specific case study region in the Darling Downs region of Queensland, shows how the possible future values of the various drivers influence the benefits and costs of CSG mining on agricultural land.

Economic assessment of CSG versus agriculture

A benefit-cost analysis (BCA) framework was used to assess the absolute and relative economic net benefits of CSG and agriculture. This involved computing and monetising the relevant benefits and costs to calculate the net benefits generated by either CSG mining, agriculture, or both on the same piece of land. Where the values of the variables are unknown or known but subject to uncertainty, sensitivity analysis has been conducted to identify the effects of a plausible range of values for these variables on the net benefits.

Scope and data description

We conducted a case study of Arrow Energy's Surat Gas Project, which covers an area of approximately 8600 km² in the Darling Downs, a region renowned for its agricultural productivity (Figure 2). Sixty percent of this area is considered productive agricultural land (Coffey Environments, 2012). Unpublished agricultural gross margin data was provided by local farmers in the Darling Downs. To establish that the reported productivity is indeed consistent with prime agricultural land, the gross margin values have been compared with other local farmers' gross margins and the publicly available farm budgets for a comparable region in New South Wales (NSW Department of Primary Industries, 2011). CSG production volume and prices, while difficult to predict, are sourced from publicly

available information and projections. Further details of data and assumptions are provided in Table 1.

The stream of future benefits and costs is expressed first in annual net benefit terms, and ultimately in net present value in 2012 dollars. The time horizons that are common in BCA, typically in the range of 30 to 50 years, would be unsuitable for the present study because CSG benefits all accrue in the first several decades while the environmental costs and degradation of agriculture continue for long after the CSG has been depleted. While one could argue for even longer time horizons, we settled on 100 years.



Figure 2: Map of Arrow Energy’s Surat Gas project in Darling Downs region
 Source: Surat Gas Project Environmental Impact Statement, Coffey Environments (2012)

Net benefits calculation

The conceptual framework for net benefits calculation for various activities is presented here, and details of the values used in the calculations are explained further in Table 1. Agricultural net benefits are calculated as rents using the asset pricing model. The returns from the land or asset are capitalised into land rents using a budgeting approach (Randall and Castle, 1985).

Single period rent per hectare is calculated by capitalising the profit from producing commodities. Profit π_x is the difference between the total revenue from producing a vector of commodities x_i and its total costs in producing commodities x_i described by the cost function $C(x_i)$ that takes into account all direct costs involved in production, and agricultural land rent p_a (equation 1).

$$\pi_x = p_{xi}x_i - C(x_i) - p_a \quad (1)$$

At equilibrium, profits are driven to zero. Land rent is equal to the total revenue deducting total costs of the agricultural commodities (equation 2):

$$p_a = p_{xi}x_i - C(x_i) \quad (2)$$

Now the land rent per hectare is scaled-up to rents accruing to the total area of land by factor h , the number of hectare (equation 3):

$$P_A = hp_a \quad (3)$$

Assuming agricultural rent grows at annual rate of g where $0 < g < 1$, agricultural land rent at time $t + 1$ is given by equation (4):

$$P_A(t + 1) = P_A(t)(1 + g) \quad (4)$$

The net present value, NPV , of agricultural production is the sum of discounted annual rents calculated from period 0 to the end period T , where T is 100 years (equation 5):

$$NPV_A = \sum_{t=0}^T \frac{P_A(t)}{(1+r)^t} \quad (5)$$

The impact of CSG extraction and processing on agricultural rent, I_t , at time t can be written as the product of rent P_A and B_t , where B_t is the percentage of reduction on agricultural production if CSG mining is present (equation 6).

$$I_t = P_A(t)B_t \quad (6)$$

A budgeting approach similar to that used for calculating agricultural rents was applied for calculating CSG rents per hectare at time t . Where the net profits from domestic gas Z_1 and LNG Z_2 are the revenue from gas and LNG minus the costs of production $C(Z_1 + Z_2)$, the environmental costs $C(E_t)$ and the CSG rents generated per hectare p_s (equation 7).

$$\pi_s = p_{z1}Z_1 + p_{z2}Z_2 - C(Z_1 + Z_2) - C(E_t) - p_s \quad (7)$$

At equilibrium, profits are driven to zero, the CSG rents per hectare at time t are (equation 8):

$$p_s = p_{z1}Z_1 + p_{z2}Z_2 - C(Z_1 + Z_2) - C(E_t) \quad (8)$$

To convert rents of CSG generated per hectare to rents for total area of land, rents per hectare can be scaled by factor w (equation 9):

$$P_s = wp_s \quad (9)$$

While agriculture-only and CSG-only are plausible options, so is the coexistence of CSG mining with agriculture. In the coexistence case, the rents include the net benefits of CSG rents P_s and the agricultural rents P_A diminished by the negative impacts of CSG operations I_t (equation 10).

$$P_C = P_s + (P_A - I_t) \quad (10)$$

The *NPV* of the coexistence case is the sum of discounted annual rents from period 1 to period T of coexistence rents, where T is 100 years (equation 11).

$$NPV_C = \sum_{t=0}^T \frac{P_C(t)}{(1+r)^t} \quad (11)$$

If CSG mining results in complete elimination of agricultural rents then the rents are limited to CSG rents. Complete lost agricultural rents as a result of CSG mining is represented by the impacts I_t where (equation 12):

$$I_t = P_A(t) \quad (12)$$

Substituting (12) into (10), the calculation for coexistence, we obtain CSG rents only as P_C is equal to P_S (equation 13):

$$P_C = P_S + (P_A - P_A) = P_S \quad (13)$$

The *NPV* for CSG rents is computed by equation (14):

$$NPV_S = \sum_{t=0}^T \frac{P_S(t)}{(1+r)^t} \quad (14)$$

The exact impact of CSG on agricultural productivity is specific to the location, farming practices, extraction methods, and safeguards implemented; therefore, the level of diminished agricultural productivity has been tested in sensitivity analysis.

