Australasian Agribusiness Review
2022, Volume 30, Paper 6
ISSN: 1883-5675

The ABARES Approach to Forecasting Agricultural Commodity Markets – Description and Design Choices[1]

Rohan Nelson[†‡], Andrew Cameron[†], Charley Xia[†] and Peter Gooday[†]

† Australian Bureau of Agricultural and Resource Economics and Sciences

‡ Corresponding author, 7 London Circuit Canberra ACT 2601, rohan.nelson@agriculture.gov.au, 0455 023 094

Abstract

This paper describes the approach that has been used by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) to produce quarterly forecasts since 1948 for Australia's most important agricultural commodity markets. The Australian Agricultural Forecasting System (AAFS) is comprised of a database, a group of loosely-coupled commodity-specific balance sheets and a system for publishing forecasts. AAFS has evolved from decades of design choices that have revolved around the competing methodological merits of balance sheets and structural models. Balance sheets have emerged as the preferred method because they provide an efficient means of forecasting in their own right, as well as a means of incorporating insights from other forecasting methods and expert judgement. An issue for ABARES has been that the systems attributes of AAFS have at times gone unrecognised and proven to be incompatible with conventional approaches to management. Recognising the systems characteristics of AAFS has allowed the transfer of management principles from a range of literatures that study complex systems.

Key words: Agriculture, forecasting systems, commodity markets, balance sheets, managing systems

Introduction

The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) has published quarterly forecasts for Australia's agricultural commodity markets since 1948. The ABARES system for producing agricultural forecasts – along with its systems for conducting and analysing farm surveys – is a core capability of the Bureau[2] that has evolved alongside the agricultural economics profession in Australia. Despite this depth of institutionalisation and constant use over more than seven decades, ABARES' approach to producing agricultural market forecasts has never been publicly described, and the design choices shaping its forecasting methodology have not been peer reviewed. This has limited

---

[1] The authors acknowledge our colleagues in ABARES and across the agricultural economics profession who have contributed to the development of ABARES' forecasting system over the decades since 1945.

[2] The term 'Bureau' is used to refer to ABARES (2010 - present) and its predecessor organisations the Bureau of Agricultural Economics (BAE, 1945 - 1987) and the Australian Bureau of Agricultural and Resource Economics (ABARE, 1987 - 2010).

clarity outside ABARES as to what methods are used to produce forecasts, and reduced clarity within ABARES over how best to manage and develop the underlying forecasting system. This paper summarises an institutional analysis and redesign of ABARES agricultural forecasting system conducted between 2017 and 2022. The goal was to review the purpose of ABARES forecasts, describe the forecasting system in detail and critically review past design choices to ensure that it remains fit-for-purpose.

Documenting Forecasting Systems

The methodologies used by public sector agencies such as ABARES to produce agricultural commodity market forecasts are rarely documented in detail. Exceptions include a description of the approach to forecasting used by the United States Department of Agriculture (USDA) (Vogel and Bange, 1999) and an institutional review of that forecasting system by CFARE (2013). The Organisation for Economic Cooperation and Development (OECD) also provides a description of its forecasting process with each annual 'policy baseline' for agricultural markets (OECD/FAO, 2021) and has documented the underlying partial equilibrium modelling system (OECD and FAO, 2015). Meyers *et al.* (2010) comprehensively documented a similar model-based system for medium term forecasting developed by the Food and Policy Research Institute (FAPRI) at the University of Missouri. The Food and Agriculture Organisation of the United Nations (FAO) provides comprehensive documentation for its food balance sheets but uses these to track trends in food consumption rather than for forecasting prices (FAO, 2017). It would be uncharitable to list the agencies similar to ABARES who have not yet documented their forecasting systems – but it is sufficient to say here that a review of the literature and websites reveals that it is 'most of them'. ABARES approach to forecasting has previously only been partially described at earlier stages of its evolution by Freebairn (1975) and Sheales (1993).

There are compelling reasons why most systems of this kind go undocumented, sometimes for decades. Documenting any modelling system is costly and difficult to do, and rarely prioritised over more immediate operational tasks (Holzworth *et al.,* 2018). Model documentation is usually considered an input to modelling systems rather than an output (Holzworth *et al.,* 2015). Constant revision can mean that operating manuals are perpetually incomplete and out of date (Meyers *et al.,* 2010). A self-criticism of the authors is that economists developing agricultural forecasting systems within public sector agencies are often under less pressure to publish than their academic counterparts and have a guaranteed policy audience for whatever they produce, reducing the motivation to produce documentation concerning underlying processes.

The difficulties and cost involved mean that it is rare for modelling systems in any field to be documented. However, it has long been recognised that documentation of system design is a foundational element of good practice in the development of information systems in general (Davenport and Prusak, 1997). This has long been established as a basic requirement in the development and application of the agricultural systems models that provide production forecasts for agricultural commodity market forecasting systems (Keating and McCown, 2001; Keating and Thorburn, 2018). Documentation is necessary for peer review, and peer review remains the global standard for establishing the quality of any modelling system. Peer review is also routinely used to validate models used to support policy and regulation in agricultural (NZPCE, 2018) and environmental applications (USEPA, 2009). Critical review by independent experts provides confidence that model outputs such as forecasts can be relied on for policy development, regulation and decision making.

AAFS is routinely applied to generate forecasts used by Australian governments to monitor the progress of Australia's agricultural sector (see for example Littleproud (2021)), and it would seem appropriate for it to comply with these global quality standards. Documentation reveals underlying methods and assumptions to the potential users of agricultural forecasts, enabling them to appropriately interpret forecasts and judge their reliability (Irwin *et al.,* 2015; Schnepf, 2017). For policy and management applications, Green and Armstrong (2015) argued that decision makers should only rely on forecasts for which they can understand the method, embodied knowledge, key relationships and implications for alternative courses of action. This requires system developers to not just document the technical content of forecasting models, but to also describe how they can be used to support decision making.

Documentation also generates important internal benefits for the development and maintenance of reliable and efficient forecasting systems. Peer review provides developers with independent expert benchmarks for prioritising methodological development. Peer review can help the developers of forecasting systems to assess which aspects of the capability demanded by forecast users can be developed to appropriate standards at reasonable cost. Further, documentation supports collaboration with experts in forecasting institutions using similar methodologies around the world. It also facilitates transfers of more general knowledge and practice from other fields developing similar types of information and modelling systems.

Within ABARES, the process of documenting AAFS has been providing a foundation for training and facilitating collaboration between the dozen or so individual forecasters who operate its various commodity modules. Documentation has helped to distil – and make accessible – tacit knowledge that has been accumulated by experts over many years. This facilitates the training of new forecasters and enables the mobility of forecasters between commodities. Documentation accelerates learning for inexperienced forecasters who tend to learn the mechanics of forecasting before fully understanding the method they are using or its limitations.

