Managing Complexity in Modern Farming

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Abstract

Modern farming in Australia is no longer simple. Farms are large, multi-enterprise businesses underpinned by expensive capital investments, changing production technologies, volatile markets and pervasive regulation. The complexity of modern broadacre farming leads to the question: what is the nature of the relationship between farm business complexity and farm profitability? This study uses bioeconomic farm modelling and employs eight measures of complexity to examine the profitability and complexity of a wide range of broadacre farming systems in Australia. Rank order correlations between farm profitability and each measure of complexity show inconsistent relationships, although the most profitable farming systems are found to be reasonably complex on several criteria. Among the set of highly profitable systems are found some characterised by less complexity. Using the farmer's annual hours worked as a measure of complexity that affects current farm management, the trade-off between profit and this measure of complexity is found not to be large. A case is outlined where the farmer's annual hours worked could be reduced by 9 percent for a 3 percent reduction in farm profit. If farmers' workloads are proving problematic now and in the future, then agricultural R&D, service delivery and policy development will need to focus much more on being highly attractive to time-poor farm managers.

Key words: complexity, farm modelling; management; profitability

1. Introduction

Business complexity is seen as one of the world's top ten business problems (Business Change Forum 2008) as it complicates business management and creates integration problems and inefficiencies due to the number and variety of goals and business units (Lissack and Gunz 1999; Performance Management 2009). Excessive complexity drives up operating costs and hampers business growth (Enz and Potter 1998; Gottfredson and Aspinall 2005; Jagersma 2008). As product variety expands, the complexity of operations increases, leading to a rise in the need for support activity, which can then decrease the overall profit margin of the enterprise (Enz and Potter 1998).

In a global survey of over 900 executives (Gottfredson and Aspinall 2005) nearly 70 percent admitted excessive complexity was raising their firm's costs and hindering their profit growth. The same survey showed that some businesses in manufacturing, retail, services and fast food had benefited greatly from simplifying their operations. Another survey of 65 managers of 20 global companies (Jagersma 2008) found that the complexity of operations and structures added over 25 percent to business costs and that simplification or reconfiguration to reduce complexity could importantly affect these firms' global competitiveness.

Conversely, however, Gottfredson and Schwedel (2008) argue that being too simple also can hinder business growth through ineffective risk management and an inability to capitalise on different consumer tastes. These authors explain how some degree of complexity is essential for managing risk and maintaining flexibility. Closs *et al*. (2008) note how product portfolio complexity creates a range of difficulties yet also can increase sales through product differentiation.

Aside from its impact at the firm level, complexity also affects individual choice (Hu 2006; Masatlioglu and Ok 2005; Boxall *et al*. 2009). Individuals change their decision making strategies in response to choice context and the complexity of the choice environment (Payne *et al*. 1988; Holling 2001; Swait and Adamowicz 2001). In adoption literature complexity of an innovation generally negatively affects its uptake (Fliegel and Kivlin 1962; Rogers 1995 and 2003; Batz *et al*. 1999; Pannell *et al*. 2006). System complexity also poses challenges for researchers (Ho and Sculli 1995; Hobday *et al*. 2000; Limburg *et al*. 2002; Schiere *et al*. 2004; Reeson and Dunstall 2009; Ekboir 2009) and extension staff (van Keulen and Schiere 2004; Price *et al*. 2009).

Turning to the specific case of broadacre farming in Australia, McGuckian (2006) notes that it is a difficult system to manage and a difficult environment in which to make decisions. He later reports key findings from a detailed interview-based survey of 50 mixed enterprise farms across Australia and concludes that "Mixed farming systems are complex and require a high level of skill to run profitably." (p. 5, McGuckian 2007). This view is echoed by Price and Goode (2009) who review research centred on Australian mixed enterprise farming and conclude that the "research showed that making decisions for a mixed farm is a complex and demanding process." (p.19). Similar views are stated by Kemp *et al*. (2003) who suggest that in Australia "The complexity of management has increased" (p.1) and that "Future farm managers will be operating in an increasingly complex bio-business and biophysical environment." (p.9). Lewis *et al*. (2006) comment how farm management involves the consideration of a "complex mix of many factors that can be broadly categorized as being of a human, technical, economic, financial, risk, institutional and social nature." (p.333). Chavas (2008) more generally notes that "Agro-ecosystems are complex processes." (p366).

Pannell (1999) argues that a more complex farming system has an increasing number of elements and interactions that become more difficult to understand and manage and therefore there is more chance of problems occurring. Ewing and Flugge (2004) and Robertson *et al*. (2009) point out that crop-livestock integration in Australian agriculture has benefits, but also challenges. Lewis *et al*. (2006) comment that the more complex the farming system, the more understanding and management skill is required. Cattle and White (2007) describe how larger, more diversified and complex broadacre farms in Western Australia are less technically efficient and Fraser (1990) shows that numerical solutions to farm management problems become necessary in the face of a complex combination of enterprise diversification, product complementarity and risk aversion. Chavas (2008) uses the language and tools of production economics to suggest that the complex challenge in agricultural production is to jointly consider the ramifications of economies of scale, specialization, diversification, technical progress and risk.

Most researchers, such as those already named, describe agricultural systems and their management as complex, but usually they do not define the term complexity. Where definitions are provided (e.g. Simon 1981) a complex system is commonly defined as one that comprises numerous parts that interact to yield outcomes not easily predicted. The advice of Meier (2008) is that complexity is best defined in the framework of a specific application. This advice is heeded in this study. Metrics of complexity are used that suggest complexity is greatest where there are many enterprises, many activities and many interactions present in the farming system, with the resultant workload for the farmer being large. These metrics are described in a later sub-section.

The complexity of broadacre farm business management in Australia is affected by a range of trends and changes (Kingwell 2002a; Kingwell and Pannell 2005; Price and Goode 2009). Firstly, broadacre farms are becoming fewer and larger (Productivity Commission 2005). ABARE farm survey data for Australia's wheat-sheep zone from 1988/9 to 2007/8 show a 29 percent decline in the number of farms and a 48 percent increase in average farm size. Carroll (2005) predicts that by 2020 less than 100,000 farms will remain in Australia. Larger farms have an increased likelihood of needing to manage a greater diversity of land management units that can complicate spatial and enterprise management. Fewer neighbours can mean a socially less vibrant grower community, fuelling volunteer burn-out (Rockloff 2003), heightening the requirement for self-reliance and making the life of farming socially less attractive.

Secondly, deregulation of grain marketing (McCorriston and MacLaren 2007; DAFWA 2009) means farmers are now responsible for marketing their product as well as producing it. In practice this can entail a farmer becoming knowledgeable about grain marketing, or at least knowledgeable about which firms offer sound, cost-effective marketing advice.

Thirdly, farmers' enterprise management choices, although more and varied, are also constrained by the needs and actions of a greater range of stakeholders with diverse interests in quality assurance (Kingwell 2003; O'Keefe 2004), occupation health and safety, marketing (Cary *et al*. 2004; Bushell and MacAuley 2007), animal welfare (Kingwell 2002b; Thornber 2007) and environmental protection (Han *et al*. 2006; Carruthers 2006; Pahl and Sharp 2007). The traditional production focus of farming now additionally is required to encompass these concerns (Lyson 2002). Ketelaar-de Lauwere *et al*. (2002) comment how aside from these stakeholder requirements farmers face other issues such the failing attractiveness of the sector as an employer and uncertainties surrounding agricultural supply chains. They say: "All these developments have made modern agricultural entrepreneurship increasingly complex. It is open to question whether and how farmers are able to deal with such complexity." (p. 1).