The best estimates of key variables underlying the benefit and cost calculations are based on the assumptions and data sources summarised in Table 1. Variables subject to high levels of uncertainty and/or contention, such as the discount rate, environmental costs, diminution of agriculture in the coexistence case, and gas prices, are further discussed below in the context of sensitivity analysis.

Table 1: Key variables, assumptions and explanations, and data sources

Variables	Assumptions and explanations	Data sources
x_i	Agricultural commodity $i = 1,2,3, \dots n$ These commodities are mostly grain and cotton crops	(Primary data from local farms)
p_{xi}	Price of agricultural commodity i	
π_x	Profits of agricultural commodities	
$C(x_i)$	Cost function producing agricultural commodity i , inclusive of labour, capital and all input costs required in the production	
p_a	Agricultural rents accruing to a hectare of land	
h	Scaling factor from one hectare to total area of land. The total area of agriculture land is 5160 km^2 , Arrow Energy EIS scope description estimated 60 percent of the total project area of 8600 km^2 is productive cropland	(Coffey Environments, 2012)
P_A	Agricultural rents accrued to total area of land	
g	Growth factor of agricultural value, $0 < g < 1$, $g = 0.013$ The real value growth rate estimated by ABARES from 2012 to 2050	(ABARES, 2012)
t	Time in years, $t = 0,1 \dots 100$	
T	The end time period, in this paper, T is 40 and 100 years	
NPV_A	Net present value of a stream of agricultural rents	
I_t	The reduced net benefits of agriculture due to CSG extraction. This is based on the mining firm's payments under access agreements and is used as a lower bound in the sensitivity analysis	Anecdotal evidence
B_t	Percentage of reduction on agricultural rents by CSG	
π_s	Profits of CSG production on a hectare of land	
Z_i	Quantity of gas in produced; $i = 1$ (domestic gas), $i = 2$ (LNG, using Arrow Energy EIS chapter 5 projected production description)	(Coffey Environments, 2012)
p_{zi}	Gas prices	(BREE, 2011;

	$i = 1$ Domestic gas: table 6.4 Gas Market Report, $i = 2$ LNG; extrapolated from figure E Australian Energy Projections to 2034-35	BREE, 2012b)
$C(Z_i)$	Cost of producing 1 petajoule of domestic and LNG, inclusive of exploration, development and general gas production costs	(Core Energy Group, 2012)
$C(E_t)$	Environmental costs and decommissioning costs, which are approximated by the offshore gas decommissioning costs, onshore data are unavailable, offshore decommissioning costs are assumed to be higher	(Department of Resources Energy and Tourism, 2008)
K	The proportion of environmental costs that CSG firms have internalised; assuming the treatment of by-product water by CSG firms. Cost of treating for the by-product water produced using reverse osmosis costs are capital and operational costs	(GHD, 2003)
p_s	CSG rents accrued to a hectare of land	
w	The weighting factor of the gas production volume that would occur on the total area of land	(Coffey Environments, 2012)
P_S	CSG rents accrued to the total area of land	
P_C	Coexistence rents accrued to the total area of land	
NPV_C	Net present value of a stream of coexistence rents	
P_R	CSG rents accrued to Australians, inclusive of royalties and environmental costs	
P_{CR}	Coexistence rents accrued to Australians, inclusive of royalties, environmental costs of CSG and the leftover agricultural rents	
NPV_{CR}	Net present value of a stream of coexistence rents accrued to Australians	
NPV_S	Net present value of a stream of CSG rents or the case in which complete elimination of agriculture occurs	

Time paths of net benefits

While the obvious benefits of CSG development come in the first few decades, there follows a potentially long period of agricultural and environmental degradation. As shown in Figure 3, external costs continue long after the end of gas production in year 40. CSG rents and coexistence rents incur high capital costs in the beginning but realise the benefits of extraction from year 4 to year 40 from the demand for LNG. The environmental costs, however, continue after mining is completed but gradually decrease over time based on the assumptions that decommissioning of CSG infrastructure and recovery of agriculture occur. Agricultural rents grow steadily, driven by technological change and rising demand for food crops, at an annual growth rate estimated by ABARES (2012).

The most important impact of CSG on agriculture is diminished agricultural productivity, in the case of agriculture and CSG coexistence. After the CSG has been depleted, the coexistence net benefits will always stay below the agriculture line as diminished agricultural production continues long into the future. This indicates the possibility that the net benefits gap between CSG mining and agriculture-only may be closed given enough time.