The Australian Agricultural Forecasting System

The Australian Agricultural Forecasting System was recently described in detail in an ABARES technical report by Nelson *et al.* (2022), and so only a summary is provided here. AAFS is comprised of a database, a group of loosely-coupled commodity-specific balance sheets and a system for publishing forecasts. The design of AAFS has changed over time with evolving demand for forecasting services.

The changing objectives of AAFS

The design of any agricultural forecasting system is contingent on the objectives that it is designed to meet (Allen, 1994). The evolving demand for the forecasting services generated using AAFS since 1948 was comprehensively reviewed in a companion journal by Nelson (2018). Agricultural market forecasts have always had public good characteristics (Freebairn, 1978a), but these have changed over time. The development of AAFS was initiated in the 1940s to support the equitable function of markets and industry development. Contrary to popular sentiment, support for on-farm decision-making was never the primary goal of ABARES forecasts, and the earliest market studies were designed to evaluate soldier settlement schemes proposed by state governments. Soldiers returning from World War II were often resettled on small farms created by government schemes, the economic viability of which was subject to intense public scrutiny following the failure of similar schemes after World War I.

Following World War II, market forecasts were part of the market information necessary to administer statutory marketing schemes – a protection measure designed to provide a ‘living wage’ for small farmers in a policy environment deeply concerned about the potential abuse of market power by traders and retailers. Price support schemes could create significant government budget obligations if export prices fell. When the Australian Wool Reserve Price Scheme was terminated in 1991, for example, it left a 4.6 million bale stockpile and government debt of A$2.4 billion (Abbott & Merrett, 2019).

Following global market reforms during the 1990s, policy demand for the Bureau's forecasting services refocused on the competitiveness of Australian agriculture in world markets. Globalisation reduced the demand for public-sector forecasting services within vertically integrated value chains, but intensified demand from businesses operating outside them – with concerns over market power persisting in both cases. This means that in 2022 the forecasts produced using AAFS continue to provide a base level of education that helps ensure fair trading and the smooth operation of agricultural markets, noted as a key objective by Freebairn (1975). The spread of information and communication technologies since the 1990s has also facilitated the evolution of a thriving commercial forecasting sector meeting the demand for forecasts tailored to specific business applications. Commercial forecasts are complementary to - and often dependent on – public-sector market information and forecasts (Just and Zilberman, 2002). In terms of policy demand, the forecasts produced using AAFS remain one of the only independent means of analysing scenarios of public interest for Australia's agricultural sector, such as the market impacts of threats posed by the COVID-19 pandemic or trade disputes (Cameron *et al.,* 2021).

In the 2020s, a key design objective of AAFS is to meet policy demand for coherent and reliable forecasts of agricultural production and exports for Australia's agricultural sector. An historic policy focus on forecasting the performance of the sector as a whole (Lewis, 1949) has been intensified by a combined industry and government target of raising the value of agricultural production to A$100 billion by 2030 (NFF, 2020; SCAWR, 2020). Coherent forecasts of sector performance are challenging to achieve because each commodity varies in its contribution to production and exports, and in the quality and completeness of data available to produce forecasts. Beyond issues with data, the greatest challenge to achieving reliable forecasts remains Australia's highly variable climate (Nelson *et al.,* 2020). For example, data on domestic stocks of grain rarely limit forecasts, but can require additional forecasting effort in years of severe drought (Xia *et al.,* 2019). This is compounded by climate variability in other countries that affects the prices of Australia's agricultural exports. Deeply uncertain trade disputes, conflict and changes to market access are other features of world markets that continue to affect the choice of appropriate forecasting methods.

In global terms, an important distinguishing feature of AAFS is that it is not required to forecast government budget commitments imposed by complicated or large-scale farm support packages. This is a major objective of much larger public–sector agricultural forecasting systems maintained in Canada (AAFC, 2021), the United States (CFARE, 2013; Schnepf, 2017) and Europe (EC, 2020; OECD/FAO, 2021). Australia's lower farm support means that AAFS does not need to be resourced to the same extent even though Australia has an industrialised agricultural sector making similar contributions to gross domestic product. Complicated farm support policies require the development of complicated information and forecasting systems to support them. For example, regulations designed to restrict supply and raise farmgate milk prices in Canada result in over 30 distinct regulatory categories of milk (CDC, 2021).

An emerging question is whether and to what extent ABARES should complement the forecasts produced using AAFS with foresighting services. The forecasting methods embedded in AAFS rely on extrapolating the recent operation of markets into the short-term future, which works well when markets are stable and reasonably predictable. In a rapidly changing world, predictive approaches to forecasting can lead to a preoccupation with 'what usually happens' under a range of familiar circumstances, distracting from less likely but potentially much larger disruptions (Miller, 2007). Scenario-based planning methods have evolved to provide more realistic decision support in situations characterised by deeper forms of uncertainty (Wack, 1985). Exposure to targeted scenarios can help decision makers identify unreliable assumptions and adjust mental models beyond the confines of past experience to better manage unexpected forms of change.

Data requirements

The data that ABARES requires for forecasting are determined by the commodity coverage of AAFS and the structure of the balance sheets within it. The commodity coverage of AAFS is determined by the main objective of ABARES forecasts, which is to forecast reliable estimates of the value of Australia's agricultural production and exports. It has changed significantly over time as the relative contribution of individual commodities to the value of production and exports has varied. Over the period 1979–80 to 2019–20 an evolving mixture drawn from 158 commodities was included at various times in the coverage of AAFS (see Nelson *et al.* (2022) Appendix D). The finite resources available for forecasting are preferentially allocated to the commodities that contribute most to the value of agricultural production and exports at each point in time. However, the need to calculate estimates of the total value of agricultural production for Australia means that ABARES has to create forecasts for many more commodities than are published with forecast narratives. For example, forecasts for 46 commodities were produced in 2020, mostly published only within aggregate statistics (see Nelson *et al.* (2022) Appendix B).

The coverage of production data is defined as all classes in Subdivision 01 (Agriculture) of Division A (Agriculture, Forestry and Fishing) of the Australian and New Zealand Standard Industrial Classification (ANZSIC) (ABS, 2006; ABS, 2013). The coverage of export forecasts does not follow the ANZSIC framework but is instead closely aligned with the product coverage of the World Trade Organisation Agreement on Agriculture (WTO, 1995). Small modifications are made to account for Australia's particular agricultural supply chains. In 2021 this covered around 2000 tariff lines across sixty-two commodity groups (see Nelson *et al.* (2022) Appendix C).

