1 Increasing variability and farms

1.1. Introduction

Climate change is a salient issue for southern Australia, which has been identified as one of the regions most vulnerable to climate change in the world (Head, Adams, McGregor, & Toole, 2014; Kirono, Kent, Hennessy, & Mpelasoka, 2011; Watson, Iwamura, & Butt, 2013). Australian agriculture already faces the highest rate of income variability in the OECD (Martin, 2013). Given this, agriculture in Australia can be rather glibly described as ‘the canary in the mine,’ due to the perceived vulnerability of farms to the impacts of climate change. The potential impacts of climate change on farms could be profound and may require that primary producers adapt their farms to a much greater degree than currently undertaken (Anwar, Liu, Macadam, & Kelly, 2013; Ash, Nelson, Howden, & Crimp, 2008; Howden, Crimp, & Nelson, 2010; Nelson, R., Kokic, Crimp, Martin, et al., 2010; Nelson, R., Kokic, Crimp, Meinke, & Howden, 2010). Generally speaking, it is expected that climate change will require considerable change to primary industries, with the responsibility for this change lying squarely with primary producers, many of which are small family businesses. In this research I explore the capacity of producers to adapt their farms in the face of climate change. Underpinning this exploration is a question regarding the role, if any, for public policy to support producers with managing climate change impacts.

Broadly, responses to climate change tend to be framed as either ‘mitigation’ or ‘adaptation’. Mitigation responses refer to limiting the severity of long-term climate change by reducing net carbon emissions while adaptation relates to responses for minimising the impacts of climate change (Fisher et al., 2007). Of interest to me in this research is the realm of adaptation. Interestingly, adaptation and mitigation responses may entail the same practical response within the farm. For example, alterations to fertiliser use and changes to cropping or grazing practices may be relevant to both adaptation and mitigation.

How producers change their farms through time in response to climate change may have implications for the future of primary industries (Stokes & Howden, 2010), rural communities (Pritchard et al., 2010) and the capacity of governments to achieve policy objectives[1]. This can relate, in part, to the potential for undesirable unintended outcomes, in terms of maladaptations (Johnston & Chiotti, 2000; Smit et al., 2001; Stokes & Howden, 2010). Given the vulnerability of farm businesses, and the potential for undesirable unintended outcomes, a fundamental question is whether there is an imperative for government to support farm adaptation to climate change. If government support for adaptation is needed, what should it entail? Understanding the capacity of producers to alter their farms over time will move toward clarity on the question of the role, if any, for public policy in supporting farm adaptation to climate change.

There has been considerable effort made to understand the threat of climate change and the potential adaptation responses to it in agriculture (for example, see Intergovernmental Panel on Climate Change, 2007; Johnston & Chiotti, 2000; Rickards, 2013; Stokes & Howden, 2010). Given my focus on exploring the capacity of producers to adapt their individual farms to climate change, the relevant literature comprises that in which climate change adaptation is considered at the farm level. What I suggest in the next section is that there is actually little research, indicating a gap in knowledge, regarding how current producers can alter their farms as they move into a future with a changed climate.

To understand the capacity of producers to change their farms through time, it is necessary to consider some important relevant concepts from the climate change literature that will point to a meaningful conception of the problem being addressed. First, I will consider the distinction between the impact of short-term variability and

[1] Such as Victoria's aim to double the state's agricultural production by the year 2030 (Department of Primary Industries, 2013).

long-term trends. It is through this distinction that a picture begins to form for understanding how producers respond to climate change. Second, I will look at the notion of adaptation in the literature as a core construct for describing change in farms. Third, I will consider barriers or constraints on adaptation as a way of framing determinants of farm-level decisions.

1.2. Long-term trends and variability

Broadly, climate change research in agriculture has considered the potential impacts of climate change (as determined by entity exposure and sensitivity) (Meinke & Stone, 2005; Nelson, G. et al., 2009) and the capacity to reduce these impacts through adaptation (also called adaptive capacity) (Adger & Vincent, 2005; Füssel & Klein, 2006; Nelson, R., Kokic, Crimp, Meinke, et al., 2010; Park, Howden, & Crimp, 2012). The vulnerability of a system (for example: community, industry, ecosystem or farm) is a function of adaptive capacity and potential impacts. Vulnerability is described in some research in terms of resilience (Cork, 2010; Smit & Wandel, 2006).

When considering the capacity of producers to adapt to climate change, we must first ascertain what it is that producers are adapting to. That is, what are the impacts that are leading to current and future changes on farms? Climate change is predicted to lead to significant impacts through changes in long-term trends and increased variability (Intergovernmental Panel on Climate Change, 2007, 2012).

While the increasing body of research about long-term trends is clearly useful to society and governments in considering broad implications of climate change, the usefulness of this research is less clear when considering the viability of farming. For example, when Howden, Soussana, Tubiello, Chhetri, and Dunlop (2007) analyse the adaptation options in wheat production by modelling the benefits of adaptations in a future of different projected future temperatures, they acknowledge that variability associated with flood and drought currently account for 15 to 35 per cent of yield variation of wheat, oilseeds and coarse grains. While it may be argued that producers are beginning to adapt their farms already to long-term trends (Pannell, 2010a), what is questionable is whether producers will be so crippled by increasing short-term variability that this longer-term adaptation is not possible. This suggests that it is not long-term trends that threaten the viability of current farms; rather, it is the increased dynamic variability[2] in the task environment.

Variability is not new to Australian producers. Within Australia, farms are some of the most exposed businesses to the whims of the weather and other sources of variability. Reeve, Marshall, and Musgrave (2002) eloquently describe the practical reality of farming:

> Although farmers tend to have relatively more political power that many other groups that make up a similarly small proportion of the national population, they nonetheless experience a great deal of powerlessness in other ways. These include their inability to insulate themselves from the unpredictable swings in prices and seasonal conditions. The rhetoric of empowerment will often have a hollow ring about it for those on the roller coaster of variable prices and seasons. (p. 15)

In this perennial reality, producers constantly make changes to their farms to manage variability, which makes adaptation a normal part of farm management (Pannell, 2010a).

Variability, as described in this research, rarely leads to benefits for producers. While variability may generate benefits, the likelihood of variability generating disbenefits is higher. This is because variability can come from a number of different critical inputs and values either side of their averages, from one season to the next, may harm production. For example, a recent heatwave in Victoria led to a drop in milk output (Bruns, 2014); a subsequent cold spell will not offset this impact.

Climate change is expected to increase variability in critical inputs, such as temperature and rainfall, that producers must manage if they are to maintain viable businesses (Intergovernmental Panel on Climate Change, 2007, 2012; Stokes & Howden, 2010). As well, increased variability may also offer opportunities to producers that were not previously available (Meinke & Stone, 2005). The consequences of increased variability for farms will be determined by producers' capacity to manage any increased variability so that it does not translate into negative impacts on farm output quantity and quality, and to harness opportunities to achieve potential benefits.

[2] Based on Child (1972), variability in this research is the degree of change in components of the environment that interact with the farm (termed as inputs and outputs of the farm system) and a function of the frequency, magnitude and irregularity in the overall pattern of change.

While farms are being adapted now in response to increased variability and climate change (Ash, Stokes, & Howden, 2010; Pannell, 2010b), little is known about how this may affect the capacity to make adaptations in the future (Adger & Vincent, 2005; Risbey, Kandlikar, Dowlatabadi, & Graetz, 1999). For example, there are costs associated with the change process (Cowan, R. & Gunby, 1996). As well, decisions that are made about farm configurations may define the options for adaptations that are possible into the future on the farm. What farming and rural communities will look like in the future will be determined, to some degree, by the decisions made by current producers to manage the myriad variability shocks in the short-to-medium term. This implies that analysis of the capacity to adapt in the future should include consideration of the influence of historical adaptations in the farm.

The response needed from producers to manage the long-term effects of climate change is slow, while the shorter-term effects of increased dynamic variability require producers to act quickly. This places increased climate variability at the forefront of concern in relation to the viability of agricultural businesses in southern Australia. The dynamic reality of compounding variability (e.g. back-to-back years of drought or changing market prices and flooding) means that the variability issue is complex. This suggests that constraints or limitations on adaptation can be compounded. Consideration of the dynamic interaction between sources of constraints is crucial for understanding the capacity of producers to manage this variability. In reality, frameworks that can be applied to compounding effects are not common, particularly when trying to capture the variety of constraints on small businesses. Path dependence is one such framework that is considered in this thesis (Arthur, 1989).

Given my concern with the capacity of producers to adapt their farms to the dynamic reality of variability, the appropriateness of options for responding to variability will be determined by context (elements of the farm and environment that influence the operations of the farm business) (Kaine, 2008; Pannell, 2010a). This means that research intending to identify useful adaptation options needs to consider context in analysis and needs to be scaled to the farm level. There has been research to identify options for adaptation (for example, see Dwyer, Gunner, & Shepherd, 2009; Stokes & Howden, 2010). This research does not extend to exploring the practicality of integrating these adaptations into existing farms (Kerr & Mooney, 1988; Risbey et al., 1999).

1.3. Understanding adaptation

Given the nature of the problem being considered, what I have argued so far is for a need to focus research on variability management at the farm level, with a mindfulness of context. A broadly agreed assumption regarding increased climate variability and agriculture is that change will be needed in how farms are configured and managed. A concept from the climate change literature that is often used to describe changes made to a system, such as a farm, in response to climate change impacts is 'adaptation'[3] (Smit, Burton, Klein, & Wandel, 2000).

The notion of adaptation can be described as a rather loose concept. Two issues arise when considering adaptation in the climate change literature. First is the question of distinguishing adaptations from activities or behaviours that are not adaptations. Second is the lack of clarity on how to usefully compare adaptation options in particular farm contexts.

Given the importance of considering change at the scale of the farm, this entails observing activities on farms. However, 'activity' is the day-to-day reality on farms which, on the face of it, could be perceived as serial adaptations. Conversely, adaptations that are being made may be missed within the sequences of farm activities. Without a clear distinction between adaptations and other farm activities, how can adaptations to increased variability be understood? There is little consideration of this issue in the climate change literature with a notable exception in farm control theory (Cowan,L., Kaine, & Wright, 2013; Kaine & Cowan, 2011).

