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Antipodean agricultural and resource economics at 60: risk and uncertainty*

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Risk and uncertainty issues have been long addressed by members of AARES, reflecting the importance of the issue in agriculture, particularly in Australia. Members have been among the most innovative developers of methods and insights, around the world, as is reflected in the many publications in journals beyond the domestic shores. It seems, given the recent keen attention to such issues in the Australian literature and beyond, that, with high probability, members will continue to make strong contributions to this area of agricultural and resource economics.

Key words: decisions, risk, state-contingent, uncertainty, utility.

1. Introduction

Risk and uncertainty are pervasive features of life in general, but nowhere more so than in agriculture. Farmers must deal with an unpredictable climate, volatile prices driven by events in distant markets and public policies that may either mitigate or exacerbate the risks they face.

To the best of our knowledge, no one has yet attempted a global analysis of the relative riskiness of national agricultural sectors but it seems likely that such an analysis would put Australian agriculture well up in a list of the most risky. It is not surprising then that the fledgling profession of agricultural and resource economics should early turn to analysis of the risky reality: in marketing, especially of exported wheat (Anonymous 1948a,b) and wool (Gruen 1960; Powell 1960); and in production, with exploration of farm management and agricultural policy options to address the inherent problems (King 1948; Rutherford 1950; Williams 1953; Campbell 1958).

In subsequent decades, agricultural economists, including AARES members, have been among the leading contributors to the economics of risk and uncertainty. Given the pervasive importance of risk in agriculture, and the variety of approaches to the problem, a comprehensive survey of these contributions is beyond the capacity of the authors. Inevitably, we have been selective, and our inclusions and omissions reflect our own perspective on the

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field. Nevertheless, we have attempted to cover as much of the field as possible within the word constraints under which we have worked.

Our approach to this review was to identify several of the most important themes in the field of dealing with risk and uncertainty in agricultural and resource economics, to assemble a chronological list of relevant papers and then to provide a commentary on the history as we see it. Our path been eased by the historical elements of Just (2003), Hardaker (2006), Chavas *et al*. (2010, pp. 362–365) and Hardaker *et al*. (2015) for which we are most grateful.

2. Production under uncertainty

The variability and unpredictability of Australia's rainfall, immortalised by Dorothea McKellar's poem *My Country*, and the resulting production risk, is a defining feature of Australian agriculture. A large number of studies aimed at describing and quantifying the riskiness of the Australian agricultural sector have been undertaken (Anderson 1972; Battese and Francisco 1977; Wonder and Howlett 1977; Bartholomaeus and Hardaker 1981; Tisdell 1986). The pioneering work of Freebairn (1976) initiated a stream of research on the economics of better forecasting in the sector (Ritchie *et al*. 2004; Crean *et al*. 2015).

A variety of approaches has been employed to model production uncertainty. The most notable have been the stochastic production function approach and the state-contingent production model.

2.1 Stochastic production functions

Formal analysis of production uncertainty began in the 1970s with the development of the stochastic production function model, in which output (or sometimes yield) was modelled by a function of the form $f(x,e)$, where x is an effort level and e is a stochastic shock (Anderson *et al*. 1977; Pope and Just 1977; Brennan 1982; Anderson and Hamal 1983; Fraser 1986, 1988; Quiggin 1991).

A substantial literature emerged, examining the response of risk-averse producers (typically modelled as maximising expected utility (EU), or else as trading off mean and variance) to production uncertainty represented in this form. In formal terms, the analysis is closely related to the problem of production under price uncertainty, first analysed by the Scandinavian school (Sandmo 1971).

The crucial result, modified and generalised in various ways in the literature, is that the optimal effort level is lower, the more risky is production and the more risk-averse the producer (Anderson and Griffiths 1981; Griffiths 1986; Tisdell 1986; Kingwell 1994; see, however, Fraser 1986 and Quiggin 1991). Possible policy implications are that insurance, provided publicly or through markets, may yield welfare improvements (Battese and Francisco 1977), as may interventions that reduce risk, for example by encouraging farm syndication (Bartholomaeus and Hardaker 1981).

Later, more econometrically oriented analysts influenced by the works of Pope and Just (1977) formalised estimation methods that related the moments such as mean and variance of crop yield to varying levels of input use (Anderson and Griffiths 1981, 1982), with some such linking more directly to the EU model by deploying moments based on subjectively elicited probability distributions (Griffiths *et al.* 1987).

2.2 State-contingent production

The stochastic production function model is simple and yields some powerful insights. However, as a model of technology under uncertainty it is highly restrictive, and in some cases actively misleading. Furthermore, it is ill-suited to the application of modern production theory based on duality analysis.