The primary source of historical data for AAFS is the Australian Bureau of Statistics (ABS). For data on past agricultural production in Australia the primary sources are the *Agricultural Commodities, Australia* (ABS, 2019) and *Livestock Products, Australia* (ABS, 2021*)* publications. These provide production volumes, planted area and animal numbers for most major agricultural commodities. Other sources of data are used in AAFS where they are deemed reliable and sufficiently accurate, sometimes as interim estimates before later being replaced with ABS statistics.

Much of the data used in AAFS comes from international sources. ABARES does not have the resources to collect its own global data, and instead relies heavily on the data published by much larger institutions around the world including the USDA, International Grains Council (IGC) and the FAO.

Balance sheet forecasting

The data used for each commodity within AAFS is determined by the structure of the balance sheets which collectively make up the system. These include past-year data for supply (opening stocks, production and imports), utilisation (consumption, exports and closing stocks) and prices (see Table 1). Balance sheet forecasting is based on accounting for stocks and flows of agricultural commodities, which has ancient origins and has been in continuous use since at least 3500 BC (Doğan *et al.,* 2013). The modern approach to forecasting agricultural markets using balance sheets coevolved alongside the development of modern agricultural statistical systems in the nineteenth century (Taylor, 1939). It was well-established by World War I (FAO, 2001) and has been in common use since its adoption as a global standard by the Food and Agriculture Organisation of the United Nations (FAO) in the 1940s (FAO, 1949).

Balance sheets continue to be the foundation of agricultural forecasting systems around the world such as those of the USDA (Vogel and Bange, 1999), the IGC (IGC, 2021) and the FAO (FAO, 2001; FAO, 2017). Balance sheets are also used for forecasting agricultural markets by smaller agencies with similar resources and capability to ABARES. Examples include the *Situation and Outlook for Primary Industries* publications of New Zealand's Ministry of Primary Industries (NZMPI, 2021) and the *Agri Market Outlooks* produced by the United Kingdom's Agriculture and Horticulture Development Board (AHDB, 2021). Other organisations use balance sheets to organise stock and flow data for agricultural commodities, but don't go the next step and use them to produce price forecasts. Examples include the *Quarterly Economic Overview – Agricultural Sector* produced by the Directorate of Statistics and Economic Analysis in the South African Government's Department of Agriculture, Land Reform and Rural Development (ALFRD, 2021), and the ASEAN Agricultural Commodity Outlook (AFSIS Secretariat, 2022).

Table 1. The structure of commodity balance sheets

	Supply (kt)					=	**Utilisation (kt)**					**Price**
Year	Opening stocks	+	Production	+	Imports	=	Consumption	+	Exports	+	Closing stocks	$/unit
2019	..		..		..		..		..		..	..
2020e	..		..		..		..		..		..	..
2021f	..		..		..		..		..		..	..

A step-by-step description of the process for constructing food balance sheets and using them to forecast food consumption was described by FAO (1949), and this methodology remains in use for analysing global trends in food insecurity (FAO, 2017). Ashby (1964) described the use of balance sheets to produce price forecasts in agricultural markets. Modern application to forecasting in agricultural commodity markets is similar to the step-by-step process outlined by Ashby, except that computing technology allows much more frequent iteration of forecasts. This facilitates scenario experimentation and progressive updating of forecasts as new information comes to hand during the forecasting cycle.

The application of balance sheet forecasting described by Ashby still describes the ideal method underpinning ABARES forecasts. The first step is to organise historical data and current-year estimates for supply, utilisation and price into balance sheets for the major importing and exporting countries that affect world prices. These historical data can then be used to analyse changes in price that have occurred in recent years to equate supply and utilisation. Ashby recognised that lags in data availability mean that the current year often has to be treated as a forecast year, with estimates progressively updated as data becomes available.

Forecasts are undertaken by initially assuming no change in price for the forecast year and forecasting each element of supply and utilisation for each country with sufficient trade to influence the world price (Ashby, 1964). The aggregate net balance of trade across all of these countries is then used to analyse how much the price is likely to have to rise or fall to equate utilisation with supply. Trends and shocks in the underlying drivers of supply and demand are taken into account when forecasting the market clearing price.

The procedures for predicting the impact of changes in the underlying drivers of supply (climate, input costs, profitability of competing land uses) and demand (population, incomes, preferences and the price of substitutes/complements) can involve a mix of qualitative and quantitative methods. For rapid forecasts of less important commodities with incomplete or low-quality data, expert judgement is often the most efficient method for producing a forecast that provides acceptable insights into future market conditions at reasonable cost. For detailed assessments of important commodities with adequate data, expert judgement is at times supported by quantitative methods such as time series analysis, econometric modelling and mathematical programming.

The forecasts that ABARES produces using AAFS are informed by analysis of the macroeconomic factors influencing demand for Australia's agricultural commodities in domestic and world markets. Forecasts of Australian and global production are supported by seasonal climate forecasts. These have been described in detail by Nelson *et al.* (2020) and Nelson *et al.* (2022).

Publishing forecasts

ABARES agricultural forecasts have been solely published via the ABARES website since 2018. The Agricultural Commodities publication is a registered journal and has been published quarterly in various forms since January 1948. It contains an overview and commodity notes — short articles describing forecasts for major commodities and commodity groups including beef, sheep meat, dairy, wheat, coarse grains and oilseeds (for details see Nelson *et al.* 2022). Cotton and wool forecasts are published together in a natural fibres note due to a shared focus on textile markets. Forecasts of crop production are published each quarter in the *Australian Crop Report.* ABARES produces forecasts for all elements of the balance sheet and indicator prices for each commodity. Forecasts published in March are for the next five July-June financial years. Forecasts published in June, September and December provide updates of forecasts for the next (June forecasts) or current (September and December forecasts) July-June financial year.

The National Outlook Conference has been a significant dissemination pathway for forecasts since 1971 (see Nelson *et al.* (2022) for a detailed history). Regional Outlook Conferences became an important dissemination mechanism for agricultural forecasts from the year 2000 onwards, with four to seven conferences held in regional centres each year, interrupted temporarily by the COVID-19 pandemic in 2020 and 2021.

System Performance

ABARES evaluates the performance of AAFS from three perspectives: the ability of the system to produce accurate forecasts; and the ability of the system to meet changing institutional objectives (see Nelson, 2018); and the value–in–use of its forecasts to diverse end-users (see Nelson *et al.* (2022) for details). This combined approach overcomes the resource-contingent limitations of using accuracy as the main quality parameter of forecasting systems. It may be possible to improve forecast accuracy but doing so may encounter diminishing returns to increased forecasting effort (Kingma *et al.,* 1980). Accuracy may also not be the most important factor limiting the value of forecasts for decision making (Cash *et al.,* 2002).