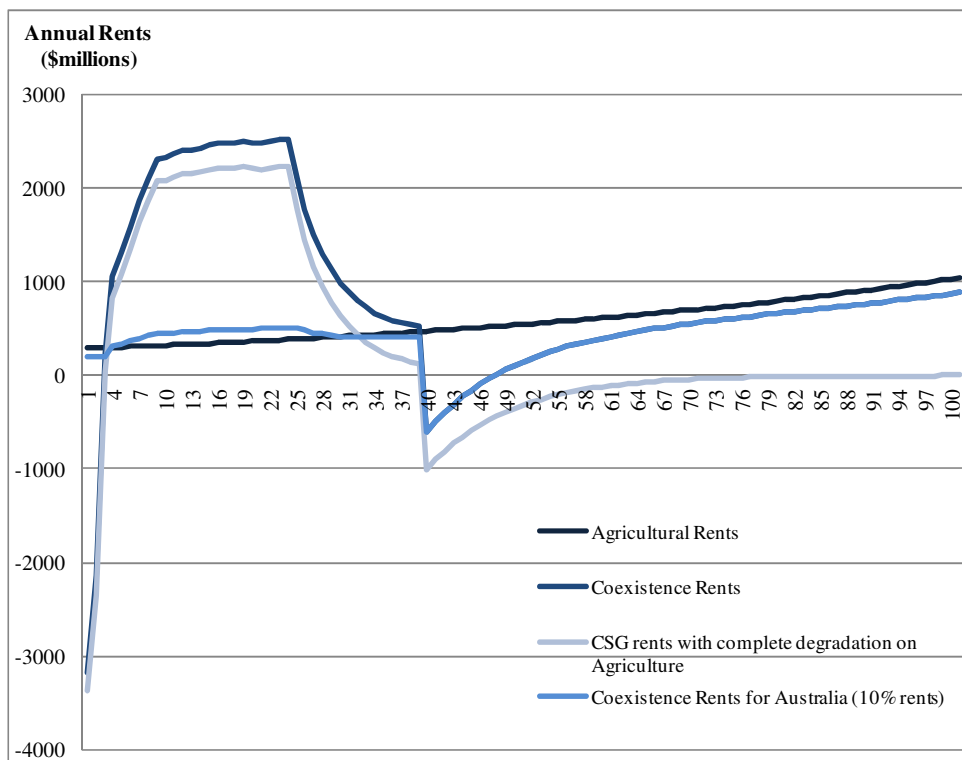


Figure 3: Time path of annual rents

Benefits retained in Australia

From a national perspective it is reasonable to evaluate CSG in terms not of its net value to the mostly international operators, but in terms of the net value retained in Australia. The most obvious economic benefits retained in Australia are the royalties of 10 percent *ad valorem* collected by state governments on petroleum and natural gas (Montoya, 2012), and we have chosen 10 percent to serve as our worst-case rent-capture scenario from an Australian perspective. From this perspective, the benefits accruing to Australians include the 10 percent estimated CSG rents, in the form of *ad valorem* royalties to state government, the proportion of environmental costs internalised by CSG companies k , and the untreated proportion $(1 - k)$ of environmental damages caused by CSG (equation 15):

$$P_R = 0.1 (p_{z1}Z_1 + p_{z2}Z_2 - C(Z_1 + Z_2) - kC(E_t)) - (1 - k)C(E_t) \quad (15)$$

Coexistence rents P_{CR} would then be the royalties from CSG production P_R plus the leftover agricultural rents (equation 16):

$$P_{CR} = P_R + (P_A - I_t) \quad (16)$$

Similarly, the *NPV* of the coexistence case, which only includes CSG rents that accrued to Australians is (equation 17):

$$NPV_{CR} = \sum_{t=0}^T \frac{P_{CR}(t)}{(1+r)^t} \quad (17)$$

Figure 3 shows the case of coexistence when only 10 percent of CSG net benefits are retained in Australia. The coexistence net benefits are above agriculture-only net benefits during the extraction phase and below the agriculture-only net benefits post-CSG.

The question of whether enough royalties and taxes have been collected in Australia to compensate for the depletion of exhaustible resources and the damages caused by CSG extraction is still in debate. Since the actual and desired levels of royalties and taxes on CSG remain contentious, different levels of CSG net benefits collected in Australia have been tested using sensitivity analysis to examine the economic contest of CSG versus agriculture from a national perspective.

Post-CSG project life external costs

Uncertainty applies to almost every aspect in this long-term analysis, but especially to environmental damages and treatment and remediation costs. Here we consider the different trajectories that external costs may take and the degree to which external costs affect net benefits over the time horizon of 100 years. In Figure 4, the possible paths of external costs can be traced from point A when CSG extraction ends. The path of declining external costs and rising net benefits assumes decommissioning of the CSG infrastructure is conscientious and effective, allowing a rapid recovery of land quality. The path that plateaus from point A assumes the ongoing uniform impacts of external costs on the environment and agricultural activities if decommissioning is not so effective. Another possibility is the continuous increase in costs from point A in the case of serious irreversible depletion of aquifers and other irreversible environmental impacts discussed earlier. In the complete absence of decommissioning, external costs would accelerate from point B, causing rents to decline even more steeply. At point A the annual rents are roughly negative-\$0.5 billion and can be lower or higher depending on the severity of the CSG-induced environmental impacts.