Surprisingly, a more flexible model incorporating the stochastic production function as a special case has been available since the early 1950s: the state-contingent production model of Arrow (1953) and Debreu (1952). Chambers and Quiggin (2000) developed the properties of this model in detail, bringing to bear the tools of modern production theory, and particularly of duality.

The state-contingent approach has been taken up with particular enthusiasm by Australian agricultural economists. The result is a steadily growing literature encompassing theoretical analysis (Quiggin and Chambers 2006); empirical modelling (O'Donnell and Griffiths 2006; Chavas 2008; Nauges *et al.* 2011; Shankar 2013, 2015), efficiency analysis (O'Donnell *et al.* 2010; Shankar 2015); the value of forecast information (Crean *et al.* 2013, 2015); and policy analysis (Quiggin and Chambers 2004).

2.3 Drought policy

The drought that afflicted much of Eastern Australia in 1965 prompted much analytic work and policy analysis. At the level of individual farm managers, efforts to formalise analytic frameworks were made by many AARES members including Makeham *et al.* (1968). The EU framework was applied by Anderson and Hardaker (1973). The valuation of meteorological information for improved decision-making in the face of climatic risk was considered by Byerlee and Anderson (1969, 1982). Subsequent work on this topic included that of Marshall *et al.* (1996, 1997).

At broader policy levels, the topic of dealing with drought was subject to intensive analysis through the Report on Rural Incomes Fluctuations by the Industries Assistance Commission (1978). Contributions from AARES members included Freebairn (1983) and Alaouze (1991). Insurance-type mechanisms were a particular focus of debate (Bardsley *et al.* 1984; Bardsley 1986; Quiggin 1986; Quiggin *et al.* 1993).

The National Drought Policy, introduced in 1992, was based on the recognition that drought was a part of the natural cycle, for which farmers should plan, rather than a natural disaster requiring an emergency response.

This idea is naturally represented in state-contingent terms (Quiggin and Chambers 2004).

However, the severity of the Millennium Drought of the early 21st century produced a partial reversion to older policy approaches under the banner of 'Exceptional Circumstances'. Increasing evidence that climate change will lead to more frequent and severe droughts in Australia, and may already be having this effect, has further complicated the issue (Adamson *et al*. 2009).

3. Price uncertainty and price stabilisation

For much of the postwar era, Australian governments made energetic, and to some extent successful, attempts to stabilise and, if possible, increase, the prices received by farmers for agricultural commodities. The most notable single measure was the *Wheat Industry Stabilisation Act 1948* which created the Australian Wheat Board, with powers of compulsory acquisition. By the 1960s, most of the Australian agricultural sector was subject to some form of stabilisation. Wool was a relative latecomer, with the establishment in 1973 of the Australian Wool Commission, operating a buffer stock system. The inherent difficulties of managing the supply of cattle ensured that ideas of extending stabilisation to the beef industry went nowhere (Bureau of Agricultural Economics 1978).

By the late 1970s, the general anti-interventionist shift in economic thinking led to a gradual winding down of stabilisation schemes. Stabilisation was replaced by underwriting and then abandoned altogether. The process was accelerated by the spectacular collapse of the wool industry scheme in 1991, leaving a stockpile which took years to clear.

Much of the academic literature, influenced by the work of Waugh (1944), Oi (1961) and Samuelson (1972) in the USA, focused on the question of whether buffer stock stabilisation could be beneficial. The era of 'stabilisation economics' in AARES drew on these contributions, and also generated an arcane debate on the existence or otherwise of 'hidden gains and losses' (Gruen 1964; Campbell *et al*. 1980; Haszler and Curran 1982; Richardson 1982).

AARES economists were generally critical of stabilisation (McKay 1965; Longworth 1967; Longworth and Knopke 1982; Bardsley and Cashin 1990). However, Quiggin and Anderson (1979, 1981), drawing on the work of Sandmo (1971) and others, argued that risk-reducing stabilisation, based on the buffer fund principle, could be beneficial.

As stabilisation fell out of favour, attention turned to the use of futures markets for producer hedging (Gruen 1960; Goss 1980; Bond *et al*. 1985; Fraser 1997; Simmons and Rambaldi 1997) and to the use of private storage to manage uncertainty (Omura and West 2015).

4. Global and resource policy issues

With the end of the stabilisation era and the development of the National Drought Policy in 1992, the focus of the Australian policy debate turned away from attempts to reduce the risks associated with agricultural production and agricultural markets and towards risks concerning food security and resource management.