Forecast accuracy

Cameron (2021) published an online database enabling the accuracy of the Bureau's agricultural forecasts to be analysed for the years 2000-01 to 2018-19. A companion paper in this journal (Cameron and Nelson, 2022) describes this database and expands on reasons for its development. This database can be used to compare ABARES forecasts to the official estimates published by the ABS for around 100 forecast variables. Comparison to official estimates combines errors associated with forecasting as well as errors associated with ABS estimation methodologies. For some variables ABARES forecasts can only be compared to ABS estimates calculated for slightly different purposes using appropriate methodological assumptions. There is often lively debate about the accuracy of official statistics pertaining to agriculture, especially when trusted third-party data sources are available which appear to contradict the official estimates (McRobert *et al.,* 2019).

The accuracy of forecasts for the 100 variables covered by the database generally improves as lead times between forecasts and outcomes are reduced. Forecasts across all intervals exhibit a slight negative bias over the two decades 2000-01 to 2018-19, with 54 per cent of forecasts lower than observed, and 46 per cent higher. In a case study, the Bureau's forecasts achieved similar accuracy compared to other institutions such as the USDA who also forecast Australian wheat production and exports.

Medium-term (five-year) forecasts of the gross value of agricultural production are issued once each year in March. For the 20 years between 1999-00 and 2018-19, the gross value of production was underpredicted at a rate of 76 per cent over a total of 105 forecasts. However, the scale of underprediction was not particularly large, even for forecasts 5 years into the future. Average relative errors ranged from 7 per cent for the financial year ahead up to 9 per cent for 5 years ahead. Errors exceeded a 10 per cent threshold 25 per cent of the time.

Medium term forecasts of the value of agricultural exports tended to overpredict in the first decade (1999-00 to 2008-09) and underpredict in the second (2009-10 to 2018-19). Over the entire period, 65 of 105 issued forecasts undershot the actual outcome (a rate of 62 per cent). However, this result is skewed by the inclusion of more forecasts in the sample from the second decade where forecasts underpredicted the value of exports. Average relative errors over this period ranged from 8 per cent for the financial year ahead up to 12 per cent for 5 years ahead. Errors exceeded a 10 per cent threshold 43 per cent of the time.

Wheat and beef are the two commodities contributing most to the value of Australia's agricultural production and exports, and relative errors for components of these forecasts are shown in Table 2. Relative errors for ABARES forecasts of the overall value of crop production issued in March for the forthcoming July to June financial year averaged 10 per cent over the period 2000-01 to 2018-19. This fell only slightly to 9 per cent by the time forecasts were revised in September and to 8 per cent by December. Relative errors for forecasts of the value of livestock production averaged 8 per cent in March and fell to 4 per cent by December. Relative errors for forecasts of the value of crop exports were 11 per cent in March and fell to 5 per cent in December. For forecasts of the value of livestock exports relative errors fell from 10 per cent in March to 7 per cent in December.

The Design Choices Shaping AAFS and its Management

AAFS has been a surprisingly difficult forecasting system to characterise both by those developing it, and by external observers. Understanding the characteristics of AAFS is essential for interpreting and evaluating the forecasts produced using it, and for managing AAFS efficiently and effectively as a forecasting system. Here we consolidate and refine an earlier exploratory attempt, by Nelson *et al.* (2022), to gather some of these issues.

Table 2. The range of relative errors† for forecasts of wheat and beef, 2000–01 to 2018–19

Commodity	Series	Unit	March – for next FY	Jun - for next FY	Sep - for current FY	Dec - for current FY
Wheat	Price - APW Pool	$/t	15%	17%	8%	5%
Wheat	Price - ASW Pool	$/t	22%	16%	12%	7%
Wheat	Production	kt	21%	21%	11%	5%
Wheat - NSW	Production	kt	-	39%	18%	11%
Wheat - QLD	Production	kt	-	29%	15%	10%
Wheat - SA	Production	kt	-	28%	22%	7%
Wheat - VIC	Production	kt	-	36%	29%	9%
Wheat - WA	Production	kt	-	17%	13%	6%
Wheat	Harvested area	'000 ha	8%	7%	6%	6%
Wheat	Export volume	kt	23%	19%	13%	8%
Wheat	Export value (fob‡)	$ million	22%	19%	12%	9%
Beef	Saleyard price§	c/kg (cw¶)	10%	8%	5%	4%
Beef	Production	kt (cw)	6%	6%	4%	3%
Beef	Beef cattle herd	million head	5%	4%	3%	3%
Beef	Export volume	kt (sw††)	12%	10%	10%	7%
Beef	Export value (fob‡)	$ million	18%	16%	15%	11%

† Symmetrical mean absolute percentage error is $\frac{\textbf{\textit{Absolute value of}}: (\textbf{\textit{Forecast}} - \textbf{\textit{Actual}})}{(\textbf{\textit{Forecast}} + \textbf{\textit{Actual}}) \times \textbf{0.5}}$ and expressed as a percentage, see Hyndman and Koehler (2006). ‡ Free on board. § Weighted average saleyard price of cattle. ¶ Carcase weight. †† Shipped weight. *Source*: (Cameron, 2021)

Balance sheets vs structural models

The difficulties in characterising AAFS are partly due to a perpetual sense that market forecasting with balance sheets is overly simplistic, and that more sophisticated methods and models should be (or should eventually become) more accurate and efficient. The earliest market outlooks produced by the Bureau of Agricultural Economics (BAE) did not specify which methods were used, although early crop forecasts included FAO-style balance sheets (FAO, 1949; Campbell, 1950; BAE, 1952). We also know that BAE staff contributed to the establishment of the FAO and the systems it developed for monitoring global food security (Wood, 1948; Ashton, 1949).

In later decades, balance sheets were at times considered an inferior forecasting method, particularly during periods when more sophisticated methods were showing promise – especially partial equilibrium models. Sheales (1993) considered balance sheet models to be a transitionary forecasting tool in the Bureau while ‘large scale economic models’ were being developed. The development of increasingly powerful computers in the 1960s and 1970s led to global expectations that agricultural forecasting with sophisticated structural models was likely to eventually outperform simpler methods (Allen, 1994). In the BAE, aspirations to build detailed partial equilibrium models for forecasting Australia’s agricultural markets peaked in 1985 with the publication of the Econometric Model of Australian Broadacre Agriculture (EMABA) (Dewbre *et al.,* 1985). Computable general equilibrium models also have a long history of use in agriculture, mostly for exploring policy scenarios (Hertel, 2002) or longer-term trends in markets (see for example Linehan *et al.* (2013)).