Once adaptations have been distinguished from other farm activities, a second issue arises relating to a lack of meaningful approach for comparing adaptations on farms. Much of the research focusing on impacts of and responses to climate change and variability in farms has approached the problem via the use of simulation models (for example, see Berger & Troost, 2013; Hanslow, Gunasekera, Cullen, & Newth, 2014;

[3] Adaptation is sometimes defined in terms of making 'adjustments' to the system (Smit & Wandel, 2006). Adjustment will not be used in this research as a synonym for adaptation, in order to avoid confusion with the term 'agricultural adjustement 'in Australian agriculture which refers explicitly to exiting from the industry.

Howden et al., 2007; Klein, Holzkämper, Calanca, Seppelt, & Fuhrer, 2013; Meinke & Stone, 2005; Mukherjee, Bravo-Ureta, & De Vries, 2013; Stokes & Howden, 2010). A commonality across these approaches is that they do not enable consideration of farm-specific circumstances. The feasibility and relative costs associated with adaptations will differ across farms, depending on context (Kaine, 2008; Marshall, Stokes, Howden, & Nelson, 2010). These costs can be short-term, relating to those associated with incorporating the change within the farm. The costs could also be long-term, relating to the irreversibility of decisions. This notion of irreversibility may be fundamental to considering the impact of responses to short-term variability on the capacity of producers to respond to long-term trends.

The first steps to considering how adaptations can be compared is offered by Howden et al. (2010). Their model (see Figure 1.1) touches on a link between the current reality and potential futures in a hypothesised relationship between incremental and transformational change. These authors suggest that, as climate change progresses, the complexity, cost and risks of adaptations are expected to increase, leading to increasingly transformational innovations. While the Howden et al. (2010) model is a useful starting point, arguably, the constructed meanings along the continuum of 'incremental' to 'transformational' change have not been defined in a way that enables useful analysis in the practical reality of farms. What constitutes complexity, cost, and risk may not be generalisable across farms.

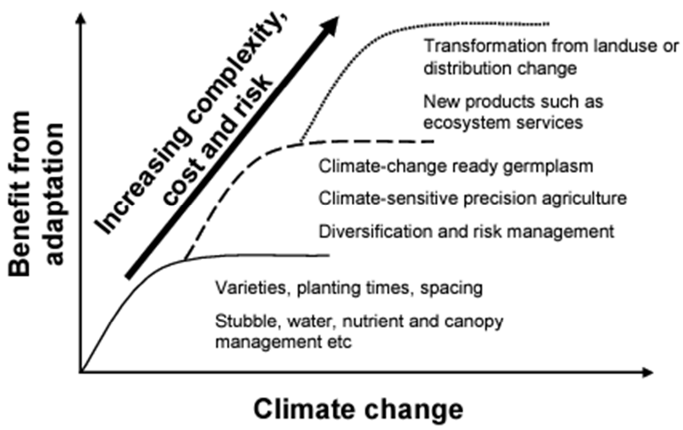

Figure 1.1: Illustration of conceptual model depicting relationship across degrees of adaptations the progress of climate change, from Howden et al. (2010)

As well, the concept of ‘transformational change’ can appear nebulous. On one hand it may be an aspirational description of the future world after farms have performed sequences of incremental adaptations over years. On the other hand, it can describe radical change decisions. The meaning of transformational change is unclear and the contribution of the idea to analysis equally so. Nonetheless, the concept has emerged as a popular construct in the climate change literature (for example, see Anwar et al., 2013; Ash et al., 2008; Cork, 2010; Folke et al., 2002; Kates, Travis, & Wilbanks, 2012; Walker, Abel, Anderies, & Ryan, 2009).

1.4. Constraints on adaptation

While much has been done to identify potential impacts of climate change on farms, and to offer generalised adaptation options, more research is needed to understand the capacity of producers to adapt their farms. In this research I consider constraints on adaptation as a way of framing determinants of farm adaptation decisions. Constraints can broadly be described as barriers or impediments to change.

In the Marshall et al. (2010) framing of vulnerability, adaptive capacity is described as a function of operating context, knowledge and options, and individual capability (see Figure 1.2). Howden et al. (2010) suggest that population growth and consumption patterns, elements outside of the producer’s control, will affect adaptive capacity. In a comprehensive review of the literature on climate change adaptation in agriculture, Rickards (2013) provides a collection of observed constraints on adaptive capacity in primary production, though rural communities are included in this framing of primary production (see Table 1.1).

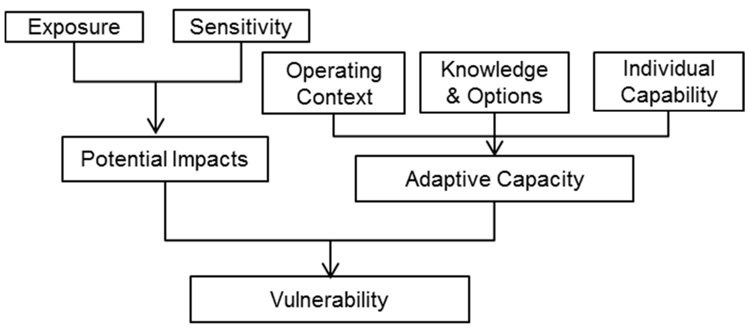

Figure 1.2: Determinants of vulnerability in agricultural systems, adapted from Marshall et al. (2010)

Table 1.1. Main adaptive capacity constraints in Australian primary industries suggested to date, adapted from Rickards (2013)

Type of capital	Adaptive capacity constraints in some populations or areas of primary industries suggested by research to date
Human capital	Poor physical and mental health Unhelpful coping strategies Low levels of understanding and acceptance of climate change Distorted perceptions of climate change and risks of different response options Time scarcity
Social capital	Poor social networks and support Lack of government support Labour constraints and lack of alternative employment Eroding or constraining intergenerational bonds Unhelpful cultural norms Threats to consumer support Constraining industry characteristics Inadequate research and professional capacity
Financial capital	Limited on-farm investments Excessive or limited access to credit
Physical capital	Limits to current productive biodiversity, including genetic diversity Limits to and limitations of irrigation
Natural capital	Natural limits to carrying capacity Loss of landscape quality Path dependence
Cross-capital issues	Conflicting goals Development trajectories Barriers to participation Barriers to climate change communication Barriers to coordination

Rodriguez et al. (2011) argue that adaptation generally requires “relevant experiential information” (p. 158). Given the uncertainty associated with climate change, they propose an approach that includes producers in scenario modelling on four simulated farm businesses. Results suggested that producers who were able to more readily alter their farms in response to variability, which they describe in terms of ‘plasticity’, achieved higher levels of farm profit. Interestingly, Rodriguez et al. (2011) found that there were a number of factors, some of which could not be explicitly incorporated into their simulated farms, which influenced farm decisions (see Figure 1.3). Even so, there is little discussion in the research regarding the elucidation of these factors in the research process.

Webb, Stokes, and Marshall (2013) explicitly consider socio-economic constraints in their research to assess adaptation options in agriculture. The constraint criteria in this research were described in terms of effectiveness, flexibility, economic efficiency, ease of implementation, co-benefits, trialability, institutional compatibility, desirability, feasibility, and aspiration to implement. After interviewing farmers to gauge their views about 12 adaptations according to these criteria, Webb et al. (2013) compared interview results to the findings from modelling of potential benefits.

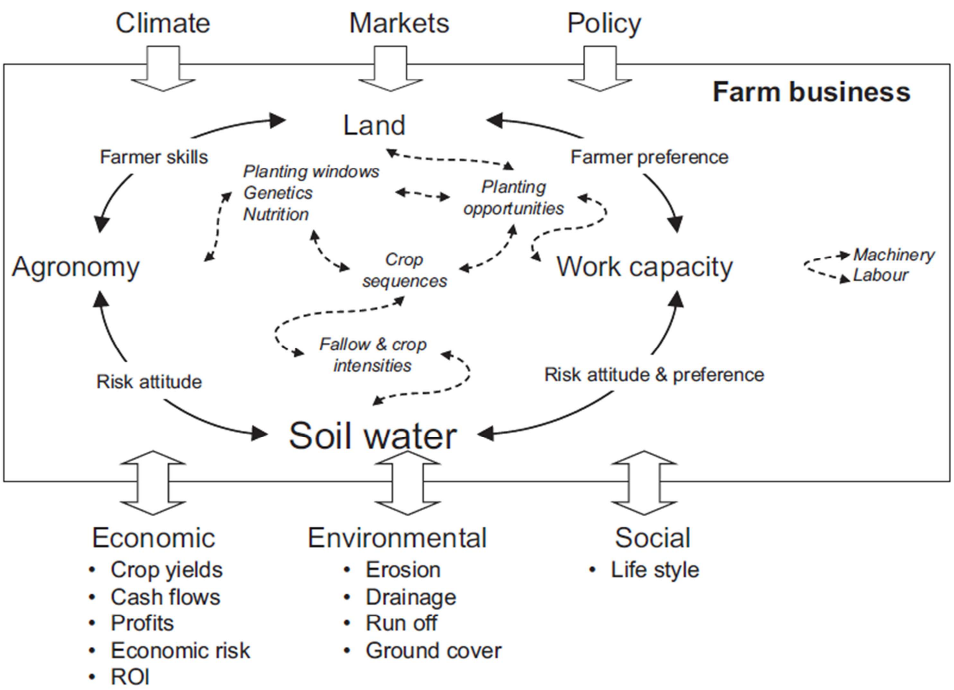

Figure 1.3: Determinants of the farm system behaviour, from Rodriguez et al. (2011)

While this work is a step towards a fuller picture of constraints in farms there are limitations. There is little discussion of the rationale for the set of socio-economic constraint criteria. This makes it difficult to understand the thinking underpinning the demarcation of relevant constraints. As well, the work appears to be based on an assumption of homogeneity among farms, as the comparison of adaptations emphasises options that had the most support and least support. The authors acknowledge that their approach did not offer a full analysis on constraints when they indicated that the "associated transaction costs of improving land condition were not captured in the model assessment, and accounts for much of the disparity in the model and stakeholder assessments of the adaptation option" (Webb et al., 2013, p. 1174). Arguably, there could be other constraints besides transaction costs that account for disparity in the results, though without clear insights regarding the constraints criteria this cannot be known.