Adding to the complexity of mixed enterprise farming systems and their management are demographic changes such as smaller family sizes and more family members working off-farm (Productivity Commission 2005), which reduces the supply of both family labour and other regional full time farm workers (Tonts 2005). It can make division or specialisation of farm family labour less possible. Increased reliance on hired casual labour adds to the costs of labour search, training and supervision or leads some farmers to adopt an enterprise mix less dependent on labour.

Finding and retaining farm labour can be difficult. A survey of WA farmers (Rabobank 2007) reported that of the 69 percent of farmers who required additional labour over the previous 12 months, 14 percent said it was impossible to find labour. A further 62 percent said they had experienced some difficultly attracting adequate labour. To overcome this labour shortage, 41% of the survey participants said they had increased their own working hours. Yet this management workload falls on an ageing farmer population. In 2008 only 16 per cent of Australia's farmer population was less than 45 years old and the average age was 57. By contrast, 25 years previously in 1983, 40 per cent of the farmer population was less than 45 years old (Mallawaarachchi *et al*. 2009).

The increase in business complexity, combined with scarcity of family and skilled farm labour, places additional demand on farmers' time and skills. For example, an ABS (2002) survey of 20,000 Australian farms reported that almost 60% of all farms nominated time-pressures as a main reason for limiting their response to salinity problems. Also, based admittedly on a small sample of face-to-face interviews with 50 broadacre farmers across Australia, McGuckian (2006) reported that many were looking for ways to make life simpler and easier, at a time when the Rabobank (2007) survey findings suggest many farmers' workloads were increasing.

Given these trends and influences on farm management, the question arises: Are the returns associated with running a complex set of enterprises sufficient to justify the greater demands on a farmer's time and skill? The fact that McGuckian (2006) found so many farmers in his small sample keen to opt for a simpler life suggests that current returns to complexity insufficiently compensate or reward these farmers. He found for example as did Rabobank (2007) that many farmers were reluctant to employ labour due to the difficulty of finding skilled labour and the need to comply with occupational health and safety regulations. Many farmers preferred to reduce labour required on their farm through enterprise choice or work more hours themselves.

Aside from interview-based studies to reveal farmers' management intentions and perceptions of their management tasks, there has been little research formally investigating the relationship between profitability and broadacre farm business complexity. This lack of knowledge is the principal motivation for this paper.

This paper is structured as follows. The next section provides descriptions of measures of business complexity. Then the modelling framework and analysis to explore the relationship between business complexity and profitability is outlined. The presentation and discussion of modelling results follows and last, a conclusion.

2. Measures of Business Complexity

Early definitions and measures of organisation complexity by Child (1972) and Duncan (1972) refer to complexity as (a) the number of factors in the decision environment and (b) the dissimilarity or heterogeneity among them. Tung (1979) extended their work by differentiating between factors internal or external to the business. She developed a complexity index that drew on the key internal and external key factors that affected a CEO's decision-making. This index can be expressed as:

$$I = (\sum_{i=1}^{n} C_i W_j).n^2 \quad j \in [1,2]$$

where C_i is the ith key factor perceived by the CEO as affecting their business decision-making and W_j is the weighting of the factor, such that if it is external (j=2) to the firm its weighting is 2 whereas if it is internal (j=1) the weighting is unity. Hence if there were three key factors nominated, with two of these being external to the firm, then I would equal 45= (1+2+2)*3^2.

Dess and Beard (1984) drew on the theoretical work of Aldrich (1979) to measure business complexity. They comment firstly that: "managers facing a more complex (i.e. heterogeneous) environment will perceive greater uncertainty and have greater information-processing requirements than managers facing a simple environment." (p.56) and secondly that "organizations competing in industries that require many different inputs or that produce many different outputs should find resource acquisition or disposal of output more complex than organizations competing in industries with fewer different inputs and outputs." (p.57). They found that as businesses expand spatially and diversify into new markets and produce additional product lines that the business management and administration becomes more complex.

Kotha and Orne (1989) characterised complexity using a product line paradigm whereby the ingredients of complexity were the number of different products produced, the complexity of the products (i.e. the number of components), and the range of product volumes. Boyd (1990) considered business complexity as a function of competitive diversity and used a Herfindahl index, H as a measure of competitive diversity, where the index considered n firms with the ith firm having a market share of s_i such that:

$$H = \sum_{i=1}^{n} s_i^2$$

This approach, however, was criticised by Sharfman and Dean (1991) who argued that these measures failed to capture the complexity of an environment that arose from high levels of technical or scientific sophistication that also characterised some environments.

Miller and Chen (1996) measured complexity as simply the number of enterprises within a system. Delaney *et al.* (1997) argued for the use of firm size as a measure of complexity, making reference to the increased numbers of products and markets that are often associated with organisational scale. However, firm size alone is a controversial measure of complexity, as a firm may increase in size yet not increase the diversity of their product line and markets.

Grant *et al.* (2000) measured business complexity with the metrics of the number of lines of business and the number of geographical regions in which firms operated. Hence, their assessment of complexity yielded the most simple firm being one with a single line of business operating in only one region. Setzekorn *et al*. (2000) extended this measure of complexity to also include volatility. Volatility was measured by suppliers' delivery unreliability; the size of forecasting errors, the frequency of late changes in due dates of deliveries; the frequency of late changes to engineering and design tasks; and duration of a production plan and its frequency of revision.

Flood (1987), Sharfman and Dean (1991) and later, Cannon and John (2007) reviewed the measurement of organisational complexity and concluded that that there are three main aspects to organisational or environmental complexity:

(i) number of environmental components with which a firm must interact.

(ii) heterogeneity or dissimilarity among these components.

(iii) technical knowledge required to interact effectively with these components.

Applying their nomenclature to agricultural production would suggest that its complexity would depend on the number of environments or components that require management, their heterogeneity and the level of technical knowledge required for their proper management.

Hendrickson *et al.* (2008) ranked agricultural systems according to their management complexity. Their hierarchy started with a basic agricultural production system that comprised no more than two enterprises with a minimal flow of resources and production focused on delivering a single consistent commodity. Next were diverse agricultural production systems that contained three or more species of crop or livestock. Interactions between crop and livestock were limited and the enterprises were managed in a pre-determined manner. The most complex agricultural system they considered was an integrated agricultural production system. This involved multiple enterprises managed dynamically, interacting synergistically in space and/or time. When Hendrickson *et al*. (2008) applied their hierarchy to broadacre farming systems in Australia, these systems were judged as displaying the highest level of complexity among all the agricultural systems they considered.

In summary, the literature on measurement of complexity provides no single widely accepted measure of complexity. Each study often has several different measures of complexity and so to be consistent with this literature in this study several measures of farming system complexity are used:

- Diversity of revenue sources

  $$R = \sum_{i=1}^{n} r_i \, ln(\frac{1}{r_i}) \qquad (1)$$

  Underpinning this entropy-type index is the assumption is that the more revenue sources and the more equal their shares (r_i) of total farm revenue the more diversified yet complex is the faming system to manage. In equation (1) and similar subsequent equations it is customary (Theil 1972) to define:

  $$r_i \, ln(\frac{1}{r_i}) = 0 \quad \text{if } r_i = 0$$

- Diversity of land use

  $$U = \sum_{i=1}^{n} s_i \, ln(\frac{1}{s_i}) \qquad (2)$$

Here the assumption is that the greater the array of i land uses and the more equal their shares (s_i) of the farm's area, the more diversified yet complex is the faming system to manage. Land use refers to the area allocated to each type of crop and pasture.