The attraction of structural models is their ability to explicitly represent demand and supply equations with own- and cross-price elasticities. Accounting for cross-commodity interactions has long been recognised as the principal weakness of balance sheet forecasting (Freebairn, 1978b). These interactions can be mathematically represented in structural models in ways that are at least transparent to other experts within forecasting teams, even if this is usually less transparent to forecast users. In contrast, balance sheets in their most basic form only represent the annual supply and utilisation of individual commodities. This means that forecasting systems like AAFS that are built from aggregations of individual balance sheets do not automatically evolve mechanisms for explicitly representing cross-commodity interactions (Freebairn, 1975). This is exacerbated by the natural evolution and maintenance of agricultural forecasting systems from the bottom up, with analysts often working independently to develop forecasting methods for individual commodities (Allen, 1994).

Incorporating cross-commodity interactions within systems of balance sheets involves building systematic interactions, between the individual forecasters who operate related balance sheets, and assigning clear responsibilities for making sure these interactions are consistently implemented. In balance sheet forecasting systems, social processes between team members replace mathematical relationships and constraints in structural models.

This locates agricultural commodity market forecasting in a boundary zone between soft- and hard–systems methodologies (see Checkland (2000) for a detailed exposition). From a 'hard'-systems perspective, agricultural forecasting is a reductionist problem with well-defined goals and mathematically optimisable solutions. This involves applying a deductive approach to inference. From a 'soft'-systems perspective, the human dimension is inseparable from the forecasting process due to data limitations and constantly changing market circumstances that alter forecasting objectives, causal relationships and the optimum mix of methods. This mode of inference is known as 'retroduction', in which events are explained by postulating the mechanisms capable of producing them (Downward & Mearman, 2007). Two completely different sets of skills and aptitudes are required to implement these two approaches, which in ABARES' experience has at times created cross-cultural tensions, low productivity and high turnover arising from the misallocation of staff to roles incompatible with their preferred mode of working. Similar incompatibilities were noted by Allen (1994).

Experimentation aimed at replacing the softer human dimensions of distributed balance sheets with more mechanistic structural models proved unsuccessful – especially for short-term (1 year) market forecasting. Structural models proved expensive to build and maintain and did not significantly improve the accuracy of short-term forecasts. Econometric models struggled to represent the frequent climate-induced supply shocks that drive variability in agricultural markets and keeping them up-to-date during periods of rapid change proved impractical (Allen, 1994). As a result, forecasting institutions have often had to maintain duplicative systems, and this was ABARES' experience in the early 2000s. Balance sheets were maintained to overcome the short–term disadvantages of structural models for short–term price forecasting, while structural models were used to account for longer-term cross-commodity interactions. This is very similar to the forecasting approach used by OECD, in which the Aglink-Cosimo model is 'used to ensure the consistency of baseline projections' while prices are forecast separately (OECD/FAO, 2021, p. 243). Another source of inefficiency is that the mathematical requirement for structural models to be complete in order to solve across all commodities led to the allocation of disproportionate effort to minor commodities with the least complete data.

The result is that structural models are yet to meet the forecasting aspirations once held for them. Allen (1994, p 97) found that, at the height of their development for agricultural market forecasting, structural models were only more accurate in 10 out of 38 comparisons relative to less sophisticated forecasting approaches. Of 60 agricultural models identified in 1994, most were used experimentally and then discarded. More recently, across broader business applications, Green and Armstrong (2015) found 32 papers comparing the accuracy of 97 sophisticated econometric models relative to simpler forecasting methods. In 81 per cent of these comparisons the simpler methods were equally or more accurate than the sophisticated econometric methods to which they were compared. For 25 papers providing quantitative estimates, the errors generated by econometric models were on average 27 per cent greater than those generated using simpler forecasting methods.

Structural models have proved much more useful for analysing long-term policy scenarios in institutions such as the OECD (OECD/FAO, 2021). The Food and Policy Research Institute at the University of Missouri was established to build and maintain structural models to analyse the long-term impacts of changes in United States government farm support policies to complement the short-term market forecasts produced by the USDA (Meyers *et al.,* 2010). ABARES continues to use structural models for similar long-term scenarios in trade policy in which accounting for short-term market fluctuations is less essential (see for example Cao and Greenville (2020)).

Looking back on the history of their co-development, balance sheets and structural models tend to emerge as complementary rather than competing approaches to agricultural market forecasting. Structural models played a crucial role in enabling the development of medium-term forecasting methodologies during the 1980s. Structural modelling depended on the development of coherent datasets for all major commodities, both historic and for the projection period. They also required cross-commodity interactions to be distilled from abstract economic concepts into model code, forcing a more explicit approach to their derivation and application. The coevolution of medium-term forecasts and the EMABA model in the BAE (Dewbre *et al.,* 1985) indicates that structural modelling was a critical antecedent and enabler of medium-term forecasting in ABARES. An open question for the future is whether methodological breakthroughs will make it easier to adapt structural models to new applications. There is also a need to develop models that can produce scenarios that are not constrained by the past structure of the agricultural sector - a requirement that has been challenging to meet with most existing approaches to general and partial equilibrium modelling.

Reframing the role of balance sheets

Another insight from the development of agricultural commodity forecasting systems in ABARES and elsewhere is that balance sheets are as much an enabler of all other forecasting methodologies as they are a simple forecasting methodology in their own right. Balance sheets provide agricultural forecasters with three essential capabilities. They are the simplest and lowest cost method for forecasting individual commodity markets (Ashby, 1964), they provide a means of combining forecasts produced using other methods (Green and Armstrong, 2015), and they enable expert judgement to be incorporated into forecasts (Bunn and Wright, 1991). Part of the intuitive appeal of balance sheets is that they represent annual stocks and flows of commodities into and out of a country or region. This makes them computational analogues – a mathematical representation of an observable physical process – in this case flows of commodities through economies (Laing, 1981). The close conceptual proximity of balance sheets to physical flows reduces the weight of assumptions users need to process in order to understand the forecasts generated using them (Green and Armstrong, 2015).

Combining forecasts generated using different methods is one of the most important capabilities provided by balance sheets because it allows the most efficient combination of methods to be used for each application. Separate methods can be used for each commodity as well as for each component of supply and utilisation based on their relative importance, data availability and the resources (including the skill of forecasters) available for forecasting. These methods can range from the most sophisticated time series or structural models through to the most cursory applications of expert judgement. This flexibility makes balance sheets an efficient tool for building robust agricultural forecasting systems in increasingly resource-constrained public sector forecasting institutions (Nelson, 2018).