A key constraint that is especially pertinent to farm management decisions in the face of climate change is uncertainty. Producers are under mounting pressure to make major changes to their farms (Nelson, R. et al., 2010). However, the complexity of the climate change problem, as well as limitations in information and knowledge about its impacts, creates irreducible uncertainty regarding how to respond (Adger & Vincent, 2005; Anwar et al., 2013; Ash et al., 2010; Jotzo, 2010; Shankar, 2013; Vermeulen et al., 2013). This uncertainty is compounded as consideration moves from the global to regional to local scale (Adger & Vincent, 2005; Risbey et al., 1999; Stokes & Howden, 2010). This means that producers face an increasing number of unknowable and unpredictable changes in their operating environment (Debelle, 2010; Knight, 1921; Wright, 1984). This increased uncertainty means that methods previously used by producers to manage variability may no longer be sufficient. As Wright (2011a) states, in relation to farm management decisions, “substituting information with hope . . . is not a solution” (p. 8).

What is apparent in these identified adaptation constraints is that they are multifaceted and require multidisciplinary consideration. This may not be surprising, given that farms are managed biophysical production systems within socio-ecological systems. An implication of this is that there is no single research discipline which can characterise all of the relevant factors that constrain decisions in the practical reality of farms. A multidisciplinary approach may be needed to ensure all relevant constraints are considered.

Additionally, these identified constraints are likely to be interactive and cumulative. By this I mean that constraints may not work in isolation; instead, they may act to amplify each other. Using the Marshall et al. (2010) categories of constraints as an example, it is possible that a constraint on individual capability will interact with knowledge and perceptions of options for the farm. An approach to understanding constraints in this context needs to enable consideration of the interaction between constraints, including the potential for compounding constraints.

An important consideration about constraints on adaptations is that impediments to particular adaptation options may push producers toward other adaptation responses, which may lock them into particular trajectories or paths. This may have implications for the capacity of producers to make adaptations through time on their farms. That is, while it is expected that farms will be adapted (Pannell, 2010a; Stokes & Howden, 2010), it is uncertain whether farms will be altered in ways that provide the best outcomes for farm businesses (and public benefits). Given that any changes in practice can either facilitate or constrain future decision options, understanding the latter is quite important for supporting long-term viable farm systems in the face of climate change (Adger & Vincent, 2005; Dwyer et al., 2009).

Much of the literature about climate adaptation in agriculture identifies a role for public policy in supporting farm adaptation. Smit and Skinner (2002) go so far as to say that the term "adaptation is often considered as a government policy response in agriculture" (p. 86). Marshall et al. (2010) argue that climate change will "require strong support from government and industry institutions if agricultural resources and the extended social systems dependent on them are to be sustained" (p 246). Pannell (2010a) argues that adaptation is happening and policy support needs to be offered under a clear rationale for government intervention.

Just as producers are facing increasing uncertainty, those making and implementing policy face increasing uncertainty. The complexity and uncertainty associated with climate change, as well as conflicting views about causation and appropriate responses, generate a number of challenges for policy (Friman & Strandberg, 2014). Thinking critically about the role, or not, of policy in supporting farm adaptation to climate change is critical to the future of Australian agriculture for two reasons. First, government will be under increasing pressure, as variability increases, to help farm businesses cope with ever-increasing waves of poor performance. Analysis of useful policy options will help direct limited resources into targeted programs. Given that agriculture is not the only sector in Australia that needs to manage climate change, targeting resources effectively will be important.

Secondly, there may be a need to change the policy settings to achieve public benefits in ways that alter constraints on farms. Policy decisions, such as mitigation responses to climate change, may unwittingly influence the capacity of producers to manage the impacts of increased climate variability. From this perspective it is clear that policy itself can be framed as a constraint on farms. Hence, sound public policy is crucial in developing an effective response to climate change (Janis, 1992).

1.5. Dairy production in northern Victoria

While the issues described in this chapter are relevant to Australian agriculture, in general they are especially relevant to the dairy industry. Dairy production operates within a commodity market and near-perfect competition. This means that dairy producers have very little control over their output beyond the farm gate. Options to access niche markets that may be used by other producers (e.g. fruit, vegetables and herbs) are not, currently, an option for Australian dairy producers. This means that dairy producers must manage their business performance within the production system itself. The efficient use of infrastructure (e.g. an irrigation system, milking shed, feed pad) is critical for managing performance within the production system. However, the use of such infrastructure implies embedded costs, including those associated with the influence current infrastructure has on adaptation options for the dairy farm.

The dairy industry is the largest rural industry for Victoria, Australia (Department of Environment and Primary Industries, 2014). As well, Victorian dairy supplies more than 85 per cent of Australia’s export dairy product (Department of Environment and Primary Industries, 2014). Multiple years of drought, changes in irrigation policy and an increase in the value of the Australian dollar have had an impact on the Victorian dairy industry (Crase, 2010; HMC Property Group, 2010). Given the sensitivity of Victorian dairy to variability in price (e.g. commodity/value of the Australian dollar) and water access, understanding the constraints on adaptation to this industry could significantly benefit policy intended to support viable the industry into the future.

In this chapter I argued that producers are constrained in the set of options available to them regarding feasible adaptations to their farms. These constraints are multifaceted and entail the sequential and compounding changes made to the farm through time. Understanding the capacity to adapt the farm, then, logically needs to consider these dynamic constraints. Path dependence offers a lens for framing these constraints in a way that I believe offers insights regarding the practical reality of farming and clarity about the role of policy in supporting farm adaptation to climate change.

2 Existing research for understanding constraints in farms

2.1. Introduction

It has been argued in the previous chapter that increased variability due to climate change is likely to present threats and opportunities to Australian producers. What this means for the future viability of farms depends on the capacity of producers to respond to these threats and opportunities. To consider how producers are able to respond in changing circumstances it is necessary first to understand how they currently manage variability. Current approaches producers use to manage variability inform, to some degree, what approaches may look like in the future. Second, it requires consideration of the factors that influence the capacity of producers to manage variability. It is hypothesised in this research that path dependence offers a lens for framing these factors, or constraints, that influence the capacity of producers to manage variability.

The fundamental aim of this research is to understand the constraining effect of path dependence on the capacity of producers to manage the increased variability associated with climate change. A necessary starting point towards achieving this aim is to define and describe the meaning of key constructs in this statement. The layers of meanings are best understood within the domains of relevant literature; hence, the literature will be used in this chapter to establish useful conceptual boundaries for this research.

First, general systems theory (GST) literature will be used to conceptualise how producers manage variability. After this, constraints on the capacity of producers to manage variability will be considered through the lenses of path dependence and image theory. The focus will then turn to identifying how to characterise the farm business in terms of constraints, through a construct of a farm as a value chain. The concepts drawn from farm control in GST, path dependence, image theory and value chain analysis will then be incorporated into a conceptual model for characterising the constraints on producer decision options in managing variability.

2.2. General systems theory

This research is built upon a systems-theoretic perspective of farms. A systems approach offers a way of considering both how the elements of the farm interact with each other and how the farm interacts with the environment. It is through the management of interactions that producers manage relevant variability in their environment.

In this section relevant fundamental system concepts will be defined and described. Attention will then be directed to the consideration of what systems theory offers the analysis of managing variability in farms. From there, implications will be identified for the development of a conceptual model of the constraints on producer decisions made to manage variability.

General systems theory (GST) arose from an interest in identifying principles and rules that are relevant across different disciplines, described as isomorphisms (Miller, 1965; 1968). These isomorphisms include the notions of emergence, hierarchy and control. It was hoped that identifying common constructs to describe entities across all disciplines would make cross-disciplinary research more effective as well as offer a way to map real-world complexity (Germana, 2000; von Bertalanffy, 1975).

From this origin, systems approaches have spread across multiple disciplines, and across multiple epistemological perspectives. Ison (2008) offers a visual representation of some of the contemporary contributors to systems theory across a diverse range of disciplines (see Figure 2.1). Some approaches continue to focus on identifying relevant principles and rules across systems, such as the taxonomy of isomorphisms considered in the ‘system of system processes’ approach (Troncale, 2006, 2009). Other approaches emphasise theory development and application around particular isomorphisms, such as system dynamics in which stocks and flows are used to model the dynamics of feedback in complex systems (Forrester, 1989); or cybernetics (Ashby, 1999), which von Bertalanffy (1975) describes as a “special case” of GST, because of its exclusive focus on control (p 122).

There are also other systems theoretic approaches that emphasise the application of system concepts to address contemporary problems. For example, Bellamy, Walker, McDonald, and Syme (2001) offer a systems approach to evaluating natural resource management programs. As well, Ison (2008) considers the role that systems thinking can play in enhancing success within the discipline of Action Research.

My research falls within the category of systems research that emphasises the application of systems concepts to address contemporary problems. My intention is to apply systems concepts to salient problems within farms from the perspective that this offers promise that new ways of thinking about these problems and solutions will emerge from applying this construct of the farm. Hence, it is important that the notion of ‘system’ be seen as a metaphor of a farm system rather than as a representation of a farm (Atkinson & Checkland, 1988; Weinberg, 2001).