- Number and land share of rotations

$$S = \sum_{i=1}^{m} n_i \, ln(\frac{1}{n_i}) \qquad (3)$$

This assumes that the greater the number of rotations across the farm's m land management units and the more equal their shares (n_i) of the farm's area the more complex is the farming system to manage.

- Number of rotations

$$N = \sum_{i=1}^{m} u_i \qquad (4)$$

where u_i is the number of selected rotations on land management unit i and there are m land management units on the farm. The more rotations that underpin the farming system the greater is the assumed task of farm management.

- Number of unique rotations

$$D = \sum_{i=1}^{m} d_i \qquad (5)$$

where d_i is the number of unique rotations on land management unit i and there are m land management units on the farm. So the more land managements units and the more unique are the rotations on those land management units, the more challenging or complex is the management of the faming system. The measure in equation (4) may over-state farming system complexity because a land use such as permanent pasture if selected on 4 land management units would count as 4 rotations whereas under equation (5) they would count as a single unique rotation.

- Diversity of expenditure

$$E = \sum_{i=1}^{n} e_i \, ln(\frac{1}{e_i}) \qquad (6)$$

Here the assumption is that the greater the range of types of expenditure (fuel, fodder, fertiliser, chemicals, animal purchases, hired labour, etc) and the more equal their shares of farm total expenditure then the more complex is the task of managing all the expenditures associated with the farming system.

- Farmer's average monthly labour and its variability

  $$L = E(m) + b(E(m)^2 + V(m)) \qquad (7)$$

  where $E(m)$ is the average hours worked each month by the farmer;

  $V(m)$ is the variance of the monthly hours worked by the farmer;

  b is a curvature parameter (= 0.000005), set such that L is a lesser number as $E(m)$ and $V(m)$ diminish and that for any $E(m)$, L increases as $V(m)$ increases. Each type of farming system will have a unique pattern of monthly demand for the farmer's labour (L). The assumption is that the more complex a farming system the greater are its management requirements as reflected in the average monthly hours worked and the variance of the workload across the farm year.

- Annual hours worked by the farmer

  $$F = \sum_{i=1}^{12} h_i \qquad (8)$$

  where according to the nature of the farming system, the farmer is required to work h_i hours in month i and annually works for F hours.

These 8 measures are the complexity metrics used in this study.

3. A Model of Mixed Enterprise Farming

The agricultural model employed in this study of farm business complexity is the whole-farm bioeconomic model known as MIDAS (Model of an Integrated Dryland Agricultural System; Kingwell and Pannell 1987). Being a main developer and user of this model (Kingwell 1996; Kingwell 2002b; O'Connell *et al*. 2006; Kopke *et al*. 2008; Gibson *et al*. 2008; Bathgate *et al*. 2009) provides knowledge and insights regarding its utility to portray important aspects of the complexity, management and profitability of a broadacre mixed enterprise farming system.

The MIDAS model has been used to assess and explore the profitability of a wide range of innovations, the impacts of various policy changes and the responsiveness of broadacre farm profit to a wide range of influences. Most recently Robertson *et al*. (2009) have used MIDAS to derive relationships between NRM targets and farm profitability. However, the responsiveness of farm profit to changes in system complexity is yet to be addressed.

Originally a single model, MIDAS is now a portfolio of representative farms for different agro-ecological zones across Australia. Each model is a traditional steady-state mathematical programming model of a representative farm that describes in more detail than is often the case with such models, the biology, interactions and within-year enterprise management requirements of a broad range of enterprise options.

The particular version of MIDAS used in this study is representative of a farm in the central agricultural region of Western Australia (see Figure 1). This region comprises about 6.4 million hectares of which 3.5 million is cropped and 2.9 million is grazed. Annual average rainfall in the region is 350mm to 450mm, with 75% of this falling in the growing season between May and October. Summer rainfall is highly variable, whilst winter rainfall is much more reliable, making the region most suited to annual crops and pastures. The region displays the lowest coefficients of variation in wheat yields (see Fig 4.5 in NLWRA 2001; Schut *et al*. 2009) across Australian shires and displays the lowest coefficients of variation in wheat prices (Scoccimarro 1996).

(Figure 1 about here)

The major crops grown in the region include wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), lupins (*Lupinus angustifolius* L.) and canola (*Brassica campestris* L). Merino sheep are by far the dominant livestock enterprise and they graze mainly annual pasture, although small areas of perennial pastures are grown (Kingwell *et al*. 2003). Wool production was the traditional focus of the sheep enterprise, by value of production, although a rapid shift in the relative importance shipper and prime lamb production has occurred over the last several years due to improved prices (Bathgate *et al*. 2009).

The soils of the region are derived from an ancient landscape, resulting in highly weathered, highly leached, infertile, coarse textured soils with poor structure. Soil acidity affects a large proportion of the soils in the region.

The MIDAS model that describes a representative farm of the region is a steady-state, linear programming model with a tableau of 1835 columns (activities) and 746 rows (constraints). Its database is contained in a 60MB Excel® file and Visual Basic routines draw on Lindo® as the solver. The model's objective function is profit maximisation, subject to managerial, resource and environmental constraints (Bathgate and Pannell 2002; Robertson *et al*. 2009). Profit is defined as net cash returns minus non-cash costs (e.g. depreciation) minus the opportunity cost of capital, exclusive of land. MIDAS is based on an average season and assumes product and input price certainty.

Key components of the model

The standard model includes:

(i) Crop/ pasture rotations; up to 60 different rotation options for each of eight land management units (LMU). The LMUs are listed in Table 1. The rotational options include wheat, barley, oats, field peas, faba beans, chick peas, canola, lupins, perennial pasture and mixed swards of annual pasture. Each rotation has specific crop yields, pasture growth and input levels. For example, pulse crops and legume pastures reduce the carryover of cereal diseases and fix soil nitrogen. This affects potential cereal yield and optimum nitrogen rate. The number of continuous years of crop affects the ability of pastures to regenerate naturally and thus the number of livestock that can be grazed profitably.

(Table 1 about here)

(ii) Machinery. A complement of typical cropping machinery is represented that allows crop and pasture sowing usually within four weeks of the growing season's opening rains. Yield penalties for late sowing are included in the model.

(iii) Grain, wool and livestock selling. Selling activities in the model link the physical output of the model with the cashflow and objective function.

(iv) Pasture production. The production year is divided into 10 periods of varying length depending on the growth rate of pasture. There are 5 periods of growth and 5 periods of senescence and pasture decline. Germination depends on the LMU and crop/pasture sequence. Growth rate in each period is a function of feed on offer (kg of dry matter per ha), and is approximated by linear segments. Feed on offer is a function of feed on offer at the beginning of the period, the amount of pasture grazed by livestock during the period and the rate of physical deterioration and trampling by livestock. Pasture quality and quantity decline rapidly after senescence (Periods 6–10). Conservation constraints prevent over-grazing of pastures and crop residues. Further detail on the representation of pasture production is found in O'Connell *et al.* (2006).