A significant advantage of balance sheet forecasting systems is that they enable forecasters to triangulate around incomplete sources of data, giving structure to the application of expert judgment. Triangulation is a term taken from navigation in which a third unknown point is located from two known points. It has long been applied to comparing alternative data sources, methods, models, and analytical perspectives in the social sciences (Denzin, 1970), but its use in economics, while ubiquitous, has sometimes been perceived as insufficiently quantitative and less than rigorous (Downward and Mearman, 2007). A common use of triangulation in agricultural commodity forecasting is to overcome the problems associated with incomplete data. A constraint on any planning system is that knowledge is always incomplete (Hayek, 1945), and some methods of forecasting in agricultural markets are better able to cope with this than others (Allen, 1994). Aspirations in the 1970s and 1980s for increasing reliance on structural models for forecasting in agricultural markets were partly contingent on the evolution of improved agricultural data (Freebairn, 1975). However, agricultural data systems never quite reached the completeness and quality required and have started to degrade in recent decades as the relative contribution of agriculture to the economy has reduced public sector investment in data collection (Potard and Keogh, 2013; ABS-ABARES, 2015; McRobert *et al.,* 2019). Balance sheets offer a rare practical methodology for triangulating between alternative information sources when there is insufficient data to explicitly estimate causal relationships.

Managing the systems characteristics of AAFS

AAFS has many of the definitive properties of a complex system, but this has not always been recognised and managed effectively throughout its development. Recognising the systems characteristics of AAFS helps to distil principles for managing it as a system into the future. This is especially a problem because the mechanics of operating and overseeing a distributed system of balance sheets can be highly complicated. ABARES has experienced periods when the systems characteristics of AAFS have not been adequately recognised or appropriately managed. This remains an ongoing risk to the future operation of AAFS. A particular trigger for this has been a temptation to default to hierarchical forms of team management, usually implemented via the process used to review forecast narratives. The quality of forecast narratives is important, but feedback on them has only limited impact on the causes of incoherence or error buried deep within the balance sheets used to generate forecasts. Focusing on the symptoms rather than the causes of forecast errors has at times led to the accumulation of systemic methodological issues that subsequently take considerable effort to resolve.

AAFS is a forecasting system made up of loosely-connected commodity balance sheets, each of which is a unique sub-system with significant commodity-specific detail. Non-linear relationships between the components of supply and utilisation within each balance sheet, and in the cross-commodity relationships between balance sheets, result in a high degree of emergence. This means that the performance of the AAFS as a system cannot be fully understood or managed by analysing its component balance sheets independently. System-wide governance is required because the commodity sub-systems both influence, and are influenced by, the operation of the whole system to meet its overarching goal of producing coherent forecasts for Australia's agricultural sector.

Recognising the systems characteristics of AAFS allows the transfer of management principles from a range of literatures that study complex systems. Best practice management for this type of forecasting system is to set clear system-wide direction and create a devolved and adaptive learning environment with lots of feedback loops that supports a high degree of self-organisation (Ahern *et al.,* 2014). Command and control styles of management are all but precluded by the complexity of, and interactions between, AAFS commodity sub-systems. Centralised uniformity can also stifle the innovative contributions of multiple participants who would otherwise bring different perspectives, expertise and knowledge to the forecasting process (Easterbrook *et al.,* 1994; Felder and Collopy, 2012). Cooperative development is essential to support self-organisation and can be facilitated by increasing the interoperability between sub-systems (Benedict, 2018). Interoperability is facilitated by feedback loops that communicate the contribution of each sub-system to system-wide goals (Ellis and Herbert, 2011). In-depth and actionable feedback enables each sub-system to continually improve its contribution to system-wide goals (Holland, 2006; Felder and Collopy, 2012).

ABARES has translated these principles into a number of practical strategies for managing the systems characteristics of AAFS:

1. Continually restate the purpose of forecasts. Unifying goals for the whole forecasting system provide those managing the component balance sheets with a common purpose.
2. Document the roles and responsibilities involved in the forecasting process. This supports 'interoperability' by ensuring that everyone involved understands what they need to do, when they need to do it, and how it relates to the roles of others. This also helps reduce the risk of losing essential tacitly-defined functions when there are staff changes.
3. Identify and allocate responsibility for important cross-commodity interactions and include these in role descriptions. Create process checks that provide feedback to ensure that cross-commodity interactions are considered, and that the outcomes are valid.
4. Document the sequence of steps involved in the forecasting process and their timing. This helps all involved understand when each process needs to be completed and is especially important for coordinating and checking cross-commodity interactions because these lie outside individual commodity responsibilities.
5. Provide structured training. ABARES has developed a structured training course to support the rapid development and self-organisation of new analysts. Training provides a sense of agency over the forecasting process, supports innovation and raises awareness of less tangible factors like cross-commodity interactions.
6. Document the system and its processes to facilitate training of new starters and the reallocation of existing staff to new roles, setting methodological development priorities and supporting collaboration with other forecasting institutions.
7. Regularly review the forecasting process and its components to provide the kinds of in-depth and actionable feedback necessary to maintain and develop the forecasting system.

Conclusions

The Australian Agricultural Forecasting System is a loosely coupled system of balance sheets enabling diverse methodologies to be used to forecast prices and the supply and utilisation of Australia's most valuable agricultural commodities. It is a soft-systems modelling environment in which the analytical capability of those who operate it is enabled by an accounting technology that has been in use for thousands of years. The core balance sheet technology enables, rather than competes with, the application of all other forecasting methods, including expert judgement as well as sophisticated quantitative approaches. AAFS is the product of a robust evolutionary process which experimented with, and drew design characteristics from, more sophisticated modelling approaches. The principal driving force behind this evolutionary process has been a quest for institutional efficiency. The efficiency of balance sheet forecasting derives from its flexibility to triangulate around fragmented data sources, and its ability to entrain the analytical advantages of all other forecasting methodologies. This has enabled the Australian Agricultural Forecasting System and its precursors to maintain institutional alignment over a period of dramatic change in technology, and changes in the relative importance of agriculture in the Australian economy. Practical strategies have evolved to manage AAFS systems attributes so that it can be used to provide efficient forecasting services into the future.

References

AAFC (2021), *Evaluation of the Market Information Program (2014 to 2019)*. Agriculture and Agri-Food Canada, Ottawa.

Abbott, M. & Merrett, D. (2019), 'Counting the cost: the reserve price scheme for wool 1970-2001', *Australian Journal of Agricultural and Resource Economics*, 63, 4, 790-813.

ABS-ABARES (2015), *National Agricultural Statistics Review*, Cat. No. 7105.0 55.004. Australian Bureau of Statistics and the Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

ABS (2006), *Australian and New Zealand Standard Industrial Classification (ANSZSIC) 2006*, Cat. No. 1292.0. Australian Bureau of Statistics, Canberra.