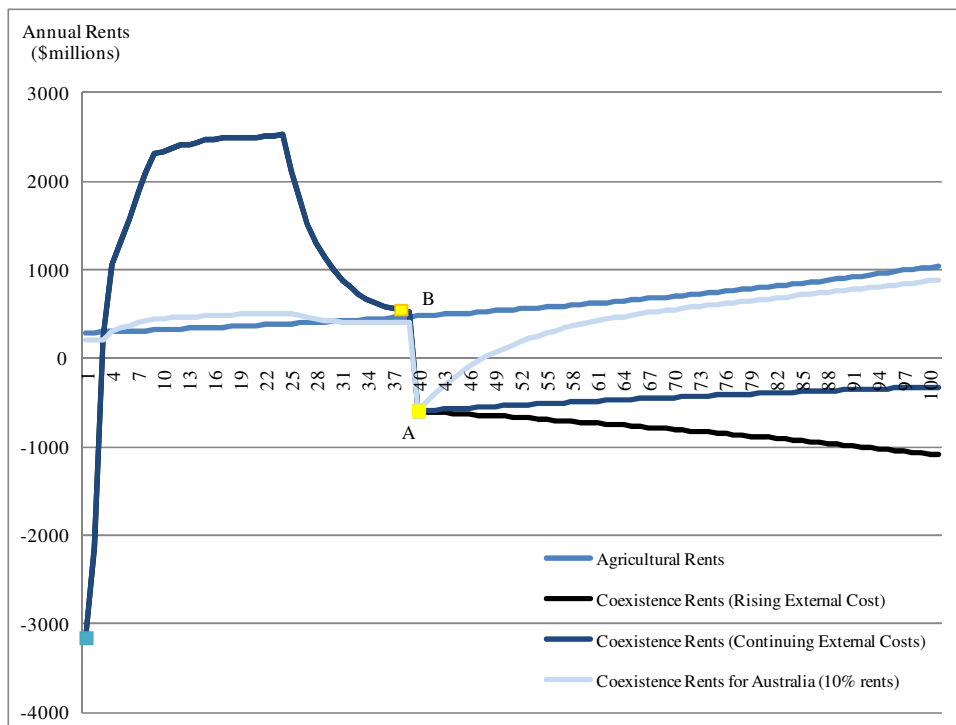


Figure 4: External costs after year 40

Although the future environmental costs of CSG are unclear, Figure 4 shows several possibilities for the course of coexistence net benefits under different external costs scenarios. The scenarios are calculated using percentage values of the impacts on agriculture from year 40, shown earlier (equation 6). If the continuing impacts of CSG are greater, recovery of agriculture is diminished and therefore the net benefits are lower. One implication of the uncertainty illustrated in Figure 4 is that a serious case can be made for requiring CSG operators to post environmental bonds consistent with the worst-case damage scenarios (Gerard 2000).

Net present value and the discount rate

To this point, net benefits have been calculated annually, and Figures 3 and 4 show the time-paths of net benefits under various scenarios. A common procedure for comparing alternatives with differently shaped time-paths, such as we see here, is to calculate net present values (equations 5, 11, 14, and 17). This generates a single net present value (NPV) number for each of the different scenarios, such as agriculture-only, CSG-only and various coexistence cases. The choice of discount rate affects the NPV of the various scenarios in absolute and also relative terms given the inter-temporal disjunction: the flow of CSG benefits is exhausted in a few decades while the environmental costs continue; and the benefits of agriculture-only are projected to keep growing indefinitely. In absolute terms, a higher discount rate reduces all NPVs; in relative terms, a higher discount rate puts more weight on near-future consequences and less on the longer term, thus favouring CSG over agriculture. Given the contentious nature of the choice of discount rate, we conduct a sensitivity analysis over a range of discount rates that have been used or advocated in the literature.

Sensitivity analysis

Uncertainty and gross ignorance about major categories of benefits and costs cast doubt on any point estimate of NPV. Instead, we report a series of sensitivity analyses showing how NPV is influenced by the values that key uncertain variables – the future demand for agricultural products and CSG, the external costs of CSG, the discount rate, and the level of agricultural degradation caused by CSG mining – might plausibly take. These variables can be categorised into two groups, variables that favour agriculture-only and the ones that favour CSG-only and/or coexistence. The variables that have a positive relationship with agriculture-only net benefits include the growth rate in agricultural value, the proportional negative impact of CSG mining on agriculture, and the external costs of CSG mining. The variable that favours CSG mining is gas prices – as gas

prices increase, the economic choice shifts towards CSG. The values of the baseline (best estimates given current knowledge) and lower and upper bound parameter values are shown in Table 2. Where there is no explicit information on upper or lower bound values, a multiple of the baseline value is used to create the upper and lower bound.

Combining variables to develop scenarios

Given there are five variables tested in the sensitivity analysis and four cases for NPV calculation, it would be impractical to present all NPV possibilities. Instead, the results of sensitivity analysis are presented in terms of 4 cases and 7 scenarios (Figure 5). The 4 cases are: agriculture-only; CSG-only or coexistence where all CSG rents count; the lower-bound case for Australia where only 10 percent of CSG rents are retained; and an intermediate case where 30 percent of CSG rents are retained.

The 7 scenarios include 2 where agriculture and CSG are mutually exclusive and 5 where agriculture may coexist with CSG suffering some negative impacts in the process.

The first two scenarios (Figure 5, Table 3) assume that CSG and agriculture are mutually exclusive. In the first, agricultural NPV is set at the “favourable for agriculture” level. Of all the scenarios we have considered, this one is most compatible with the argument that agriculture should have primacy, especially on prime farmland. In the particular case where Australia keeps only 10 percent of the rents from CSG, the NPV of CSG extraction is negative. The second “mutually exclusive” scenario, shows that CSG may dominate in terms of NPV even when it eliminates agriculture if baseline values prevail and all of the resource rents count as benefits to Australia.