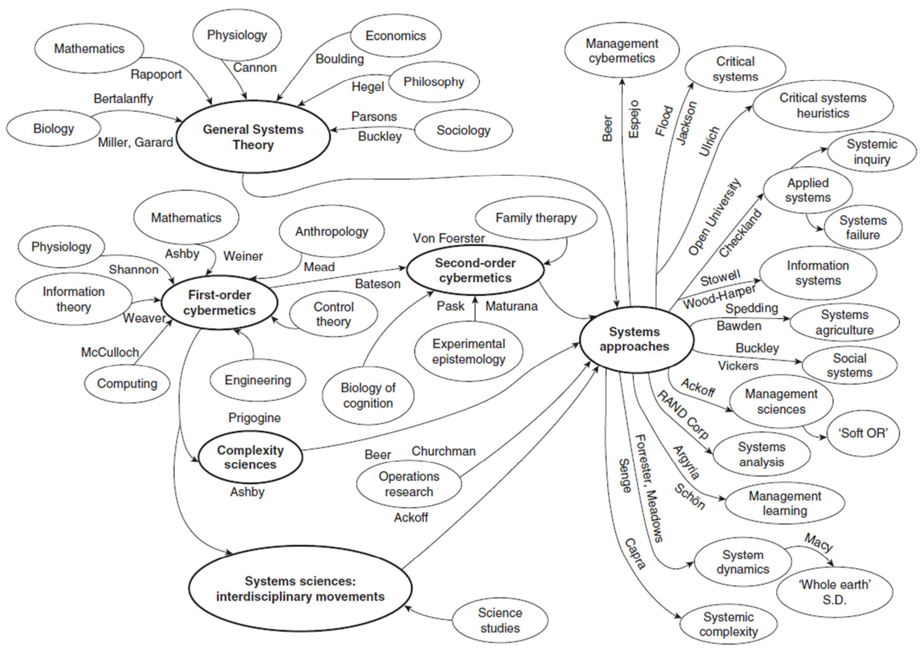

Figure 2.1. Ison’s (2008) model of influences that have shaped contemporary systems approaches

2.2.1. Farms as purposeful open systems

A system is a perceived whole comprising interconnected components (Checkland, 1996; von Bertalanffy, 1968). Components, or parts, are elements of the system that can be described discretely. The interconnections, or relationships, between components represent the nature and degree of interdependence between components (Angyal, 1969; Feibleman & Friend, 1969). A system is bordered by a boundary separating it from the environment. Ison (2008) indicates that the boundary is determined by "where control action can be taken" for the system (p 141). The environment, or suprasystem, in systems theory refers to aspects of what is outside of the system. Some systems are open systems, which means they interact directly and indirectly with their environment (Denbigh, Hicks, & Page, 1948; Drack, 2009; Katz & Kahn, 1969; von Bertalanffy, 1969).

A characteristic of systems theory is that what constitutes the system is greater than a summation of individual components, due to emergent properties (Checkland, 1996; Germana, 2001; von Bertalanffy, 1968; Weinberg, 2001). The notion of emergence indicates that what constitutes a system comes out of the components and how they have been arranged within the system to emerge into something new (von Bertalanffy, 1968).

Emergence is demonstrated through system behaviour. A system exhibits behaviours, which can be described as the observable aggregate responses of the system to stimuli (Weinberg, 2001). The output produced, in the broadest sense, is the aggregate expression of system behaviour on farms. How system components and relationships are organised or arranged within the system is a determinant of system behaviour (Angyal, 1969; Dillon, 1976; Weinberg & Weinberg, 1988).

The general systems principle of equifinality indicates that a system can be organised in different ways to achieve the same final state (Katz & Kahn, 1978; von Bertalanffy, 1968). Conversely, due to emergence, two systems which are organised in the same way may arrive at different final states. While the final state of an open system can be reached from different initial conditions and in different ways, if a system is strongly organised to emphasise one path towards a final state, this will limit the system's flexibility through a reduction in its capacity to switch to other path options (Burton, 1939; Gresov & Drazin, 1997; Katz & Kahn, 1969; von Bertalanffy, 1968).

Farms are conceptualised as purposeful open systems in this research. Purposeful open systems are considered in relation to their interaction with elements of the environment to achieve goals (Ackoff & Emery, 1972; Dillon, 1992). The purpose of the farm system, like all businesses, is fundamentally to achieve a profit (increasing net equity)[4] (Argenti, 1989). A useful construct for considering how producers achieve this purpose is the systems notion of hierarchy (van Gigch, 1974; von Bertalanffy, 1968). Hierarchy is a system isomorphism, indicating that the complexity of systems can be understood within a hierarchical order (von Bertalanffy, 1968), emphasising the interconnectedness of the system with layers of subsystems and the suprasystem.

How producers seek to achieve the purpose of the farm business can be conceptualised within a hierarchy of plans running parallel to a closely interrelated hierarchy of goals (see Figure 2.2) (Cowan, L. et al., 2013; Wright, 1984). The hierarchy of plans is about *how* the business operates and the hierarchy of goals describes *why* the business operates as it does.

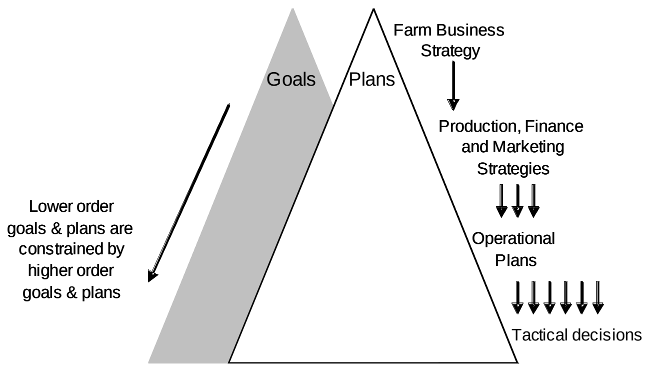

Figure 2.2: Example of the hierarchy of plans and goals in a farm business, from L. Cowan et al. (2013)

The hierarchy of plans commences with the farm business strategy, which is the fundamental decision about what the business is going to produce and for whom. Once

[4] This is not to imply that a producer may not have other purposes for the farm, such as those relating to personal and family goals (e.g. intergenerational issues)(König, Kammerlander, & Enders, 2013). However, profit is defining of the capacity to satisfy all other potential purposes as long-run profit is fundamental for survival of the business; a necessity for the achievement of other purposes.

the business is defined, lower order plans are developed, which are increasingly elaborate and specific statements of how the business is to achieve its purpose. These plans represent the decisions regarding how the farm production system is organised to produce the outputs defined in the farm business strategy. It is within the hierarchy of plans that the impacts of constraints on decisions will be manifest.

In farm businesses, the hierarchy of goals commences with a higher-order goal of survival of the farm business (Child, 1972; Dillon, 1992; Miller, 1965; Murray-Prior & Wright, 2004). Higher-order goals constrain subordinate goals. Hence, beneath the higher-order goal of survival, subordinate goals are determined based on the needs and resources of the farm (Murray-Prior & Wright, 2004; Wright, 1984). Given the interrelationship between the hierarchy of goals and plans, the higher and lower-order goals for the farm system are reflected in the hierarchy of plans, including strategic decisions and the day-to-day operations. (Cowan, L. et al., 2013; Murray-Prior & Wright, 2004; Wright, 1984).

All points in the hierarchy of plans (below the purpose) and hierarchy of goals can be revisited and altered. However, changes to lower order plans or goals need to align with higher-order plans and goals (Collinson, 2001; Kaine, 2008; Miller, 1965; Nalson, 1964). Consideration of the interrelated hierarchy of plans and goals in farms is important to this research, as higher order goals and plans constrain lower-order goals and plans.

Hierarchy offers a way to organise consideration of the influence of elements outside of the farm system, with the ‘general’ environment enveloping the ‘task’ environment. The general environment includes all elements outside of the system, directly or indirectly interacting with the farm. A lower order subset of the environment is that of the task environment, which comprises elements of the environment that currently and directly affect the system (Bourgeois, 1980). Distinguishing the task from the general environment enables useful categorisation of different types of constraints on decision options for producers.

2.2.2. System stability

Farm systems are dynamic. Inputs flow into the farm and are transformed through the biophysical production system into outputs. Maintaining the flow of inputs through to outputs is an essential factor for achieving the higher order goal of system survival. In the systems literature this is described as maintaining system stability, also called steady state (Allison & Hobbs, 2006; Ashby, 1999; Burton, 1939; Denbigh et al., 1948; von Bertalanffy, 1975)

Stability is a description of the capacity of the farm system to maintain system behaviour within acceptable limits in the face of perturbations from the environment (Burton, 1939; Denbigh et al., 1948; von Bertalanffy, 1968, 1975). Stability is managed, in part, by maintaining a sufficient range of acceptable behaviours to match the range of expected states in the environment (Ashby, 1999; Kremyanskiy, 1969). This, in turn, requires a capacity to match decisions by the decision-maker to the need for change within the system (van Gigch, 1974). Given instability poses a threat to system survival, maintaining steady state will be preferred by producers and will be reflected in decision-making regarding the configuration and management of the farm (Kaine & Cowan, 2011; Miller, 1965).

2.2.3. Questions remaining

A number of fundamental concepts from systems theory have been described (see Table 2.1). The systems metaphor offers a framing of a farm as a purposeful open system which is useful to considering the reality of farm businesses (Dillon, 1992). This will be highlighted further in the next section in which GST will be applied to describe how producers manage variability to maintain their productive potential (that is, achieve steady state). First, there are a couple of questions that emerge from the introduction of basic systems concepts that will be addressed.

2.2.3.1. How to define system components and relationships in a meaningful way?

Farm system components, by definition, must be interconnected to some degree. This interconnection implies that components influence each other. As such, a change in one component can lead to a change in another component, depending on how they are interconnected within the farm system. The nature and degree of interaction determine the constraining effect the interaction has on the system (Glassman, 1973). Understanding constraints on farm systems requires consideration of the influence system components have on each other, which means analysis of these interconnections.

Systems theory does not dictate how to define the interconnections among system components in farms. Boulding (1956) developed a general hierarchy of systems, based on complexity. Van Gigch (1974) suggests that complexity may be a useful construct for categorising hierarchy within different types of systems. Complexity can be seen in the hierarchy of plans of farm systems. However, hierarchy derived from complexity alone does not define the organisation of system components in farms. This indicates that how I characterise the farm system in this research must be based on other compatible theoretical approaches relevant to the research problem. Value chain analysis may be useful to this aim.