ABS (2013), *Australian and New Zealand Standard Industrial Classification (ANSZSIC) 2006*, Revision 2.0., *Cat. No. 1292.0*. Australian Bureau of Statistics, Canberra.

ABS (2019), *Agricultural Commodities, Australia, 2017-18*, Cat. No. 7121.0. Australian Bureau of Statistics, Canberra.

ABS (2021), *Livestock Products, Australia*, Cat. No. 7215.0. Australian Bureau of Statistics, Canberra.

AFSIS Secretariat (2022), *ASEAN Agricultural Commodity Outlook*, 28, Office of Agricultural Economics, Ministry of Agriculture and Cooperatives, Government of Thailand, Bangkok.

AHDB (2021), Agri market outlook: January 2021, Agriculture and Horticulture Development Board, accessed July 2021 - latest editions available at https://ahdb.org.uk/agri-market-outlook.

Ahern, T., Leavy, B. and Byrne, P.J. (2014), 'Complex project management as complex problem solving: A distributed knowledge management perspective', *International Journal of Project Management* 32, 1371-1381.

Allen, P. (1994), 'Economic forecasting in agriculture', *International Journal of Forecasting* 10, 81-135.

ALFRD (2021), *Quarterly Economic Overview – Agricultural Sector*, volume 19 (4), Directorate of Statistics and Economic Analysis, Department of Agriculture, Land Reform and Rural Development, Government of the Republic of South Africa, Arcadia.

Ashby, A.W. (1964), 'On forecasting commodity prices by the balance sheet approach', *American Journal of Agricultural Economics* 46, 633-643.

Ashton, L. (1949), 'World has insufficient food - FAO's work to promote production', *Quarterly Review of Agricultural Economics* 2, 47-49.

BAE (1952), *The Wheat Situation,* Bureau of Agricultural Economics, Canberra.

Benedict, M. (2018), 'Modelling ecosystems in information systems–a typology approach', In: *Proceedings of the Multikonferenz Wirtschaftsinformatik*, 6-9 March, Lüneburg, Germany.

Bunn, D. and Wright, G. (1991), 'Interaction of judgemental and statistical forecasting methods: issues & analysis', *Management Science* 37, 501-518.

Cameron, A. (2021), *Introducing ABARES Historical Agricultural Forecast Database*, Technical Report 21.02. Australia Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Cameron, A. & Nelson, R. (2022), 'Enabling users to evaluate the accuracy of ABARES agricultural forecasts', *Australasian Agribusiness Review*, 30, Paper 7, 167-190.

Cameron, A., Xia, C. and Nelson, R. (2021), 'Agricultural overview', *Agricultural Commodities* 10, 4-13.

Campbell, A. (1950), 'International wheat situation - prospects for the 1950-51 season reviewed', *Quarterly Review of Agricultural Economics* 3, 172-177.

Cao, L. and Greenville, J. (2020), *Understanding How China's Tariff on Australian Barley Exports Will Affect the Agricultural Sector*, Research Report 20.14, Australia Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Cash, D., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N. and Jäger, J. (2002), *Salience, Credibility, Legitimacy and Boundaries: Linking Research, Assessment and Decision Making*, John F Kennedy School of Government Faculty Research Working Papers Series RWP02-046. Harvard University, Cambridge.

CDC (2021), *Harmonized Milk Classification System*. Canadian Dairy Commission, Ottawa, available at https://cdc-ccl.ca/index.php/en/supply-management/harmonized-system-of-milk-classification/, accessed 16 July 2021.

CFARE (2013), *From Farm Income to Food Consumption: Valuing USDA Data Products*. Council on Food, Agricultural and Resource Economics, Washington DC.

Checkland, P. (2000), 'Soft Systems Methodology: A 30 year retrospective', *Systems Research and Behavioral Science* 17, S11 - S58.

Davenport, T. and Prusak, L. (1997), *Information Ecology: Mastering the Information and Knowledge Environment*. Oxford University Press, New York.

Denzin, N. (1970), *The Research Act: A Theoretical Introduction to Sociological Methods*. Aldine Publishing Company, Chicago.

Dewbre, J., Shaw, I., Corra, G. and Harris, D. (1985), *EMABA. Econometric Model of Australian Broadacre Agriculture*. Bureau of Agricultural Economics, Canberra.

Doğan, Z., Arslan, S. and Köksal, A.G. (2013), 'Historical development of agricultural accounting and difficulties encountered in the implementation of agricultural accounting', *International Journal of Food and Agricultural Economics* 1, 105-114.

Downward, P. and Mearman, A. (2007), 'Retroduction as mixed-methods triangulation in economic research: reorienting economics into social science', *Cambridge Journal of Economics* 31, 77-99.

Easterbrook, S., Finkelstein, A., Kramer, J. and Nuseibeh, B. (1994), 'Coordinating distributed ViewPoints: the anatomy of a consistency check', *Concurrent Engineering* 2, 209-222.

EC (2020), *EU Agricultural Outlook for Markets, Income and Environment, 2020-2030*. European Commission, DG Agriculture and Rural Development, Brussels.

Ellis, B. and Herbert, S. (2011), 'Complex adaptive systems (CAS): an overview of key elements, characteristics and application to management theory', *Journal of Innovation in Health Informatics* 19, 33-37.

FAO (2017), *Guidelines for the Compilation of Food Balance Sheets*. Food and Agriculture Organisation of the United Nations, Rome.

FAO (2001), *Food Balance Sheets: A Handbook*. Food and Agriculture Organisation of the United Nations, Rome.

FAO (1949), *Handbook for the Preparation of Food Balance Sheets*. Food and Agriculture Organisation of the United Nations, Rome.

Felder, W.N. and Collopy, P. (2012), 'The elephant in the mist: What we don't know about the design, development, test and management of complex systems', *Journal of Aerospace Operations* 1, 317-327.

Freebairn, J. (1975), 'Forecasting for Australian agriculture', *Australian Journal of Agricultural and Resource Economics* 19, 154-174.

Freebairn, J. (1978a), 'An evaluation of outlook information for Australian agricultural commodities', *Review of Marketing and Agricultural Economics*, 46, 3, 295–314.

Freebairn, J. (1978b), *Review of the Methodology for Medium-Term Projections*, BAE Technical Paper. Bureau of Agricultural Economics, Canberra.

Green, K. and Armstrong, J. (2015), 'Simple versus complex forecasting: The evidence', *Journal of Business Research* 68, 1678-1685.

Hayek, F. (1945), 'The use of knowledge in society', *The American Economic Review* 35, 519-530.