4.1 Food security

Famines and especially analysis of them by such insightful analysts as Sen (1981) led to increasing attention to this dimension of risk and uncertainty by Australian economists such as Ravallion (1987). Risk management issues associated with food insecurity have been tackled on something of a piecemeal basis, with occasional forays, such as by Anderson and Roumasset (1996), and Warr (2014). The theme became a more mainstream concern with the advent of the food price crisis of 2007 and 2008, which prompted some AARES members to conduct critical analyses among a rapidly emerging literature (Ivanic and Martin 2008). Some of them pointedly identified how it might also be helpful in policy dialogue with exporting countries (such as both China and India among the countries represented in this study) to discourage 'beggar thy neighbour' export restrictions in times of spiking food prices (Martin and Anderson 2011). Others, notably Australia's Brian Wright, have provided insightful analysis of the economics of storage options (Wright 2011).

4.2 Climate change and water

From the 1990s onwards, attention in agricultural policy was turned, increasingly, towards the interactions between agriculture and the environment. The most significant issues were water policy and climate change, both of which were dominated by risk and uncertainty. The two issues are closely interrelated, since the most damaging likely impact of climate change on Australian agriculture is a reduction in inflows to the Murray Darling Basin (Garnaut 2008).

A number of authors have considered the relationship between uncertainty in inflows to river systems and the design of property rights structures for irrigation. Approaches have included capacity sharing (Dudley 1992), and state-contingent modelling of water rights (Freebairn and Quiggin 2006). Grafton *et al*. (2014) discuss the risk management benefits that can arise from water trading.

A variety of analytical approaches have been used to address problems of uncertainty and climate change. Kingwell and Farré (2009) use a state-contingent model to analyse investment in farm machinery in the presence of climate change. Adamson *et al*. (2009), also using a state-contingent approach, model the impact of more frequent droughts on irrigated agriculture. Sanderson *et al*. (2015) applied real options theory to the analysis of Australian wheat production under climate change.

5. Stochastic programming and simulation models

With growing awareness of the importance of risk comes the necessity of developing methods that are able to represent those risks and model farmer responses. The emerging availability of mainframe computers in the 1950s and 1960s gave economists the tools to apply these methods in diverse agricultural applications (Dent and Anderson 1971; Anderson 1975).

Perhaps the most important applied methods developed are various types of mathematical programming methods and stochastic simulation models. These methods became increasingly accessible to the profession with the growing digital computing capacity available to members of AARES (Trebeck and Hardaker 1972; Hardaker *et al*. 1991; Kingwell *et al*. 1993; Kingwell 1994).

Doug Cocks, an early editor of AuJAE, pioneered one strand of analysis capturing uncertainty in farm programming models (Cocks 1968) through introducing risk in multistage discrete stochastic programming. This approach was advanced by Rae (1971), in what Hardaker *et al*. (2015) describe as embedded risk programming. Hardaker and Troncoso (1979) brought EU theory to bear on linear risk programming, as did Kennedy *et al*. (1994) to dynamic programming. Other efforts to develop methods of modifying the objective function that did not imply either a quadratic preference function or a mean–variance equivalent preference system included Parton (1979), Drynan (1985) and Batterham (1985).

Another early application of digital stochastic simulation methods to agricultural economics problems came out of the University of Queensland (Cassidy *et al*. 1970). In farm management applications, Mill and Longworth (1975) and Chapman and Anderson (1982) attempted to refine practical risk-analytic methods.

The development of state-contingent production theory showed that there was no inherent need for special methods to deal with the stochastic case. Production under uncertainty can be treated as a particular kind of multi-output technology, with goods differentiated by the state of nature in which they are produced. This approach has the advantage that the duality techniques long used in deterministic programming models can be applied directly to the stochastic case (Chambers and Quiggin 2000). State-contingent programming models have been applied to the analysis of water policy in the Murray Darling Basin (Adamson *et al*. 2007, 2009).

6. The role of decision theory in agriculture

The development of decision theory (Luce and Raiffa 1957), based on the subjective EU theory of von Neumann and Morgenstern (1944), was picked up rapidly by agricultural economists in the United States, notably by students of Earl Heady at Iowa State University (and Glen Johnson at Michigan State University). Transmission to Australia soon followed, most notably through the work of John Dillon, following up his PhD work under Heady (Dillon and Heady 1958; Dillon 1962; Officer *et al*. 1967; Makeham *et al*. 1968).

Some of Dillon's students made pioneering efforts to apply the decision-analytic concepts of subjective probability and elicited utility functions to diverse situations in Australia's risky agriculture (McArthur and Dillon 1971; Trebeck and Dillon 1971). This stream of work culminated in *Agricultural Decision Analysis* (Anderson *et al*. 1977), a book widely photocopied in US graduate schools after it went out of print around 1979.

Many of the applications at farm level pertain to decisions about adopting novel farm practices, such as fodder conservation, or of new technologies, such as inorganic fertilisers in developing countries. Farmer risk aversion and risk perception may be an important consideration in such decisions (Lindner and Gibbs 1990; Norris and Kramer 1990; Pannell and Nordblom 1998; Pannell *et al*. 2000).