(v) Livestock production. The nutritional demands and grazing abilities of several classes of sheep throughout the production year are described. Alternative sources of supplementary feed are available to ensure adequate supply of energy over the dry summer and autumn period. Crop residues provide an additional source of feed for livestock during the summer drought. The quality and quantity of stubble available for grazing deteriorates with time and with grazing. Sheep preferentially graze the high quality components of the stubble so the quality of stubble declines as it is grazed. Conservation constraints limit the total amount of dry matter available for grazing.

Merino and merino-cross livestock options are included. The sheep flock is self-replacing and one or some combination of three livestock enterprises can be selected; a wool enterprise, a merino prime lamb enterprise and/or a cross-bred prime lamb enterprise. Forty six classes of sheep are described. They differ in age, time of sale and gender. Ewes are culled after five or six years. Death rates, annual wool growth and hauter are a function of the liveweight of each sheep class. Liveweight and age of ewes also affects lambing rates. Liveweights of animals are a function of the availability and quality of feed. The relationships used to estimate production of livestock are outlined in Young (1995).

(vi) Finance. Income and expenditure associated with each activity are described in a bi-monthly cashflow. Overheads and depreciation are subtracted from the net cashflow to calculate farm profit.

To describe different sorts of farming systems, often in previous studies (e.g. Pannell 1987; Flugge and Schilizzi 2005) constraints were imposed on the proportion of the farm allocated to crops. Such an approach however shows the profit response to the area of crop rather than the response to system complexity. To represent different sorts of farming systems and provide measures of their complexity the following approach was used.

Firstly, binary switches were created for each enterprise such that the enterprise could be excluded or included in the farming system. Secondly, to overcome the possibility that impractically small areas of some enterprises could be selected, minimum area requirements of 50 hectares for each enterprise (if switched on for forced inclusion) were added. Hence, the smallest feasible land allocation to an enterprise (if included) was 2.5 per cent of the farm's area. Using these switches different types of farming systems could be explicitly considered.

The model was altered to include labour requirements during the year for each enterprise, as described by Rose and Kingwell (2009) and Rose (forthcoming), and three options of labour availability were included: the farmer plus one casual labourer for seeding and harvest; the farmer plus a permanent worker, and the farmer plus hiring casual labour at any time. This explicit treatment of labour arose from the need to investigate the time demands a farmer faces when managing different types of farming systems.

Modelling Scenarios

The relationship between the complexity of farming systems and their steady-state profitability was investigated by considering a range of farming systems and finding their optimal steady-state profitability. The range of farming systems covered 3*3*3*63 = 1701 scenarios involving:

(i) three labour supply options as described previously,

(ii) three sheep enterprise options; a self-replacing merino flock run primarily for wool and shipper production, a self-replacing merino flock specialising in merino prime lamb production and a self-replacing merino flock specialising in cross-bred lamb production whereby a portion of the merino ewe flock is mated to a terminal meat breed.

(iii) three price and cost scenarios: actual costs and prices for the years 2007, 2009 and averages over the period 2005 to 2009 are considered. The relative price and cost conditions in 2007 favoured grain production whilst in 2009 sheep production was favoured. A medium term average is based on costs and prices in the period 2005 to 2009.

(iv) 63 combinations of enterprises. The broadacre mixed enterprise farm as modelled was assumed to always produce some wheat and annual pasture. Aside from these two given land uses there were up to 6 other enterprise options typically selected in optimal farm plans: barley, lupins, canola, lucerne, oats and an alternative legume selected from faba beans, field peas or chickpeas. From one to six of these enterprise options were selected to complement the wheat and annual pasture enterprises. Denoting e as the number of enterprise options selected from the set of 6 enterprises where $e \in [1,2,..,6]$ and noting N_e as the number of unique combinations, then $N_e = \frac{6!}{e!(6-e)!}$ and $\sum_{e=1}^{6} N_e = 63$.

For each of the 1701 scenarios the MIDAS model was solved to determine optimal farm profit under each scenario. Among these scenarios a sub-set of highly profitable scenarios was also subject to further sensitivity analysis through constraining the farming system to different sizes of cropping programs to reveal the nature of near optimal solutions. Then post-optimisation, characteristics of the farm plans were used to calculate the eight measures of farm complexity. This approach provided the data on farm profitability and farming system complexity.

The next section presents key modelling results. An examination of the 1701 scenarios, complemented by additional sensitivity analysis, revealed similar findings in each of the three cost and price scenarios. Hence to economise on space, only results for the scenario of price and cost averages over the period 2005 to 2009 are presented.

4. Results and Discussion

The set of most profitable farming systems in the averaged cost and price conditions of the period 2005 to 2009 (and in the other price and cost scenarios) never included solely wool-orientated sheep flocks nor permanent labour. The most profitable farming systems relied on casual labour available either at crop establishment and harvest, or being available at any time of the year. Furthermore in the most profitable farming systems the sheep flock was structured to produce either Merino prime lambs or cross-bred lambs where a portion of the Merino ewe flock was mated to a terminal meat breed sire.

The more than 600 farming system scenarios examined for the averaged cost and price conditions of the period 2005 to 2009 generated a large array of farming system profitability and measures of complexity (Figures 2&3). Most of the farming systems yielded profits far from the maximum possible profit. These less profitable farming systems represent allocative inefficiency as greater profit could be generated if restrictions on enterprise selection and labour use were relaxed and alteration in enterprise and input selection was allowed.

(Figure 2&3 about here)

The scatter of observations in Figures 2&3 suggests no clear relationship between farming system profitability and the various measures of complexity. This implies no simple or consistent trade-off between farm profit and system complexity. However, the flatness of the profit frontiers in Figures 2&3 suggests that it may be feasible for a farming system to be both highly profitable yet not unduly complex. Moreover, in practice most farm managers would not seriously consider the majority of the markedly inferior farming systems and would be more interested in the characteristics of the more highly profitable farming systems. Many of the data points in Figures 2&3 due to their very low relative profitability would not appeal to many farmers in the study region.

To examine further the relationship between farming system profitability and complexity a sub-set of farming systems that generate profit within 15 percent of the globally most profitable farming system is selected for further comparison. This set of more profitable farming systems is more likely to be of interest to most farmers than the other far less profitable farming systems in the feasible set. This sample restriction limits data consideration in Figures 2&3 to points with annual farm profit above $95K. Although this restricts the spread of profit, nonetheless a wide range in complexity measures is still observed. The question then arises as to the nature of the trade-off between farm profit and the various measures of complexity in this restricted dataset. Of particular importance are the rank order correlations for farm profit versus the various complexity metrics, and the significance and stability of those correlations.

Figure 4 displays firstly the rank order correlations between farm profit and each of the complexity metrics for a range of sample sizes. To interpret the signs of the correlation coefficients it requires noting that the profit rankings are in descending order, highest profit (first rank) to lowest whilst all complexity rankings are in ascending order (least complex is first rank). Secondly, the t statistics for the tests of significance of the various rank order correlation coefficients are presented for a range of sample sizes. The sample size is the number of farming systems included in the analysis, with the systems ranked by their profitability. Hence as the sample size increases, farming systems yielding increasingly less profit are included. For example, farming systems entering the sample when sample size is 80 are almost 10 per cent less profitable than the globally optimum farming system.