Hertel, T. (2002,. 'Applied general equilibrium analysis of agricultural and resource policies', in B. Gardner and G. Rausser (eds), *Handbook of Agricultural Economics Volume 2A Agriculture and its external linkages*, 1373-141, Elsevier, Amsterdam.

Holland, J. (2006), 'Studying complex adaptive systems', *Journal of Systems Science and Complexity* 19, 1-8.

Holzworth, D., Huth, N.I., Fainges, J., Brown, H., Zurcher, E., Cichota, R., Verrall, S., Herrmann, N.I., Zheng, B. and Snow, V. (2018), 'APSIM next generation: overcoming challenges in modernising a farming systems model', *Environmental Modelling & Software* 103, 43-51.

Holzworth, D.P., Snow, V., Janssen, S., Athanasiadis, I.N., Donatelli, M., Hoogenboom, G., White, J.W. and Thorburn, P. (2015), 'Agricultural production systems modelling and software: Current status and future prospects', *Environmental Modelling & Software* 72, 276-286.

Hyndman, R. and Koehler, A. (2006), 'Another look at measures of forecast accuracy', *International Journal of Forecasting* 22, 679–688.

IGC (2021), *International Grains Council: About Us*. International Grains Council, London, available at https://www.igc.int/en/about/aboutus.aspx, accessed 7 April 2021.

Irwin, S., Good, D. and Sanders, D. (2015), 'Understanding and Evaluating WAOB/USDA Corn Yield Forecasts', *Farmdoc Daily* 5, 79 1-9.

Just, D. and Zilberman, D. (2002), *Information Systems in Agriculture*, Giannini Foundation of Agricultural Economics, San Francisco, ARE Update 6:1, 3-6.

Keating, B. and McCown, R. (2001), 'Advances in farming systems analysis and intervention', *Agricultural Systems* 70, 555-579.

Keating, B. and Thorburn, P. (2018), 'Modelling crops and cropping systems—evolving purpose, practice and prospects', *European Journal of Agronomy* 100, 163-176.

Kingma, O., Longmire, J. and Stoeckel, A. (1980), 'A review of three research programs in quantitative modelling in the Bureau of Agricultural Economics', *Australian Journal of Agricultural Economics* 24, 224-247.

Laing, G.J. (1981), 'The classification of models: a proposal', *Interdisciplinary Science Reviews* 6, 355-363.

Lewis, J. (1949), 'Value of rural production - forecast of levels and trends in 1948-49', *Quarterly Review of Agricultural Economics* 2, 13-15.

Linehan, V., Thorpe, S., Gunning-Trant, C., Heyhoe, E., Harle, K., Hormis, M. & Harris-Adams, K. (2013), *Global food production and prices to 2050: scenario analysis under policy assumptions*, ABARES conference paper 13.6, Canberra, March.

Littleproud, D. (2021), *Ag Production on Track to Reach record $65.9 Billion*. Minister for Agriculture, Drought and Emergency Management, available at https://minister.awe.gov.au/littleproud/media-releases/abares-agricultural-production-march-2021, accessed 23 March 2021.

McRobert, K., Darragh, L., Laurie, A. and Heath, R. (2019), *Reinventing Australian Agricultural Statistics*. Australian Farm Institute, Sydney.

Meyers, W., Westhoff, P., Fabiosa, J. and Hayes, D. (2010), 'The FAPRI global modelling system and outlook process', *Journal of International Agricultural Trade and Development* 6, 1-19.

Miller, R. (2007), 'Futures literacy: a hybrid strategic scenario method', *Futures* 39, 341-362.

Nelson, R. (2018), 'The future of public sector forecasting in Australian agriculture', *Australasian Agribusiness Perspectives* 21, paper 16.

Nelson, R., Cameron, A., Xia, C., Howden, M. and Miller, M. (2022), *The Australian Agricultural Forecasting System - System Documentation*, Technical Report 22.02. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Nelson, R., Miller, M. and Cameron, A. (2020), 'Seasonal climate scenarios for medium-term forecasts', *Agricultural Commodities* 10, 8-11.

NFF (2020), *2030 Roadmap - Australian Agriculture's Plan for a $100 Billion Industry*. National Farmer's Federation, Canberra.

NZMPI (2022), *Situation and outlook for primary industries June 2022*, Ministry for Primary Industries, Economics Intelligence Unit, Wellington accessed 24 August 2022, latest editions available at https://www.mpi.govt.nz/resources-and-forms/economic-intelligence/situation-and-outlook-for-primary-industries/sopi-reports/.

NZPCE (2018), *Overseer and Regulatory Oversight: Models, Uncertainty and Cleaning Up Our Waterways*. New Zealand Parliamentary Commissioner for the Environment, Wellington.

OECD and FAO (2015), *Aglink-Cosimo Model Documentation - A Partial Equilibrium Model of World Agricultural Markets*. Organisation for Economic Cooperation and Development, Paris.

OECD/FAO (2021), *OECD-FAO Agricultural Outlook 2021-2030*. OECD Publishing, Paris.

Potard, G. and Keogh, M. (2013), *Is Counting Farmers Harder Than Counting Sheep?* Australian Farm Institute, Sydney.

SCAWR (2020), *Growing Australia - Inquiry Into Growing Australian Agriculture to $100 billion by 2030.* Parliament of the Commonwealth of Australia, Canberra.

Schnepf, R. (2017), *NASS and US Crop Production Forecasts: Methods and Issues*, Congressional Research Service (CRS) Report, Washington.

Sheales, T. (1993), *Minerals and Metals Forecasting: the ABARE Experience*, Conference Paper 93.17, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Taylor, H.C. (1939), 'A century of agricultural statistics', *Journal of Farm Economics* 21, 697-706.

USEPA (2009), *Guidance on the Development, Evaluation, and Application of Environmental Models*. Report to the Council for Regulatory Environmental Modeling, United States Environmental Protection Agency, Washington.

Vogel, F. and Bange, G. (1999), *Understanding USDA Crop Forecasts*, Miscellaneous Publication Number 1554, World Agricultural Outlook Board, Office of the Chief Economist, United States Department of Agriculture, Washington.

Wack, P. (1985), 'Scenarios: uncharted waters ahead', *Harvard Business Review,* September-October, 72-89.

Wood, E. (1948), 'Australia's future food requirements', *Quarterly Review of Agricultural Economics* 1, 13-14.

WTO (1995), *Agreement on Agriculture*, *Uruguay Round Agreement*. World Trade Organisation, Geneva, available at https://www.wto.org/english/docs_e/legal_e/14-ag_01_e.htm, accessed 14 October 2021.

Xia, C., Brown, A., Agbenyegah, B., Collins, P., Miller, M., Cameron, A. & Nelson, R. (2019), *Forecasting national grain stocks in times of drought*, Technical Report 19.6, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.