The 5 coexistence scenarios include the baseline scenario, “favourable to agriculture” and “favourable to CSG” scenarios, and two scenarios that vary gas prices but fix the values of all other variables. A scenario of low gas prices and all other factors contributing to agriculture set at the lower bound is represented in the scenario entitled ‘all parameters low’. The second of these scenarios, ‘all parameters high’ sets high gas prices but fixes all other factors contributing to agriculture at the upper bound. These scenarios provide examples of situations that could be present between the extreme cases and demonstrate the extent to which the effects of gas prices are offset by other variables.

Table 2: Values of variables in sensitivity analysis

Parameters	Lower bound	Baseline	Upper bound
Discount rate	1.4% ^a	2.8% ^b	5.0% ^c
Agricultural value growth rate	0.5%	1.3% ^d	2.6%
CSG's level of degradation on agriculture	6% during construction years ^e 4.5% until the end of well life 3.5% thereafter	30% during construction years 25% until the end of well life 15% thereafter	60% during construction years 45% until the end of well life 35% thereafter
External costs of CSG ^f	\$555/GL capital cost (first 2 years) \$0.347/GL (operational cost) 43% lower than best estimate	\$972/GL capital cost (first 2 years) \$0.903/GL (operational cost) Starting from 2049, \$1000 million and declines gradually	\$1389/GL capital cost (first 2 years) \$2.084/GL (operational cost) 43% higher than best estimate
Gas prices	30% lower than the best estimate	Domestic and LNG gas prices projected ^g	30% higher than the best estimate

^a Discount rate in the Stern Review of Economics of Climate Change (Stern, 2006). Stern argues that this rate is appropriate for long-time-horizon problems, and it is used here as a lower bound.

^b Australia's long-term economic growth rate until 2034-35 calculated by BREE (2011) in table 4.

^c Upper value of retail and investment rate of return in private sector (Reserve Bank of Australia, 2012).

^d Agricultural value growth rate modelled by ABARES (2012).

^e Based on CSG operator payments to Darling Downs farmers under access agreements (anecdotal evidence).

^f Reverse osmosis costs per giga litre of water produced (GHD, 2003); decommissioning costs approximated by offshore gas facilities, adjusted downward (Department of Resources Energy and Tourism, 2008).

^g Refer to table 6.4 for projected domestic price (BREE, 2012b) and figure E for projected LNG index (BREE, 2011) from 2014-2035.

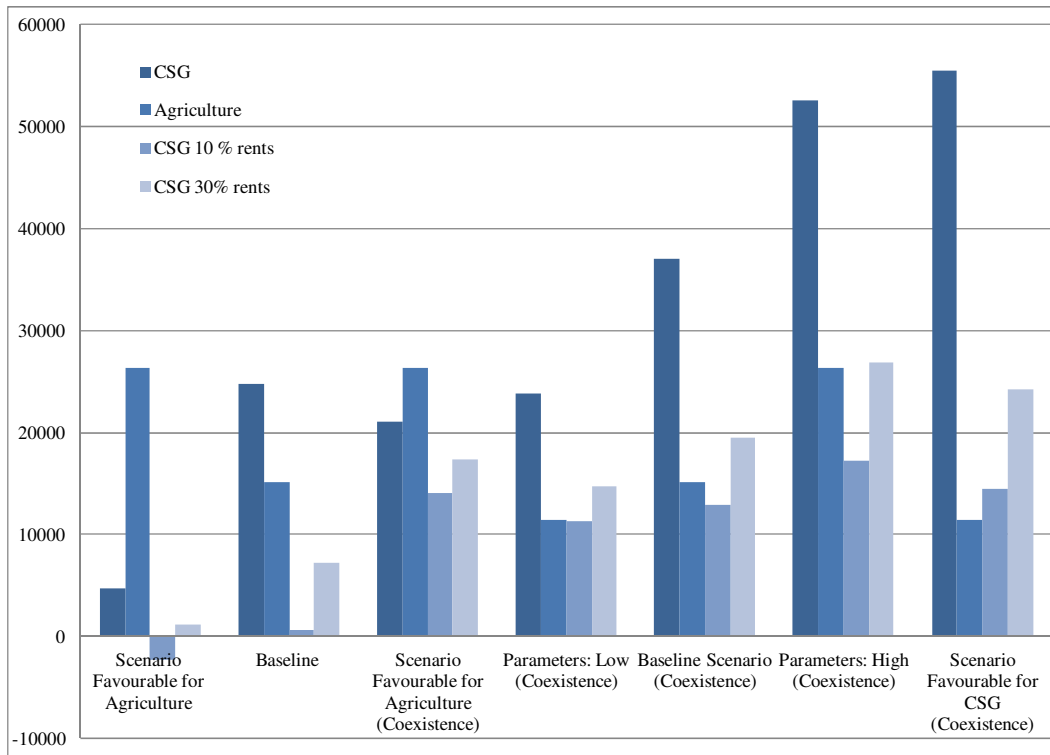


Figure 5: NPVs of 7 scenarios (in \$millions)

Table 3: NPVs of 7 scenarios and 4 cases (in \$millions)