Table 2.1: Some basic systems concepts

Systems concept	Definitions
Behaviour	The observable aggregate responses of the system to stimuli
Boundary	A border separating the system from environment that is determined by where control is exhibited
Components	Discretely describable parts of the system.
Emergent properties	A system is greater than the sum of its parts; that what constitutes the system emerges from the organisation of interrelated components.
Equifinality	An end state can be reached from different initial conditions and along different trajectories
General environment	Aspects of what is outside of the system which interacts with the system, directly and indirectly
Hierarchy	A system isomorphism, indicating that the complexity of systems can be understood within a hierarchic order, emphasising the interconnectedness of the system with layers of subsystems and the suprasystem
Open system	Open systems are those that interact with the environment.
Purpose	The reason a human-made system has been created, relating to the achievement of goals. In farm businesses, the purpose is to generate increasing net equity.
Relationships	A description of the interconnection between components representing the nature and degree of interdependence between components
Stability	A description of the capacity of the system to maintain system behaviour within acceptable limits, in the face of perturbations from the environment
Task Environment	Elements from outside of the system that currently and directly interact with the system
Variability	The degree of change in components of the environment that interact with the system, as function of the frequency of change, degree of difference involved in (i.e. magnitude of) each change, and degree of irregularity in the overall pattern of change.

Citations relevant to the table are in the text.

2.2.3.2. How to distinguish different types of constraints on the farmer?

The construct of a farm as a purposeful system highlights the importance of the hierarchy of goals and plans in maintaining a stable farm business. Clearly, the producer is central to this, as it is the producer who defines the hierarchy of business goals and plans. The decisions a producer makes about the farm may be constrained by other considerations besides the farm, such as personal goals and family circumstances. Deliberation is needed to describe the roles such external elements may play in constraining decisions about the farm system. Image theory will be offered as a comprehensive way to distinguish different types of constraints on decision-making.

2.2.4. Framing how producers manage variability

From these core concepts attention can be directed to what GST has to offer regarding the analysis of the way producers manage variability. Variability is defined in this research as the degree of change in components of the environment that interact with the system (Child, 1972), termed as inputs to the farm system. Child (1972) describes variability as a function of the frequency of change, degree of difference involved in (i.e. magnitude of) each change, and degree of irregularity in the overall pattern of change.

Producers face considerable variability, which translates into variable farm performance (Dillon, 1992). Maintaining farm stability is challenging for producers because they have limited control over much of the variability they face. Output variability, due to factors such as volatility in product prices, cannot be controlled by producers due, in part, to the near perfectly competitive nature of most farm sectors in Australia (Collinson, 2001; Malcolm, Makeham, & Wright, 2005; Wright, 2009)[5]. Variability in inputs, such as unpredictable seasonal conditions, affects the farm's capacity to transform the combination of inputs into a suitable product flow (Collinson, 2001; Malcolm et al., 2005).

2.2.4.1. Control and regulation

Cybernetics offers a framing of how variability is managed in open systems from the perspective of regulation and control (Ashby, 1999; François, 1999; Kremyanskiy,

[5] Exceptions to this exist where producers are able to access niche markets, though this option is rarely available within dairy production in Australia.

1969; van Gigch, 1974; Wiener, 1948). Regulation describes the process of managing variability to ensure that it does not lead to variable system behaviour. From this perspective, regulatory mechanisms are employed to block the flow of variable inputs from influencing system behaviour (Ashby, 1999).

Control is a description of the capacity of the system to manage variability such that stability is maintained (Ashby, 1999). Control in this sense can relate to multiple sources of variability and multiple regulatory mechanisms. Embedded in the notion of control is the concept of requisite variety, also termed Ashby's law (Ashby, 1999). Ashby's law dictates that maintaining steady state requires capacity in the system's regulatory mechanisms to match the variability in the environment as "variety can destroy variety" (Ashby, 1999, p. 207).

Grounded in this cybernetic construct of regulation and control, Kaine and Cowan (2011) offer a conceptual model of how producers manage the impact of variability on the production system in which they characterise three types of regulatory mechanisms in farms, termed system regulators (see Table 2.2)[6]. System regulators are the farm management practices and technologies used by producers to manage the flow of inputs into farms and are described as aggregation, error-control and anticipation regulators (Kaine & Cowan, 2011). The choice of system regulator is determined by, first whether enough is known about cause, timing and extent of variability to predict when to regulate and, second, the relative cost of regulating (see Figure 2.3) (Kaine & Cowan, 2011).

Aggregation regulators insulate the system from variability by holding a stock or a store of the variable input or a suitable substitute (Kaine & Cowan, 2011). They are unconditional or always active within the system; therefore information about the environment or system is not necessary for them to function. Aggregation regulators are used when sufficient information is lacking regarding the cause, timing and extent of variability to predict when to act (Kaine & Cowan, 2011).

[6] For the purposes of this thesis, the elements of applied general systems theory offered by L. Cowan et al. (2013) and Kaine and Cowan (2011) are called 'farm control theory'.

Error control and anticipation are conditional regulators. This means they are activated by the producer, based on information from the environment or system that indicates regulation is necessary (Kaine & Cowan, 2011). The selection of an error-control or anticipation regulator is determined by the relative cost of regulating (Kaine & Cowan, 2011).

Table 2.2: Farm control concepts

Systems concept	**Definitions**
Absorption	The capacity of the existing system structure to manage interactions with changes in states of the environment, such that the behaviour of the system remains within acceptable limits
Adaptation	Purpose-preserving changes made to farm system structure to return the system to a state where it can absorb variability.
Adjustment	System failure or transformation. Exiting from agriculture. (Note that this differs considerably from the general notion of adjustment, which can be seen as synonymous with adaptation.)
Aggregation Regulators	Perpetually active regulators that insulate the system from variability by holding a stock or a store of the variable input or a suitable substitute. They are used when sufficient information is lacking regarding the cause, timing and extent of variability to predict when to act.
Anticipation Regulators	System regulators that are used when the cost of unnecessarily regulating is greater than the cost of not regulating. They are triggered through the identification of variability before it enters the system.
Error-control Regulators	System regulators that are used when the cost of unnecessarily regulating is less than the cost of not regulating. They are triggered when a small amount of variability in an input begins to affect the system, used based on the assumption that a small change is a precursor to a larger change.
Farm Flexibility	The mix of tactical and strategic flexibility within a farm system in relation to an input
Strategy	A plan regarding what is going to be produced (i.e. the output mix) and how it is to be produced in the farm system.
Strategic Flexibility	The capacity to alter the output mix of the farm, to reduce reliance on a variable input, without having to change farm strategy
System Regulators	The farm management practices and technologies used by producers to manage the flow of inputs into farms (includes aggregation, error-control and anticipation regulators)
Tactics	The pre-programmed responses, such as farm management practise and technologies, built into the farm system to manage variability in an input by altering use of the input
Tactical Flexibility	The capacity of the portfolio of existing tactics to match the variability in an input

Citations relevant to the table are in the text.

Error-control regulators are used when the cost of unnecessarily regulating is less than the cost of not regulating. Error control is triggered when a small amount of variability in an input begins to affect the system (Kaine & Cowan, 2011). This regulator is used based on the assumption that a small change is a precursor to a larger change. Given an error-control regulator is activated for every small change, if a small increase in variability does not lead to a larger increase in variability then the regulator is activated when it is not needed (Kaine & Cowan, 2011). Error-control regulation requires information from the environment and system that indicates regulation is needed (Kaine & Cowan, 2011).

Anticipation regulators are used when the cost of unnecessarily regulating is greater than the cost of not regulating. Anticipation regulators are triggered through the identification of variability before it enters the system, which could affect the system in a predictable way (Kaine & Cowan, 2011). Anticipation regulators may fail to act. These regulators require sufficient information from the system and environment to predict that regulation is needed (Kaine & Cowan, 2011)[7].

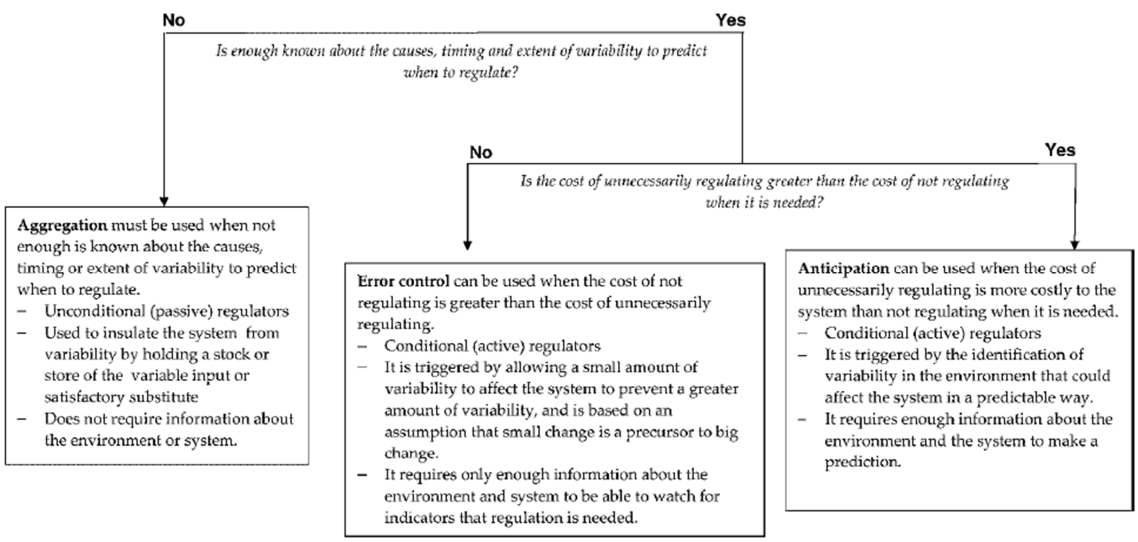

Figure 2.3 : Types of system regulators, from Kaine and Cowan (2011)

System regulators are a part of system structure. This means system regulators are best understood through consideration of their interaction within the system. From this

[7] This distinction between error-control and anticipation regulators may be more easily understood as a distinction between Type I and Type II errors (Weinberg & Weinberg, 1988).

perspective, the extent of stability in the farm system is determined by the capacity of interconnected system regulators to manage interactions with changes in states of the environment such that the behaviour of the farm system remains within acceptable limits (Ashby, 1999; Kaine & Cowan, 2011). This is defined as the capacity to *absorb* variability (Feibleman & Friend, 1969; Kaine & Cowan, 2011; Katz & Kahn, 1969).