(Figure 4 about here)

The results in Figure 4 suggest that when the sample size is above 80 then the correlation coefficients are relatively stable and are almost always significantly different from zero. When the sample size is above 80 then significant positive rank correlations exist between profit and the complexity metrics of the number of rotations (and land share of rotations), the number of unique rotations and the index based on the mean and variance of the farmer's monthly hours of labour (equation 7). Conversely, significant negative rank correlations exist between farm profit and the other complexity metrics of revenue, expenditure, farmer's annual labour and enterprise land use. The interpretation of these results, informed by inspection of relevant data points in Figures 2&3, is that highly profitable farming systems tend to be characterised by a limited range of rotations that support several different yet complementary enterprises with many resultant sources of expenditure and revenue, and their combination and management requires a large annual time commitment from the farmer, especially at seeding and harvest (Rose and Kingwell 2009).

High (low) farm profit is associated with a greater (lesser) number and diversity of enterprises and a more (less) even allocation of land resources to the various enterprises. For example, highly profitable farming systems typically include cereals, annual pastures, canola, alternate legumes and a small area of lucerne. Often these farming systems have between half to three-quarters of the farm's arable area allocated to crops, with wheat being the dominant crop. The crop dominance of these farming systems means peak labour demand occurs at seeding and harvest and is accommodated through use of casual labour rather than permanent labour and the farmer's preparedness to work long hours during these periods. In spite of the lesser demand on the farmer's time in other months, the total annual workload is considerable — the main tasks of farm management require a time commitment of more than 45 hours per week Running several crop enterprises across a range of land management units, whilst simultaneously incorporating a sheep enterprise focused on cross-bred or Merino prime lamb production, requires a large time commitment by the farmer. Hence on the metrics of the farmer's annual labour, land use or enterprise diversity, and revenue and expenditure diversity, highly profitable farming systems are complex.

By contrast, using the metrics of the farmer's average monthly labour plus its variability and number of rotations (and unique rotations) suggests that highly profitable farming systems are relatively simple to manage. Across the 8 land management units considered by MIDAS (see Table 1) highly profitable farming systems usually contain 9 to 12 rotations of which 3 to 7 represent unique rotation combinations. Hence highly profitable systems have a restricted number of rotations and in that numerical sense appear simple to manage, although several enterprises are imbedded in the set of rotations. Moreover, in highly profitable crop dominant farming systems in many months of the year the farmer's workload is less than occurs in grazing dominant systems in which many more sheep require constant management (Rose forthcoming).

The suite of measures of complexity yield inconsistent assessments of farm business complexity. By some measures such as the number of rotations (including unique rotations) highly profitable farming systems are fairly simple, where often a single best land use exists for each land management unit. However, other metrics such as the farmer's annual workload and the multiplicity of revenue and expenditure sources suggest that highly profitable farming systems are complex or at least time-consuming to manage, involving a multiplicity of tasks and different enterprises.

By using this study's measures of complexity it is feasible to reduce the complexity of the farming system (e.g. reducing the farmer's annual labour requirement or reducing the number of enterprises), but this entails a reduction in farm profit. For example, the farming system could shift to greater crop dominance allowing a reduction in the sheep population and thereby lessening the farmer's annual workload. However, this shift in land use toward crop-only farming systems eventually entails growing crops on less suitable land management units and forgoing sheep enterprise profits and some complementarities between pastures and crops (Pannell 1987). Inspection of the relevant data points in Figures 2&3 shows a reduction in profit occurs when a highly crop dominant farming system is selected. The modelling results suggest that the synergy between the relative profitability of wheat production and complementary crop and sheep production generates high profit, although it requires a farmer to work long hours each year, especially during seeding and harvest. In addition the many and varied sources of revenue and expenditure make the system complex to manage.

(Table 2 about here)

The modelling results and rank correlation findings (see also Table 2) indicate that when judged by all metrics of complexity there is no overall highly profitable very simple farming system. Depending on which measure(s) of complexity is employed, it is feasible to simplify a farming system, but typically this incurs a reduction in farm profit. The extent of the reduction in profit, however, may not be large as evidenced by the flatness of the profit frontiers shown in Figures 2&3. The profit foregone by shifting to a less complex farming system can be less than 5 per cent. However, in some cases, depending on the magnitude and nature of the shift, the profit reduction can also be far greater. Furthermore, some shifts which would be deemed a simplification according to some measures of complexity only make the system more complex according to some other measures of complexity. Therein is the farm management dilemma: in broadacre mixed enterprise farming what feature of complexity poses sufficient difficulty or challenge to farmers that they would be interested to know how best to simplify their farm business? The anecdotal evidence is that it is the farmer's annual workload resulting from all the tasks associated with managing a large mixed enterprise business that is proving problematic, especially given the ageing of the farmer population and the difficulty of finding skilled farm labour.

The trends of larger farms with more land management units, fewer neighbours and less available family labour pose a management challenge for an ageing population of farmers. In broadacre regions of Australia, the observed shift into cropping and away from wool production over the last two decades is likely due in part to the attractiveness of labour-saving crop technologies, greater economies of size in cropping, drought impacts and difficulties in finding and retaining sheep labour in some regions. As an indicator of the rapid shift away from wool production, in 2008-09 the number of sheep and lambs in Australia was 71.6 million head, the lowest number since 1905.

If the large annual workload of the farmer is proving problematic, yet is one outcome of running a highly profitable farm business then the modelling results presented here suggest that farmers can reduce their annual workload by running a different farming system. However, this will incur some reduction in profit. For example, based on inspection of data points in Figures 2&3, exclusion of lucerne and its replacement by annual pasture (in combination with other minor changes to enterprises) leads to a 3 percent decline in farm profit yet a 9 percent reduction in the annual work hours of the farmer. The reduced workload mostly stems from no longer needing to establish and spray out lucerne stands and to repetitiously move and monitor sheep mobs on and off the lucerne stands. How the relative importance of lucerne is linked to labour availability also has recently been investigated by Doole *et al*. (2009). Their findings are consistent with those reported here and of McGukian (2006) who reported that "Some farmers would be happy to run sheep at a small loss if they provided a benefit to the cropping enterprise – if they could be run simply and easily." (p. 3).

The workload and time pressures on broadacre farmers have implications for the development of technologies and policies relevant to farmers. Technologies or policies that increase the workload or time pressures on farmers are likely to be poorly received or adopted, unless they offer substantial benefits (or losses avoided). Increasingly, service and product suppliers will compete for the farmer's time as well as their pocket. The on-going challenge for technology and policy developers is to ensure their product or service is attractive to time-poor farm managers.

Farmers are more likely to be interested in labour-saving technologies and the cost-effective provision of a service by a contractor in periods when they are time-pressed. By illustration, larger machinery can boost labour productivity at seeding and harvest; direct drill technology can reduce the time farmers would otherwise spend on tractors at seeding; and GM crop technologies are destined, at least in the short to medium term, to facilitate weed management. Modern design of farm equipment and machinery, combined with vehicle and communication improvements deliver lifestyle benefits of safety, comfort and ease of access to information. So farm management is not inexorably linked to complexity and a burdensome workload. That said, the trend toward larger farms with more land management units and the likelihood of particular rotations or land use sequences being best suited to each land management unit, when combined with changing crop management technology, does suggest that the task of managing a broadacre farm is likely to remain a pressing challenge.