Agriculture and CSG are mutually exclusive	CSG only	Agriculture	CSG 10% rents	CSG 30% rents
Scenario favourable for agriculture	4767.47	26288.76	-2235.14	1116.32
Baseline scenario	24723.07	15182.58	572.04	7186.69
Agriculture and CSG coexistence	Coexistence	Agriculture	Coexistence rents 10%	Coexistence rents 30%
Scenario favourable for agriculture	21054.21	26288.76	14051.61	17403.07
Parameters: low	23887.68	11500.23	11257.04	14765.41
Baseline scenario	37002.37	15182.58	12851.33	19465.99
Parameters: high	52619.16	26288.76	17208.10	26872.55
Scenario favourable for CSG	55452.63	11500.23	14413.53	24234.89

In NPV terms, agriculture will prevail over coexistence under favourable conditions for agriculture (Figure 5), even if all CSG rents are captured in Australia. If Australians retain only 10 percent of the CSG net benefits, then in most cases except in the scenario favourable for CSG, agriculture will generate greater NPV than CSG mining. This result has important implications for policy makers; if net benefits accruing to Australians are confined to 10 percent of the CSG rents and if the national interest in economic outcomes extends to 100 years and beyond, then the CSG operations on prime farmland are likely to be a losing proposition.

If 30 percent of rents from CSG are retained in Australia, the coexistence case may prove to be economically efficient in most cases except when parameters are favourable for agriculture, and/or agriculture is fully displaced by CSG. This highlights the national interest in capturing more of the CSG rents – otherwise Australia will be depleting its CSG resources, content to be paid little more than the value of its work of extraction and processing. Among others, Sinner and Scherzer (2007) and Garnaut (2010) have discussed the economic considerations in designing a minerals resource rent tax that could be implemented to meet the economic sustainability condition suggested by Solow (1974) and Hartwick (1977).

Given the substantial external costs incurred after the project life of CSG mining and the persistent growth of agricultural value into the distant future, we have identified several sets of conditions under which agriculture-only prevails. These results demonstrate that markets, which seem to be offering unambiguous endorsement of CSG development in Australia, provide a seriously incomplete guide to CSG benefits and costs and, especially, those CSG benefits and costs that accrue to Australia.

The influence of parameters on NPV

A final set of analyses casts additional light upon the parameters that have significant impacts on NPV. Elasticities can be derived that allow us to compare the rate of change of NPV with respect to changes in the parameter values. The elasticity of a variable can be computed as the percentage change of NPV divided by the percentage change in the parameter values with parameters represented by X (Pannell, 1997).

$$\varepsilon = \frac{\% \Delta NPV}{\% \Delta X} \tag{18}$$

Table 4: Elasticity (in absolute value) of the variables, 100 years time-frame

Elasticity of the variable	Elasticity: Coexistence	Elasticity: Agriculture
Upper range discount rate	0.447	0.958
Lower range discount rate	0.539	1.037
High agricultural growth rate	0.253	0.732
Low agricultural growth rate	0.135	0.394
High level of impact on agriculture	0.154	0.000
Low level of impact on agriculture	0.030	0.000
Complete elimination of agriculture	0.111	0.000
High external costs of CSG	0.262	0.000
Low external costs of CSG	0.244	0.000
High gas prices	1.422	0.000
Low gas prices	1.422	0.000

The price of gas is the most influential variable to coexistence NPV, followed by the discount rate, and then external costs (Table 4). The agricultural growth rate and the discount rate are most influential on the agricultural NPV since agricultural value continues to grow after 40 years, by which time CSG has only negative impacts.

Sensitivity testing: summary of results

Given our data and analysis, if the net benefits retained in Australia are limited to 10 percent of the total economic rents, CSG mining will create relatively little net benefits compared with existing agriculture in most circumstances. As more net benefits of resource extraction are collected, as seen in the 30 percent and 100 percent cases, CSG mining on agricultural land becomes economically desirable compared with agriculture unless conditions are favourable for agriculture. Nevertheless, the external costs of CSG projects are speculative and difficult to quantify. If the external costs were to remain significantly large for many years into the future, coexistence could be defeated by agriculture in all circumstances. If future gas prices are low enough and all other factors are close to the best estimates, coexistence may not make a convincing economic case. On the other hand if agriculture disappoints the optimistic expectations, the CSG net benefits may dominate given moderate external costs and gas prices.

Conclusions

The economic contest between CSG and agriculture on prime farmland presents a textbook inter-temporal dilemma: CSG extraction creates negative impacts on agriculture and the environment long after the gas and associated economic activity are gone, whereas foregoing CSG development would require us to sacrifice substantial economic benefits over the next several decades.

We have framed the economic contest in net present value terms, identified the key economic drivers, assembled evidence from primary and secondary sources for a case-study region in the Darling Downs, and examined a variety of scenarios that are considered plausible given the gross ignorance that persists concerning some potential impacts and the uncertainty about most of them. Depending on assumptions about the magnitudes of variables – especially future gas prices, external costs of CSG, and the growth rate of agricultural value – the economic contest could be resolved in favour of CSG or agriculture. Two key findings can be highlighted.

First, the present-valued economic rents from CSG are insufficient to defeat agriculture, or to justify the CSG-and-agriculture coexistence solution, in the scenario favourable for agriculture where variables favouring agriculture are set at high levels and the future price of LNG is low.