L. Cowan et al. (2013) consider producers' capacity to absorb variability through the use of 'tactical' and 'strategic flexibility' (see Table 2.2). Tactics are the pre-programmed responses, such as farm management practice and technologies, built into the farm system to manage variability in an input by altering the use of the input (Cowan, L. et al., 2013). The notion of tactics aligns with the concept of system regulators. Tactical flexibility is described as the capacity of the suite of existing tactics to match the variability in an input and thus, at best, maintain steady state (Cowan, L. et al., 2013). Hence, tactical flexibility is also a description of the relationship between the farm system and an individual input. A farm can have different degrees of tactical flexibility for different inputs (Cowan, L. et al., 2013).

A strategy is a plan regarding what is going to be produced (i.e. the output mix) and how it is to be produced in the farm system (Cowan, L. et al., 2013). Inter alia, strategy determines the suite of tactics that are included in the farm system. Strategic flexibility is the capacity to alter the output mix of the farm, to reduce reliance on a variable input, without having to change farm strategy (Cowan, L. et al., 2013).

L. Cowan et al. (2013) use the concepts of tactical and strategic flexibility to classify farms according to the farm flexibility mix (see Figure 2.4). This conceptual model was applied to dried, wine, and table grape production in northern Victoria (Cowan, L., Wright, & Kaine, 2011, 2012). The applied research focused on understanding producer responses to recent flooding following a decade of drought, a drop in commodity prices due in part to a high value of the Australian dollar and increased pest and disease pressure.

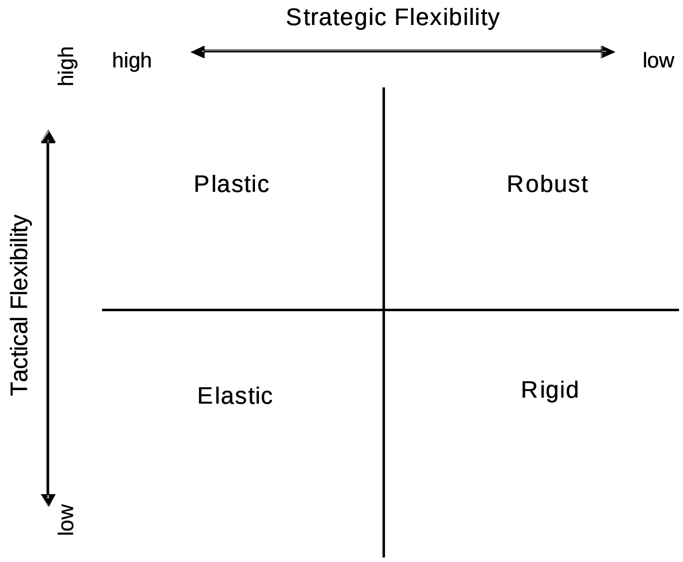

Figure 2.4: Characterising the flexibility mix in farm systems, from L. Cowan et al. (2013)

Thus far, the discussion has focused on how existing system structure is used to control the influence of variable inputs on farms. This has been described as absorbing variability. However, when the behaviour of the farm system falls outside acceptable limits in response to changes in the state of the environment, the farm system has become unstable, putting at risk the viability of the business. In such a circumstance the producer needs to make changes to system structure to return the farm to steady state. This change is ‘adaptation’ from a GST perspective (Cowan, L. et al., 2013; Kaine & Cowan, 2011; Weinberg, 2001).

So long as system purpose is preserved, adaptation can occur at any level of the hierarchy of plans, from the farm business strategy down to the adoption of a new system regulator or tactic to manage a change in variability of an input (Cowan, L. et al., 2013; Kaine & Cowan, 2011; Weinberg, 2001). Hence, adaptation can be viewed as a continuum representing incremental through to radical change (Henderson & Clark, 1990; Kaine, Hill, & Rowbottom, 2008).

If it is not possible to make sufficient structural changes (adaptations) to the farm system to preserve the system, then the farm system will either fail and disappear or transform into a new system (Cowan, L. et al., 2013; Kaine & Cowan, 2011; Weinberg, 2001; Weinberg & Weinberg, 1988). This aligns with the concept of adjustment in agriculture.

This definition of adjustment in agriculture can be confusing. First, this conception of adjustment differs considerably from the general notion of adjustment, which can be seen as synonymous with adaptation. Second, it has sometimes been used to include the range of responses to variability beyond system failure or transformation, some of which can be seen as radical adaptations. Adjustment can refer to producers exiting agriculture as well as a number of other ways these producers change business strategy, including diversification, value-adding to farm products, and working off-farm (Godden, 2006; Harris, 2005; Malcolm et al., 2005; Meredith, 2003; Stayner, 1997). Given the focus here on understanding the capacity of producers to adapt their systems, which may include changing to new enterprise types, in this research, agricultural adjustment is considered to refer only to exiting from agriculture.

In research on the impacts of multiple sources of variability on grape producers in Northern Victoria, it was noted that there were constraints on the capacity of producers to exit agriculture (Cowan, L. et al., 2011, 2012). While a farm business may have failed to achieve business purpose, constraints on adjustment may exist, relating to potential impacts on the producer and farm family. For example, a producer may not be able to sell the farm at a price necessary to enable achievement of personal and family goals. This reflects higher-order goals external to the farm.

2.2.4.2. Limitations

These farm control theories provide a relevant entry point for considering how producers manage variability through absorption and adaptation. There are some differences that need to be highlighted as they imply limitations to the usefulness of these frameworks in this research and indicate a need to draw on other literature.

First, the frameworks have thus far been applied to variability in single inputs. While L. Cowan et al. (2011) acknowledge the compounding impact of multiple sources of variability as an influencing factor for Northern Victorian producers, analysis was applied to each source of variability individually. It is unclear how the farm flexibility framework can be extended to assess a producer's capacity to manage variability in general.

Given the focus on managing a single source of variability, emphasis in the application of these frameworks has been on the interaction between the system and the variable input, rather than between system components. In my research, constraints on managing variability may stem from system components; hence, considering the interaction between components is important.

These frameworks focus on the farm at a production system level, rather than at the farm business level. While this may define the capacity to respond within the production system, it does not explicitly offer a way to consider responses to variability at the farm business level. Higher-order goals and plans, including the farm business strategy and finances, clearly influence the capacity to respond to variability.

The frameworks offered here acknowledge the role of the producer through farm management decisions and practices embedded in tactical and strategic responses to variability. These approaches are limited, however, in their consideration of the role of the decision maker. The reality of maintaining stability in these complex open systems requires active decision-making to control variable inputs (van Gigch, 1974). When seeking to identify constraints on managing variability, consideration must also be directed toward those that may emerge from the decision maker.

2.2.4.3. Critical leverage points

When considering the control and management of systems another relevant system concept that cannot go without mention is that of the 'critical leverage point'. Critical leverage points are "places in the system where a small change could lead to a large shift in behaviour" (Meadows, 2008, p. 145). Critical leverage points have been considered in systems research from a grounding in system dynamics and the work of Jay Forrester (Meadows, 2008). Hence, these leverage points are considered in relation to the dynamic relationships between stocks and flows in open, managed systems.

The notion of leverage points cuts across disciplines. Leverage points have been considered in systems-oriented research, such as the analysis of learning transfer systems and information system development (Bergvall-Kåreborn, Holst, & Ståhlbröst, 2007; Holton, Chen, & Naquin, 2003). Leverage points have also been considered from other perspectives, including supply chain management and policy analysis. For example, leverage points have been used to identify mechanisms for improving global policy initiatives (Humphrey & Schmitz, 2001). As well, Davenport and Brooks (2004) consider the role of leverage points in enterprise resource planning.

Meadows quips that the general notion of leverage points is “embedded in legend: the silver bullet; the trimtab; the miracle cure . . .” (2008, p. 145). The commonality that tends to run across the different considerations of leverage points is seeking to identify trigger points to evoke desired change, or “points of power” (Meadows, 2008, p. 145). The embedded acceptance of emergence and equifinality in the systems conception of critical leverage points implies that this may not be simply done, due to what Jay Forrester describes as the ‘counterintuitive’ nature of complex systems (Meadows, 2008). An explicit risk highlighted with manipulating systems at critical leverage points is the propensity to activate change “in the *wrong direction*” [emphasis in original](Meadows, 2008, p. 145). Hence, the aim of critical leverage point analysis from a systems perspective includes identifying how to activate leverage points in a way that achieves desired behaviour change (Meadows, 2008).

Meadows (2008) offers a general hierarchy of critical leverage point locations within systems (see the summary in Table 2.3). Importantly, the hierarchy is derived by the general effectiveness of the action at the particular leverage point. Meadows’ (2008) hierarchy of critical leverage points is clearly relevant to considering how policy settings may be useful in driving behaviour of producers. However, Meadow’s model, and the consideration of critical leverage points in general, is of limited usefulness to this research.