The difficulty in finding or creating highly profitable farming systems that are not unduly complex and burdensome to manage is not too dissimilar from the task reported by Robertson *et al*. (2009) who sought to identify profitable farming systems that generated manifold environmental benefits. As in this study they found some relatively flat trade-off functions where a wide range of similarly profitable but different farming systems could generate equivalent environmental outcomes. However, some types of environmental improvement incurred large reductions in farm profit. Also there were examples of simultaneous gains in some environmental indicators and farm profit. In short they found no single highly profitable farming system that delivered the entire suite of environmental improvements. In a similar way this study finds there is no highly profitable farming system that can be judged as simple according to all the measures of complexity.

5. Conclusion

Although several authors (e.g. McGuckian 2006; Hendrickson *et al.* 2008; Chavas 2008) acknowledge the complexity of agricultural production and journals such as *Agricultural Systems* are devoted to exploring the issues and problems that surround complex agricultural systems, nonetheless the study of the economic returns to complexity in agricultural systems remains largely neglected. Hence, the focus of this paper is to describe and measure complexity in broadacre farming systems in Australia and explore the relationship between complexity and farm profitability. Farm modelling is used to examine the returns to business and production complexity for broadacre mixed enterprise farming in an agricultural region of Australia.

The literature reports no widely accepted single measure of complexity to apply to agricultural businesses and production systems. Accordingly this study reports eight different measures of complexity and uses farm modelling to relate these measures to the profitability of a wide range of feasible broadacre farming systems in a major agricultural region of Australia. A sub-set of the more profitable farming systems is subject to further examination and rank correlations of profit versus each measure of complexity are calculated for these farming systems.

Drawing on the large set of feasible farming systems, rather than the sub-set of the more profitable systems, results show no consistent relationship between farming system profitability and all the measures of complexity. This implies there is no simple or consistent trade-off between farm profit and the various measures of system complexity when a large set of feasible systems is considered. Even when drawing on a sub-set of the more profitable systems, the measures of complexity yield different assessments of farm business complexity.

The metrics of the farmer's annual labour, land use or enterprise diversity, and revenue and expenditure diversity suggest profitable farming systems are complex and time-consuming to manage. By contrast, using the metrics of the mean and variance of the farmer's monthly labour, number of rotations and number of unique rotations suggests that highly profitable farming systems are not complex to manage.

Depending on which measure(s) of complexity is employed, it is feasible to simplify a farming system. However, some shifts which would be deemed a simplification according to some measures of complexity only make the system more complex according to some other measures of complexity.

Results in this study highlight a question for broadacre farm management: Which measure or feature of complexity poses such a challenge to the farmer that they would consider simplifying their farm business? Positing that the farmer's annual workload is proving problematic, especially given the ageing of Australia's farmer population and difficulties in employing skilled farm labour, an example of a different farming system is presented that incurs a 3 percent decline in farm profit yet reduces the farmer's annual work hours by 9 percent. In this case there is a slight negative trade-off between farm profit and this measure of complexity.

If the large annual workload of broadacre farmers is proving problematic, yet is one outcome of running a highly profitable farm business then there are important implications for technology and policy developers and service providers. Technologies, policies or services that increase the workload or time pressures on farmers are likely to be poorly received or adopted, unless they offer substantial benefits. The challenge for technology and policy developers and service providers is to ensure their product or service is highly attractive to time-poor farm managers. Designing services, products and farming systems that explicitly account for the time pressures farm managers face will be a feature of future broadacre agricultural R,D&E in Australia.

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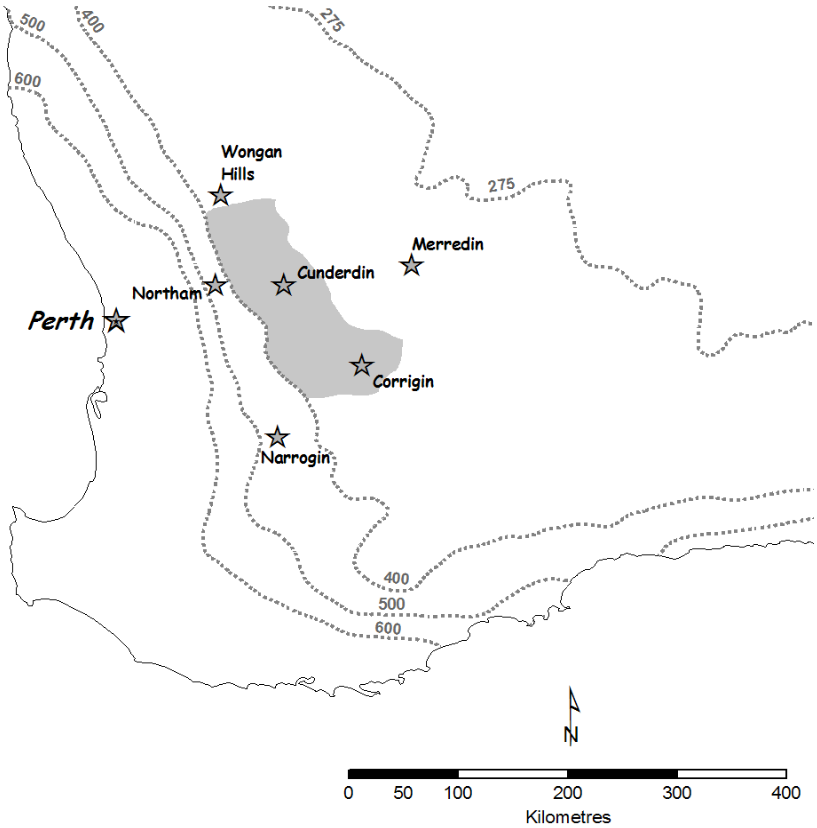