Second, the Australian national interest depends on how much of the CSG rents (i.e. the economic value of resources depleted) are retained in the country. After all, it is well known that an exhaustible-resource-extracting country can achieve economic sustainability only if all of the rents from resources depleted are reinvested in productive capital (Solow, 1974; Hartwick, 1977). The total rent from CSG comes in two parts: rents earned by those who organise and accomplish the work of finding, extracting, processing and marketing the gas; and rents that reflect the scarcity value of the resource itself – it is that second component of the rents that concerned Solow and Hartwick. The 10 percent *ad valorem* royalties collected by Australian state governments represent an attempt to capture the scarcity rent, but the 10 percent figure is attributable more to custom than to market-generated information or careful analysis. Hogan and McCallum (2010) suggest that Australia is leaving substantial minerals rents on the table. The CSG jobs for Australians and the company taxes collected by the Commonwealth government are real and important, but they represent mostly some fraction of the rents from organising and accomplishing the work – they are not connected directly to the scarcity rent from depleted resources. So it is clear that the CSG rents calculated in this study overstate the rents actually captured by Australia.

In our baseline scenario, a middle-of-the-road scenario that might be considered most likely from today's perspective, agriculture-only defeats coexistence if only 10 percent of the CSG rents are captured in Australia, while coexistence comes out ahead if 30 percent of rents are captured.

Our results show that the economic contest between CSG and agriculture is closer than we may have thought: under some plausible scenarios, the long-term economic net benefits from agriculture-only exceed those from CSG-only and CSG-agriculture coexistence cases.

Finally, we should emphasise the extent of the environmental unknowns. The impacts of cumulative water withdrawals from the Great Artesian Basin and the economic and environmental costs of treating these huge volumes and disposing of the sludge, and the ultimate costs of disturbing aquifers and subsurface geosystems are truly unknown and perhaps unknowable *ex ante*, suggesting that our upper-bound environmental cost estimates are "guesstimates" that could be exceeded in the worst cases.

References

- ABARES. (2012). Food demand to 2050 - Opportunities for Australian agriculture. *Paper presented at the 42nd ABARES Outlook conference 6–7 March 2012, Canberra*. Canberra: Australian Bureau of Agricultural and Resource Economics and Sciences.
- Bergstrom, T. C. (1984). *Property Rights and Taxation in the Australian Minerals Sector*. Selected Works of Ted C. Bergstrom, University of California Santa Barbara, CA, USA. Retrieved 25 March, 2012, from http://works.bepress.com/ted_bergstrom/93
- BREE. (2011). *Australian energy projections to 2034-35*. Canberra: Bureau of Resources and Energy Economics.
- BREE. (2012a). *Australian gas resource assessment*. Canberra: Bureau of Resources and Energy Economics.
- BREE. (2012b). *Gas market report*. Canberra: Bureau of Resources and Energy Economics.
- Carlisle, W. (2012). *Coal seam gas: by the numbers*. Australian Broadcasting Corporation. Retrieved 25 March, 2013, from <http://www.abc.net.au/news/specials/coal-seam-gas-by-the-numbers>
- Clark, T., Hynes, R. and Mariotti, P. (2011). Greenhouse Gas Emissions Study of Australian CSG to LNG. Worley-Parsons Resources and Energy. Retrieved 25 March, 2013, from <http://www.abc.net.au/radionational/linkableblob/4421188/data/greenhouse-gas-emissions-study-of-australian-csg-to-lng-data.pdf>

- Coffey Environments. (2012). *Surat Gas Project environmental impact statement*. Brisbane : Arrow Energy.
- Core Energy Group. (2012). *Gas production costs*. Prepared for Australian Energy Market Operator, Adelaide.
- Daintith, T. (2010). *Finders keepers? How the law of capture shaped the world oil industry*. Washington, DC: RFF/Earthscan.
- Dart, P. (2011, May 26). Coal seam gas a risk to food security. *The Conversation*. Retrieved 10 September, 2013, from <http://theconversation.com/coal-seam-gas-a-risk-to-food-security-485>.
- Dasgupta, P., Heal, G., and Stiglitz, J. (1980). The taxation of exhaustible resources. *Working paper 436*. Cambridge, MA: National Bureau of Economic Research.
- Department of Climate Change and Energy Efficiency. (n.d.). Coal seam gas: estimation and reporting of greenhouse gas emissions. Retrieved 17 April, 2013, from http://www.climatechange.gov.au/climate-change/emissions/~/_/media/climate-change/emissions/factsheets/NGA-FactSheet-7-CoalSeamGas-20120430-PDF.pdf.
- Department of Resources, Energy and Tourism. (2008). *Decommissioning Australia's offshore oil and gas facilities*. Canberra: Department of Resources, Energy and Tourism.
- Department of Sustainability, Environment, Water, Population and Communities. (2010, September). *Water Group Advice on EPBC Act Referrals* for Minister Tony Burke. Tabled in the Australian Senate, 2010.
- DIICCSRTE: Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education. (2013, April). Coal seam gas: enhanced estimation and reporting of fugitive greenhouse gas emissions under the national greenhouse and energy reporting (measurement) determination. *Technical Discussion Paper*.
- Foster, S. S. D. and Chilton, P. J. (2003). Groundwater: the processes and global significance of aquifer degradation. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences*, 358, 1957-1972.
- Garnaut, R. (2010). Principles and practice of resource rent taxation. *Australian Economic Review*, 43, 347-356.
- Gerard, D. (2000). The law and economics of reclamation bonds. *Resources Policy*, 26(4), 189-197.
- GHD. (2003). *Desalination in Queensland*. Queensland: Department of Natural Resources and Mines.
- Guj, P. (2012). *Mineral royalties and other mining-specific taxes*. Crawley, WA: International Mining for Development Centre.
- Hartwick, J. M. (1977). Intergenerational equity and the investing of rents from exhaustible resources. *The American Economic Review*, 67, 972-974.
- Healy, D. (2012). *Hydraulic fracturing or 'fracking': a short summary of current knowledge and potential environmental impacts*. Aberdeen: University of Aberdeen. Retrieved 29 April, 2013, from http://www.epa.ie/pubs/reports/research/sss/UniAberdeen_FrackingReport.pdf.
- Hogan, L., and McCallum, R. (2010, October). *Non-renewable resource taxation in Australia*. Report prepared for the AFTS Review Panel, ABARE–BRS, Canberra.