Table 2.3: Meadows’ (2008) general hierarchy of critical leverage points in systems

12	Numbers - constants and parameters such as subsidies, taxes, standards
11	Buffers – the sizes of stabilising stocks relative to their flows
10	Stock-and-flow structures – physical systems and their nodes of intersection
9	Delays – the lengths of time relative to the rates of system change
8	Balancing feedback loops – the strength of the feedbacks relative to the impacts they are trying to correct
7	Reinforcing feedback loops – the strength of the gain of driving loops
6	Information Flows – the structure of who does and does not have access to information
5	Rules – incentives, punishments, constraints
4	Self-organisation – the power to add, change, or evolve system structure
3	Goals – the purpose or function of the system
2	Paradigms – the mind-set out of which the system arises (its goals, structure, rules, delays, parameters)
1	Transcending Paradigms

The analysis of critical leverage points focuses on identifying opportunities for influencing change and for minimising the risk that the influenced change will follow the desired trajectory. Hence, it is relevant to identifying how policy may be used to influence the adaptation of farms. Implicitly, minimising the risk of an undesirable trajectory of change includes consideration of the constraints on activating leverage points. However, critical leverage point analysis does not explicitly address these fundamental constraints.

2.2.4.4. Risk management

In the mainstream farm management literature risk management is the predominant approach employed to optimise farm decision making when uncertainty is of concern (Anderson, Dillon, & Hardaker, 1977; Anderson & Dillon, 1992; Bullock & Logan, 1969; Chavas, Chambers, & Pope, 2010; Dillon & Anderson, 1971; Knight, 1921; Malcolm, 2004; Su, Zhao, Zhang, Li, & Deng, 2011). Risk is the probability that an action may lead to an outcome among a set of known potential outcomes (Bullock & Logan, 1969). Malcolm et al. describe risk within a farm business context as reflecting the "volatility of potential outcomes" in relation to goals or expectations for the farm (2005, p. 179). This implies that the farmer's family and personal goals or expectations are not normally considered in this conception of risk.

Assessing risk on farms is generally done through a formalised risk analysis process. It has been argued that this formalised process is more successful than, for example, relying on intuition (see below) and critical to the early identification of problems (Malcolm et al., 2005; Su et al., 2011). Risk analysis relies on known or elicited distributions of relevant decision parameters, such that the influence of a single factor on a single output can be considered at a given point in time (for example, see Anderson et al., 1977, p. 161), or samples can be drawn from multiple distributions to simulate alternative risk scenarios (for example, see Su et al., 2011). Thus, risk analysis relies on an understanding of possible future states and their probability to calculate the probability of achieving potential outcomes in relation to farm business goals. The less knowable the variables are in relation to possible future states, the less reliable risk analysis is at identifying the best choice among decision alternatives (Dane & Pratt, 2009).

The notion of uncertainty is important to the consideration of risk as it describes what is unknown and immeasurable in the assessment of risk probabilities (Knight, 1921). Uncertainty decreases the confidence decision makers have in the estimates derived regarding the probability of outcomes due to a lack of information about possible future states (Curley & Yates, 1989; Dane & Pratt, 2009; Hönekopp, 2003). Within the social psychology literature this decreased confidence has been described in terms of 'doubt' (Beach & Mitchell, 1987). What is clear in the literature is that uncertainty is a significant management problem for farmers (Malcolm et al., 2005).

Irreducible uncertainty is central to how problems associated with climate change have been described within the climate adaptation literature (see Section 1.4). A concerning feature of the evolution of parameter values driven by climate change is that there is considerable uncertainty about the stability of the distributions of these values. The risk analysis literature brings to the forefront how this uncertainty constrains the capacity of farmers formally to analyse risk associated with their decision options.

Though this literature highlights some useful concepts, the risk analysis approach employed in this literature is less useful here. First, the body of research considers risk to the farm business, rather than considering the interaction between the farmer's family and personal objectives, which could be a source of constraint on farmer decisions. Second, while this discipline enables consideration of known variables in decision making, it does not enable adequately the identification of decision *paths* under uncertainty. Finally, the sampling from distributions of parameter values, even assuming they are known with some confidence, requires consideration of so many alternative decision paths and path dependencies through time that the approach is arguably not useful for the analysis of any individual decision.

Intuition regarding farm business decisions is grounded in the farmer's experiences associated with previous, similar, decisions. This implies that intuition may reflect the compounding influence of experience, which is manifest in the constraints on options imposed by the individual's 'gut feelings'.

Beyond striving to work with probability distributions using decision analysis, farmers often rely on intuition (Malcolm et al., 2005). Synonymous with tacit knowledge, intuition relies on unconscious constructs grounded in an individual's experience to develop decision-rules or heuristics (Dane & Pratt, 2009; McCown, Carberry, Dalgliesh, Foale, & Hochman, 2012; Nuthall, 2012). However, it is very difficult to codify or model the intuitive process for effective use in analysis such as the one being conducted here.

2.3. Path dependence

In the previous section, farms were described from a general systems perspective, including the way producers manage the impact of variability on the production system. In reality, not all variability can be managed. This can leave producers facing variable production outcomes and put farm businesses at risk. Analysing the impediments to managing variability is a key step in considering how producers may be able to reduce such impediments in the face of increased climate variability.

The constraints on managing variability in the farm system emerge from the interaction between the system and the task environment. The task environment is understood to be a source of constraints, hence the need for regulation as described in the previous section. What next needs to be considered is how the farm system can have a constraining effect on options for the farm. The literature on path dependence offers useful insights about the emergence of constraints from the system itself, through the historical sequence of decisions about the system (David, 1994; Greener, 2002; Liebowitz & Margolis, 1995; Wilsford, 1994). In this section, focus will be directed toward the path dependence literature to identify how constraints within the system can be meaningfully considered in this research.

A farm business is not created at a single point, but instead is built through time as a dynamic process (van Driel & Dolfsma, 2009). Path dependence theory allows consideration of how sequences of activities through time, as a dynamic process, influence the options available within a farm system. This means that path dependence constructs can be used to reveal constraints faced by a producer that stem from the history of decisions made about the farm.

The ‘path’ under consideration in this research is defined as the critical production path at the farm business level. While a farm business can have multiple enterprises, this mix of enterprises is within one critical production path. 'Enterprise' in this farm management context means product line: wheat, wool, sheep meat, milk, apples and so on. Put another way, a production path is the interconnected sequence of activities or components that are essential for a set of outputs of a farm production system. The path includes not only what is being produced (output), but also includes how it is being produced; hence, the sequence of activities.

2.3.1. Three domains

The concept of path dependence originated in economics to explain technology adoption processes and evolution in industry (Arthur, 1989; Chhetri, Easterling, Terando, & Mearns, 2010; David, 1985; van Driel & Dolfsma, 2009). Path dependence has spread to other fields and aspects have been incorporated into some areas of ecology and biology, such as irreversibility in natural selection and chaos theory (Liebowitz & Margolis, 2000; Roe, 1995-1996).

In a practical sense, my research is about path dependence of farms as purposeful open systems. This means farms are managed systems. The path dependent concepts as they have been developed in the fields of ecology and biology do not necessarily transfer well into consideration of managed systems. An example of this is the necessity for a constant pattern of disequilibrium in chaos theory and the related idea that path dependence must originate from a small perturbation that leads to unintended consequences (Liebowitz & Margolis, 2000; Roe, 1995-1996). Liebowitz and Margolis (2000) argue that there is a lack of direct transferability because “true contingency” (i.e. irreversibility) can only exist in the fields of natural science where extinction is the outcome (p. 983).

There are some exceptions to this, where path dependence in natural sciences overlap to some extent with managed systems. For example, Roe (1995-1996) considers evolutionary theory within the law and economy through a filter of chaos theory, punctuated evolution and path dependence. As well, Tisdell (2003) considers the socio-economic factors that influence species path dependence in relation to diversity of domesticated livestock. While this looks at issues of species decline, the focus is on domesticated livestock as a part of a managed system.

I am mindful of the differences in concepts across disciplines researching path dependence. The broad fields of ecological and biological path dependence literature will not be of central focus. Emphasis here will be on path dependence of managed systems within the literature.

Path dependence of managed systems has been explored, broadly, in the literature within three interrelated domains (see Table 2.4). These domains are the institutional and political realm, industry or market economy and the organisation or firm. The system of interest differs within each of these domains of research. The domains represent a hierarchy in which the constraints of the individual firm are considered within the market economy, which in turn is considered within society's institutional structures.

Table 2.4: Examples from domains of path dependence research in the literature

Domain of research focus in the literature	**Organisations and individual firms**	**Prevailing technologies at a market economy level**	**Politics and institutions**
Examples in the literature	• Antonelli et al. 2013 • David, 1994 • Greener, 2002 • Schreyogg & Sydow, 2011 • Stack & Gartland, 2003 • Sydow et al., 2005 • van Driel & Dolfsma, 2009 • Vergne & Durand, 2011	• Aghion et al. 2012 • Antonelli, 2004 • Arthur et al., 1987 • Bergek & Onufrey 2013 • David, 1985 • Liebowitz & Margolis, 1995 • Liebowitz & Margolis, 2000 • Puffert, 2003 • Ruttan, 1997 • Vissers & Dankbarr 2013	• Dooms et al., 2013 • Notteboom et al. 2013 • Orihuela, 2013 • Pierson, 2004 • Roe, 1995-1996 • Setterfield, 1995 • Wilsford, 1994
Examples in agriculture in the literature	• Vanloqueren & Baret, 2008 • Wilson & Tisdell, 2001	• Chhetri et al., 2010 • Cowan, R. & Gunby, 1996 • Ruttan, 1996	• McGuire, 2008 • Libecap, 2004 • Lee, 2011 • Hess et al., 2008 • Tisdell, 2003

Many authors frame their argument predominantly within one domain. Even so, it is generally acknowledged, either explicitly or through consideration of externalities, that these domains are interrelated. Within Wilson and Tisdell's (2001) research on the unsustainable use of pesticides in agriculture, all three domains are identified as influencing path dependence: firm-level debt; market pressure to adopt despite reservations; and institutional structures. As well, within Chhetri et al. (2010), path dependence is described as the "cumulative outcome" from multiple levels, encompassing “technological trajectories adopted by producers and promoted by extension services, agricultural policies and agricultural research systems” (p. 897).