Figure 1 The region represented by the MIDAS Central Wheatbelt Model

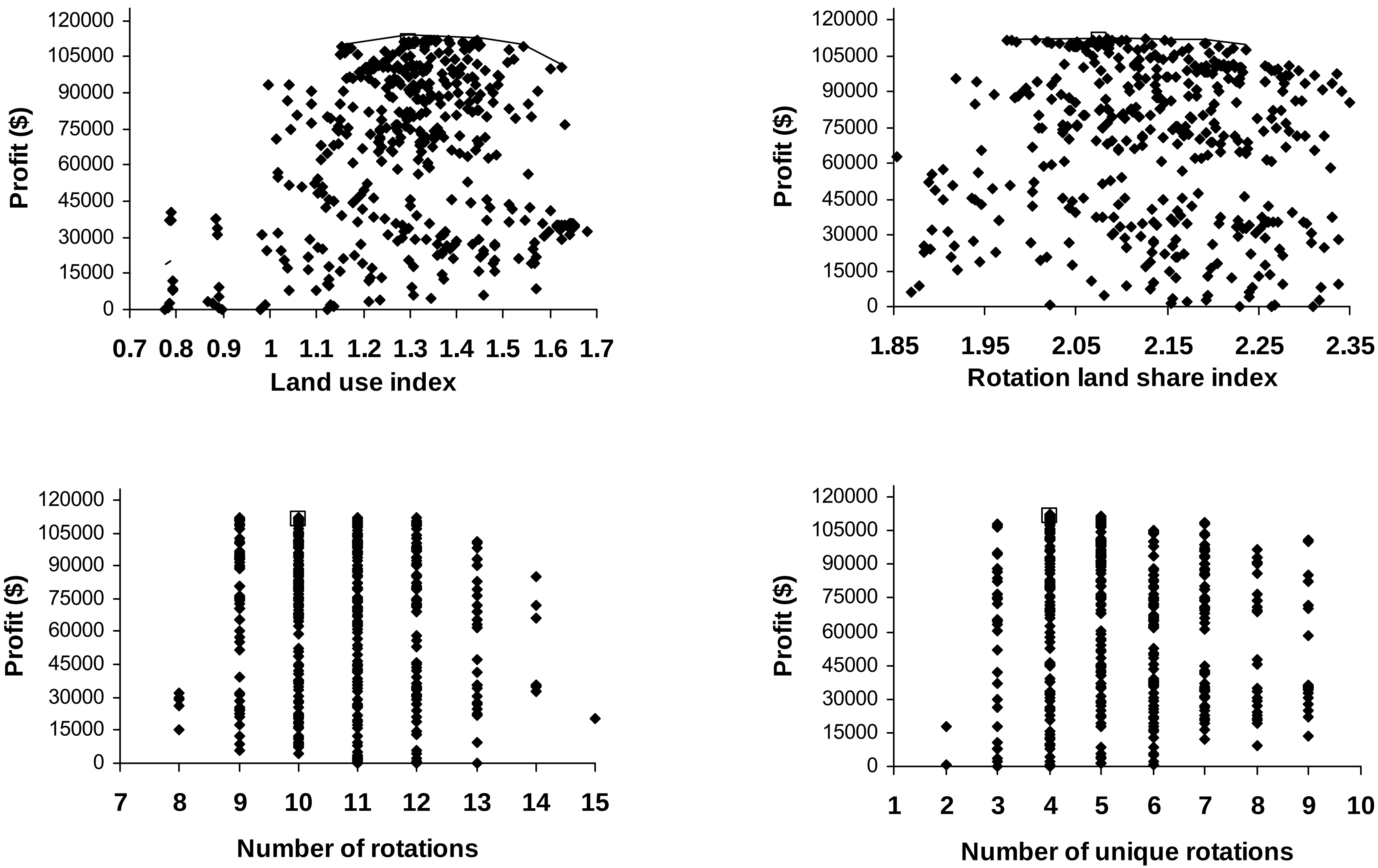

Figure 2 Land use and rotational indicators of farm business complexity based on averages of price and cost conditions over the period 2005 to 2009. The point of maximum farm profit is denoted by the small square.

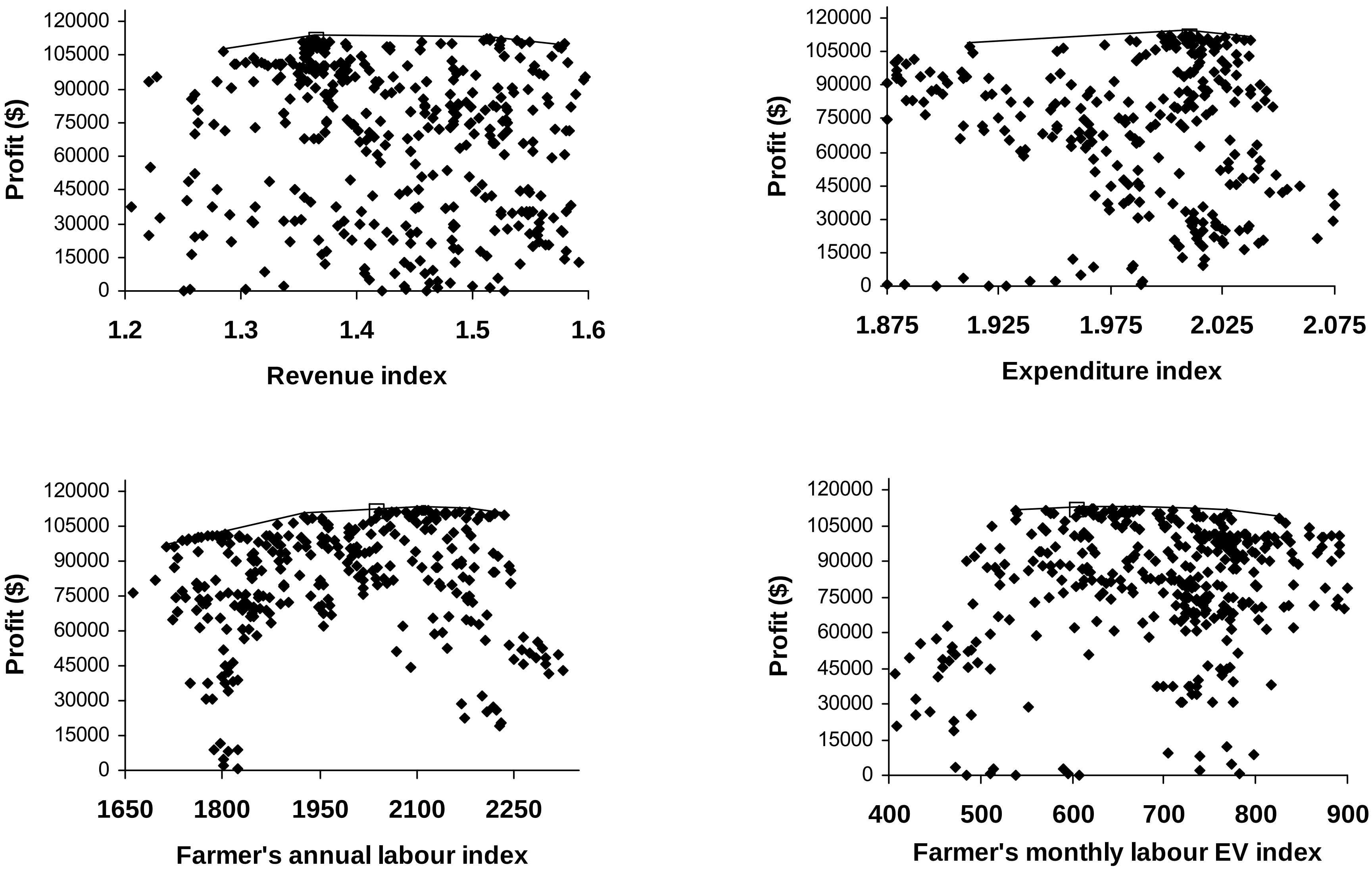

Figure 3 Revenue, expenditure and labour use indicators of farm business complexity based on averages of price and cost conditions over the period 2005 to 2009. The point of maximum farm profit is denoted by the small square.