- Jacks, D. S. (2013). From boom to bust: a typology of real commodity prices in the long run. *NPER Working Paper 18874*. Cambridge, MA: National Bureau of Economic Research.
- Livesley, K. (2010). *Australia: mining: the regulation of exploration & extraction: getting the deal through*. Retrieved 20 March, 2013, from <http://www.mondaq.com/australia/x/108106/Mining/Mining+The+Regulation+of+Exploration+Extraction>.
- Lock the Gate Alliance. (n.d.). *Find a local group*. Retrieved 29 April, 2013, from <http://www.lockthegate.org.au/groups>.
- MCMPR: Ministerial Council on Mineral and Petroleum Resources. (n.d. a). *Mineral and Petroleum Exploration and Development in Australia - A Guide for Investors; 9. Exploration and Mining Legislation – Onshore*. Retrieved 25 March, 2013, from http://www.ret.gov.au/resources/Documents/inerals%20and%20Petroleum%20Exploration/Guide_for_%20Investors_9OnshoreLegislation.pdf.
- MCMPR: Ministerial Council on Mineral and Petroleum Resources. (n.d. b). *Mineral and Petroleum Exploration and Development in Australia - A Guide for Investors; Minerals Taxation*. Retrieved 25 March, 2013, from http://www.ret.gov.au/resources/Documents/Minerals%20and%20Petroleum%20Exploration/Guide_for_%20Investors_19MineralsTaxation.pdf.
- Montoya, D. (2012). *Coal seam gas royalties in Australian States & Territories*. New South Wales: NSW Parliament, E-brief.
- National Water Commission. (2011). *Onshore co-produced water: extent and management*. Waterlines Report Series No 54. Canberra: National Water Commission.
- NSW Department of Primary Industries. (2011). Farm budgets and costs. Retrieved 20 March, 2012, from <http://www.dpi.nsw.gov.au/agriculture/farm-business/budgets>.
- Pannell, D. J. (1997). Sensitivity analysis of normative economic models: theoretical framework and practical strategies. *Agricultural Economics*, 16, 139-152.
- Queensland Government. (2010). *Queensland's LNG Industry - A once in a generation opportunity for a generation of employment*. Brisbane: LNG Industry Unit, Department of Employment, Economic Development and Innovation.
- Queensland Government. (2013) *Fracking and BTEX*. Retrieved 20 March, 2013, from <http://www.ehp.qld.gov.au/management/non-mining/documents/fracking-btex.pdf>
- Randall, A. (2011). *Risk and Precaution*. Cambridge: Cambridge University Press.
- Randall, A. (2012). Coal seam gas – toward a risk management framework for a novel intervention. *Environmental and Planning Law Journal*, 29, 152-162.
- Randall, A., and Castle, E. N. (1985). Land resources and land markets. In Kneese, A. V., and Sweeney, J. L. (Eds.) *Handbook of Natural Resource and Energy Economics*, Vol. 2, (pp. 465-755). Oxford, UK: Elsevier Science.
- Reserve Bank of Australia. (2011). *Statement on Monetary Policy. Box B: The Mining Sector and the External Accounts*. Retrieved 17 April, 2013, from www.rba.gov.au/publications/smp/boxes/2011/nov/b.pdf

- Reserve Bank of Australia. (2012). Statistical Tables - Interest Rate: Retail Deposit and Investment Rates. Retrieved 5 July, 2012, from http://www.rba.gov.au/statistics/tables/index.html#interest_rates.
- Rosenau-Tornow, D., Buchholz, P., Riemann, A., and Wagner M. (2009). Assessing the long-term supply risks for mineral raw materials — a combined evaluation of past and future trends. *Resources Policy*, 34(4), 161-175.
- Santos. (2012). *Coal seam gas water*. Retrieved 12 September, 2013, from <http://www.santos.com/coal-seam-gas/coal-seam-gas-water.aspx>.
- Schulze, W. D. (1974). The optimal use of non-renewable resources: the theory of extraction. *Journal of Environmental Economics and Management*, 1(1), 53-74.
- Sinner, J., and Scherzer, J. (2007). The public interest in resource rent. *New Zealand Journal of Environmental Law*, 11, 279-295.
- Solow, R. M. (1974). Intergenerational equity and exhaustible resources. *The Review of Economic Studies*, 41, 29-45.
- Stern, N. (2006). *Stern Review on the Economics of Climate Change*. Cambridge, UK: Cambridge University Press.
- Swayne, N. (2012). Regulating coal seam gas in Queensland: lessons in an adaptive environmental management approach? *Environmental and Planning Law Journal*, 29(2), 163-185.
- Taggart, T. (1998). The free entry mineral allocation system in Canada's north: economics and alternatives. *Working Paper 6*. Canadian Arctic Resources Commission.