6.1 Stochastic efficiency analysis

Given the many challenges inherent in direct utility elicitation, it was natural for AARES members to attempt to exploit the concepts of stochastic efficiency and stochastic dominance emerging in the US economics profession. Hardaker and Tanago (1973) were the first to publish on this theme in AuJAE. FORTRAN programs for first, second and third degree stochastic dominance analyses were published in Anderson *et al*. (1977).

Effort continued through the 1980s to explore just how useful stochastic efficiency criteria could be in practice (Buccola and Subaei 1984; Bailey and Boisvert 1989; McDonald *et al*. 1997). Over time, the analytical focus shifted to stochastic efficiency with respect to a function (Meyer *et al*. 2009). In this approach, alternative risky prospects are compared in terms of their certainty equivalents for a plausible range of risk aversion.

6.2 Issues around eliciting preferences

A critical requirement for the application of EU is the specification of a utility function over outcomes. Work on this topic began with joint research by Owen McCarthy (a student of Earl Heady) and his own student, Jock Anderson (McCarthy and Anderson 1966). Further work along these lines included that of Francisco and Anderson (1972), Hamal and Anderson (1982) and Bond and Wonder (1980). Some analysts approached risk preference estimation using econometric methods (Bardsley and Harris 1987).

Attempts to elicit preferences from decisionmakers led to the discovery that the consistency requirements of EU theory are not, in general, satisfied by decisionmakers.

Officer and Halter (1968) compared three methods of eliciting utility functions. They found that the 'von Neumann Morgenstern' method, which relied critically on the assumption that probabilities are linear in preferences performed very badly, concluding

> The N-M model gave the worst results of all the methods. This suggests the subjects had difficulty in correctly using probabilities, even though the probabilities were expressed as frequencies in this study.

Officer and Halter resolved the problem by using only comparisons between 50–50 gambles, and avoiding comparisons between risky gambles and fixed payments. This 'equally likely certainty equivalent' approach, which was refined by Anderson *et al.* (1977), was well in advance of the field at the time.

After these early contributions, the elicitation of preferences has played only a relatively minor role in the Australian agricultural economics literature. However, Nauges *et al.* (2015) use an innovative approach exploiting survey data on farmers' willingness to pay for irrigation water as a risk management tool.

6.3 Alternatives to EU theory

Australian agricultural economists were enthusiastic early adopters of EU theory. They were therefore among the first to encounter some of the difficulties raised by EU and to develop responses to those difficulties, including generalised EU models.

Quiggin (1981) drew on the work of Officer and Halter (1968) and data collected by Bond and Wonder (1980) to propose a generalisation of EU theory, then called 'anticipated utility theory' and now called 'rank dependent utility' (RDU) which allows for probability weighting. The approach used by Quiggin (1981) was later incorporated into the cumulative prospect theory of Tversky and Kahneman (1992), for which Kahneman received the Nobel Prize in Economics and Tversky a rare posthumous mention.

Quiggin (1991) showed that much of the EU theory of decision under uncertainty is unchanged when decisionmakers' behaviour is described by RDU models. Furthermore, awareness of the problem of probability weighting can assist in the elicitation of utility functions, for example using the equally likely certainty equivalent approach. So, in important respects, the development of generalised models such as RDU represented a successful response to the problems observed with EU.

The problems with probabilities observed by Officer and Halter may also be interpreted as support for the criticism put forward by Ellsberg (1961) who suggested that, in the presence of ambiguous information, it may be impossible to represent beliefs in terms of precise probabilities. A large literature on ambiguity developed from the 1990s onwards. Randall (2015) applies the idea of ambiguity to the problem of managing an ecosystem with unknown damage thresholds.

More recent developments in the theory of choice under uncertainty have focused on the problems of unawareness and 'unknown unknowns', returning to themes raised in the critique by Wright (1983). The rapidly growing theoretical literature on unawareness (Schipper 2015 provides a bibliography) is challenging for nonspecialists. However, consideration of unawareness will have important implications for agricultural and resource economists.

An example is the formulation of the, Precautionary Principle (discussed by Peterson 2006) in terms of 'burden of proof'. Grant and Quiggin (2013) show that, in interactive decisions involving unawareness, such as environmental hazard assessment of proposed developments, the Precautionary Principle will often yield results superior to those of a naïve version of Bayesian decision theory.

7. Conclusion

The concerns of the Australian agricultural economics profession have changed radically since the Australian Agricultural Economics Society was founded 60 years ago, a change reflected in part by the Society's change of name to include resource economics. Doubtless the next 60 years will see more changes, the nature of which cannot be foreseen with any precision. The only thing that can be said with any certainty is that uncertainty and risk will continue to play a prominent role.

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