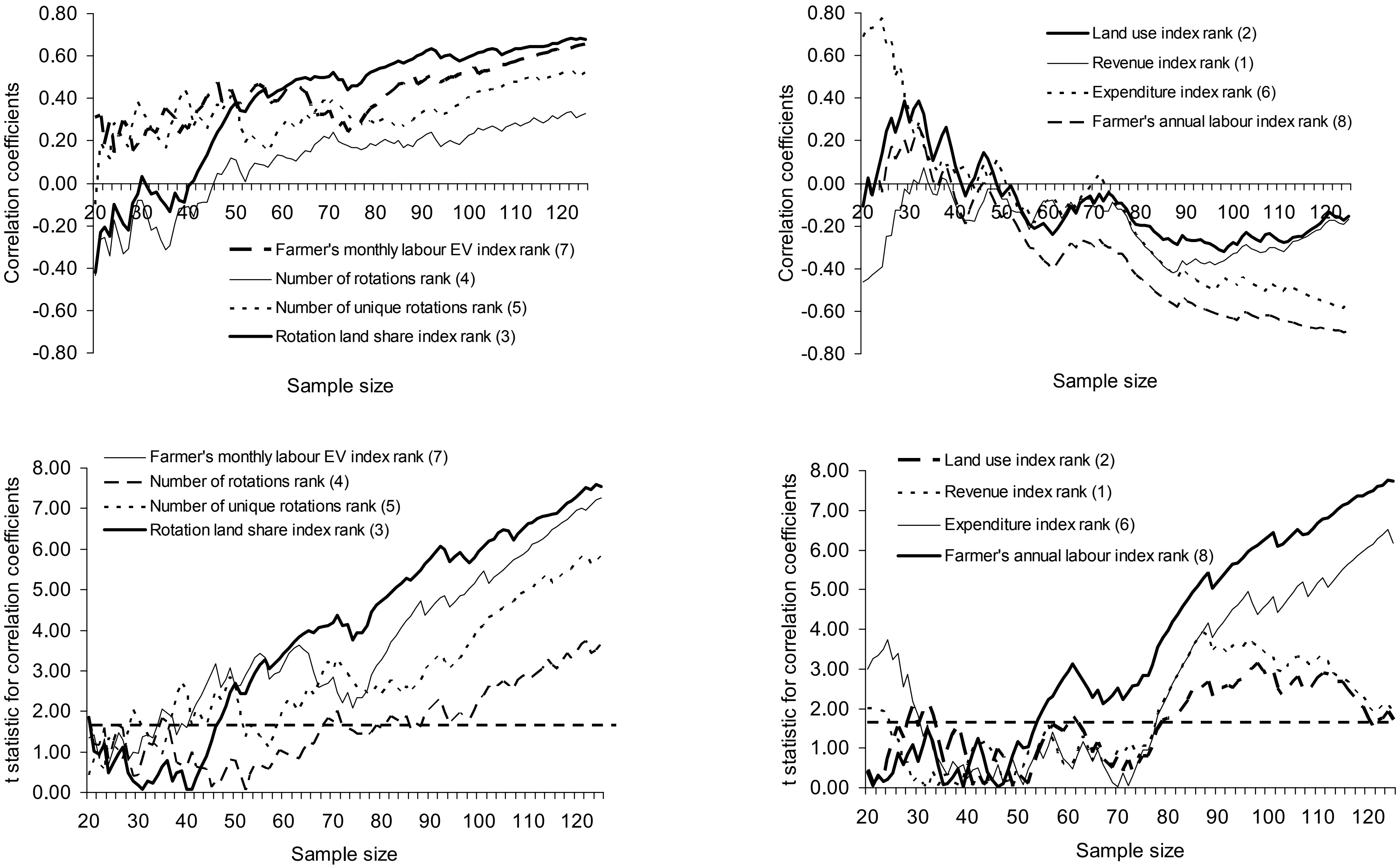

Figure 4 Rank correlations between profit and each complexity metric, the relevant t statistics for the rank correlations and their values as sample size increases. The horizontal dotted line is the level at which the t-statistic indicates a significant difference at the 5% level. Bracketed numbers in the legend refer to equations that describe each measure of complexity.

Table 1 Description of land management units (LMU) in the MIDAS model of the central agricultural region

LMU	Area of LMU in the farm model (ha)	Short description	Soil characteristics
1	140	Deep pale sand	Loose, white and pale yellow sands which are commonly over 2 metres deep with grey topsoil. Poor moisture and nutrient availability generates very poor crop and pasture growth.
2	210	Deep yellow sand	Yellow sandy soils that are commonly over 2 metres deep with brown topsoil. Cereal yields are limited by poor moisture and nutrient availability.
3	350	Yellow gradational loamy sand	Often containing large percentages of ironstone gravel and producing high cereal, lupin and pasture yields in most years. Not subject to waterlogging.
4	210	Sandy loam over clay	A soil downslope from LMU 1; on slopes of 2 to 8%. Hardsetting, heavier, grey to brownish soils with a 10 centimetre topsoil. The clay subsoil occurs at 10 tot 30 centimetres. Good moisture and nutrient availability.
5	200	Rocky red brown loamy sand/sandy loam, Brownish grey granitic loamy sand	Commonly found around rock outcrops and in minor drainage lines on slope gradients of 2 to 8%. Above average quality soil suitable for cereals, lupins and pasture. These soils may suffer from limited mositure availability in dry periods, waterlogging in seepage areas and shallow rock areas which limit root growth and reduce yields.
6	200	Red brown sandy loam over clay; Red clay valley floor; Grey clay valley floor	Heavy red and grey valley floor soils that produce good cereal and field pea crops and good medic based pastures. Production may be reduced due to soil structural decline and salinity.
7	300	Deep sandy surfaced valley; Shallow sandy surface valley soil	A sandy topsoil that ranges from 10 to over 100 centimetres in depth. A good quality soil suitable for cereal and pasture production, and where the sand profile is deep its also suitable for lupins. It is often subject to salinity, waterlogging and wind erosion.
8	390	Loamy sand over clay	Generally a productive soil with good moisture and nutrient availability. Waterlogging problems can occur in some years in areas of this soil on lower slopes. It is subject to traffic compaction pans, water and wind erosion.

Table 2 Rank correlation matrix (top 100 profitable farming systems) and t-values

Ranked Item	Profit	Land use index	Revenue index	Expenditure index	Farmer's monthly labour EV index	Farmer's annual labour	Number of rotations	Number of unique rotations	Rotation index
Profit	1	-0.28	-0.33	-0.47	0.53	-0.64	0.23	0.40	0.60
Land use index		1	0.61	0.40	-0.35	0.79	0.17	0.22	-0.16
Revenue index			1	0.49	-0.45	0.60	0.26	0.34	-0.15
Expenditure index				1	-0.41	0.58	0.17	0.30	-0.18
Farmer's monthly labour EV index					1	-0.59	0.04	0.15	0.43
Farmer's annual labour						1	-0.14	-0.12	-0.51
Number of rotations							1	0.78	0.70
Number of unique rotations								1	0.55
Rotation index									1

Rank correlation coefficient t-values. Bold values indicate statistical significance at the 95% level (t-critical is 1.64)

Ranked Item	Land use index	Revenue index	Expenditure index	Farmer's monthly labour EV index	Farmer's annual labour	Number of rotations	Number of unique rotations	Rotation index
Profit	**2.76**	**3.31**	**4.67**	**5.30**	**6.33**	**2.26**	**4.03**	**5.93**
Land use index		**6.09**	**3.95**	**3.46**	**7.84**	**1.67**	**2.20**	1.59
Revenue index			**4.87**	**4.50**	**5.97**	**2.63**	**3.36**	1.54
Expenditure index				**4.11**	**5.77**	**1.71**	**2.95**	**1.82**
Farmer's monthly labour EV index					**5.83**	0.45	1.50	**4.27**
Farmer's annual labour						1.36	1.18	**5.03**
Number of rotations							**7.78**	**6.97**
Number of unique rotations								**5.45**