2.3.1.1. Institutional domain

Within the institutional domain of the path dependence literature, I found the emphasis to often be on the constraining effects of institutions and politics on society (see Dooms, Verbeke, & Haezendonck, 2013; Hess, Kleinschmit, Theuvsen, von Cramon-Taubdel, & Zschache, 2008; Lee, 2011; Libecap, 2004; McGuire, 2008; Notteboom, De Langen, & Jacobs, 2013; Orihuela, 2013; Pierson, 2004; Roe, 1995-1996; Setterfield, 1995; Wilsford, 1994). For example, Wilsford (1994) considers path dependence in relation to the effect of institutional structures on public policy reform of the health care system. In agriculture, McGuire (2008) reveals the constraints path dependence has imposed on reforms to a plant breeding program in Ethiopia. As well, Hess et al. (2008) consider the influence of path dependence of Germany’s agricultural policies on the demand for seasonal farm labour.

While the institutional domain affects the constraints on producers, it is less relevant to this research, as it is far removed from an individual producer’s direct sphere of influence. For example, Vanloqueren and Baret (2008) identify several public regulations and agricultural policies as “indirect determinants” of barriers to widespread use of multi-resistant wheat varieties in Belgium (p. 438). The institutional domain fits within the general environment, rather than the task environment (Bourgeois, 1980). Given the interest in this research on understanding the direct constraints on how producers manage variability, focusing on indirect determinants of change from the general environment is less relevant here.

2.3.1.2. Industry and market economy

The institutional domain is strongly linked to the economy, as the “long- run material economic history has inextricably been embedded within societal history as an instituted process of power over and organization of resource use and also human organisation” (Lloyd, 2012, p. 3). This is not to be confused, however, with the focus of the path dependence literature in the industry and market economy domain. The industry and market economy domain focuses on why a particular technology becomes dominant over others within an industry or market (see Aghion, Dechezleprêtre, Hemous, Martin,

& Van Reenen, 2012; Antonelli, 2004; Arthur, Ermoliev, & Kaniovski, 1987; Bergek & Onufrey, 2013; Cowan, R. & Gunby, 1996; David, 1985; Liebowitz & Margolis, 1990, 1995, 2000; Puffert, 2003; Ruttan, 1996, 1997; Tisdell, 2003; Vissers & Dankbaar, 2013). Often cited examples in this domain of path dependence research are the dominance of the QWERTY keyboard and VHS videotapes (David, 1985; Liebowitz & Margolis, 1990, 1995; Ruttan, 1997). In agriculture, R. Cowan and Gunby (1996) highlight the market system's industry-wide influence on agriculture's path dependence with pesticide use.

The insight this industry and market economy literature offers regarding farms is generally innovation specific. While this domain of literature may explore what path dependence could mean for an individual producer, such as the costs or benefits to an individual based on the timing of adoption (Arthur, 1989), the fundamental focus is on the aggregate path dependence across firms. Liebowitz and Margolis (2000) describe this as overly simplistic: ignoring the capacity of individual businesses to actively avoid the "harms" of path dependence and reducing these individuals "to the role of spectators" (p. 990). Given the focus in my research on constraints of individual farm systems, across multiple sources of variability, an innovation-specific aggregate view of path dependence is less relevant.

On the face of it, a notable exception to this would appear to be the work of Chhetri et al. (2010) and Easterling, Chhetri, and Nui (2003). Path dependence is considered here in relation to a collective of innovations that represent change necessary to adapt the corn-growing industry to climate change (Easterling et al., 2003). The authors use a modified rate of adoption model to consider the rate of adaptation within a region (Chhetri et al., 2010; Easterling et al., 2003). Fundamentally, adaptation can be described as the innovation under consideration in this research, at an aggregated level. The focus is on the trajectory of adaptation across a single region (Southeast U.S.) and within a single industry (corn) through time.

Grounded in modelling, it is understandable that the research of Chhetri et al. (2010) and Easterling et al. (2003) is simplified. The approach highlights some issues that reduce its relevance to this research. First, using variable rates of adoption across a region as a proxy for path dependence assumes that all influences on rates of adoption are subsumed within the rate of adoption concept, a trajectory in thinking I am unwilling to follow given the complex and contested field of adoption research (Wright, 2011b).

Second, adaptation is considered within the enterprise of corn production, ignoring adaptations that entail changes in output (i.e. enterprises) and ignoring system failure. This narrow focus may be necessary to reduce complexity in the model. However, it also reduces the practical usefulness for the aim here to understand other dimensions of path dependence, including producer capacity to change enterprise mix and adjust out of agriculture.

Third, the future orientation calls into question whether the model can possibly reflect the emergence that occurs with path dependence, from the unexpected consequences that stem from small changes in the past (Liebowitz & Margolis, 2000; Schwartz, 2004). Hence, while, on the face of it, the practical problem being considered in the industry and market economy domain aligns well with this research, the approach taken to explore this problem does not enable insights into the experiences of producers as they manage variability.

2.3.1.3. Organisation and firm

Logically, my research fits within the third domain of path dependence literature, at the level of the organisation and firm. There are several factors that contrast farm systems with the typical conceptualisation of organisations in the path dependence literature. This creates challenges in aligning some of the literature in this domain to farm systems.

First, the human social system is the system of interest in the organisational path dependence research, such as social networks and management processes relating to human resources (see David, 1994; Greener, 2002; Stack & Gartland, 2003; Sydow, Schreyogg, & Koch, 2005; van Driel & Dolfsma, 2009; Vergne & Durand, 2011). The vast majority (94%) of farms in Australia are small or micro businesses within which one to two people make all of the management decisions (Fragar, Henderson, Morton, & Pollock, 2008; Martin, 2013; Pritchard, 1999). The focus on social networks and management processes relating to human resources is not relevant to these micro businesses.

Second, farms are strongly interconnected with the family. Often the family lives and works on the farm (Crosthwaite & Malcolm, 2000). There can also be a deep and long-held family relationship with the farm (Barr, 2009). These influence the constraints on producer decision-making in ways that are likely to be different to most small businesses in Australia.

Third, farms have a high level of exposure to the environment. Unlike most organisations, producers must constantly manage environmental variability if they are to maintain viable businesses (Chhetri et al., 2010; Howden et al., 2007). Even with numerous technological advances in agriculture, the overall exposure to variability in farming has not diminished (Hornbeck, 2012). Overall, the sources and degrees of variability that are managed by Australian producers far outstrip the typical variability contemplated in the organisational path dependence literature.

Antonelli, Crespi, and Scellato (2013) offer a different framing of path dependence in firms in their research to describe the relationship between productivity growth and innovation in firms. These authors identify a pattern of persistence in productivity growth in individual firms that is linked to persistence in innovation. This pattern differs between firms, based on idiosyncratic firm characteristics, and is characterised by path dependence. Of significant interest to us here is that these authors identify “competence and knowledge” as critical factors in the relationship between innovation and productivity (Antonelli et al., 2013, p. 4). This implies that capability may be an issue in farms, especially given the small number of people who make up the capability-base of the business.

Separate from the organisational literature, there are a small number of papers that consider path dependence on farms at the firm level, though perhaps not exclusively at this level. Wilson and Tisdell (2001) build on the work of R. Cowan and Gunby (1996) in considering the path dependence of pesticide use in agriculture at the expense of an alternative, Integrated Pest Management (IPM). While these researchers consider the level of the farm as a firm, the analysis focuses on why IPM was more sustainable and a better option. The identification of a better option for pest control is used to demonstrate that path dependence exists. A number of factors, based on literature and speculation, are offered that may contribute to path dependence of farm systems (for example: market prices, ignorance, interconnection of pesticides with high yielding varieties, biased agricultural research, debt, lack of services needed to use IPM). However, the research does not seek to identify which of these actually played a role in the path dependence under consideration. Hence, this paper offers path dependence as a general concept for understanding the collection of potential constraints of producers in relation to pesticide use. It does not take the next step of identifying the reality of these constraints embedded in the experience of producers.

Vanloqueren and Baret (2008) come at path dependence to pesticide use from a different angle than Wilson and Tisdell (2001) when they describe research to understand the barriers to widespread use of multi-resistant wheat varieties in Belgium. To identify these barriers they interviewed "influential stakeholders" in the cereal agricultural industry food chain (e.g. scientists and technical advisors in extension) (Vanloqueren & Baret, 2008, p. 438). They also conducted an analysis of extension literature. From this they identify 12 factors that impeded (directly or indirectly) systematic use of multi-resistant wheat cultivars, which fundamentally relate to pesticide lock-in. These factors were at a number of different levels: producer, market, public extension services and research, public regulation, and past agricultural policies. Given this research sought to identify path dependence generating constraints at the farm level (amongst other factors), it begins to fill the gap highlighted above. However, the data gathered here is through influential stakeholders and experts, rather than speaking directly to producers. A major assumption embedded in this research, then, is that accurate data regarding the constraints on farms can be gleaned through this approach. It does not consider an important source of data that is fundamental to understanding path dependence on farms: the producer. This is unfortunate given the importance of producer knowledge of farm context when analysing the constraints on farms.

Path dependence theory of managed systems is based on an assumption of control by a decision-maker (Antonelli, 2006). It is apparent that these three interrelated domains are all relevant in varying degrees to understanding the constraining effect of path dependence on control. However, they fail to explore the practical reality of the constraints on the producer to control the farm system.

Predominantly, the constraints presented in the literature are either indirect and beyond the control of the producer or focused on producers in aggregate and in relation to an individual innovation. As well, the limited firm-level path dependence literature fails adequately to consider the fundamental decision-maker within the farm system, the producer. A critical assumption within my research is that farms are heterogeneous and decisions that producers make about their farm systems are grounded in their idiosyncratic farm context (Crouch, 1981; Kaine, 2008). Therefore, understanding the constraints on farms requires understanding farm context. This is a gap in the current path dependence literature.

2.3.2. Fundamental elements of path dependence in the literature

While there are three different domains with varying degrees of applicability to the current study, there are common interrelated constructs in how path dependence is described across the literature (see Table 2.5). These elements will next be described and applied to farm business. Consideration will be given to how they may be of help in developing a meaningful conceptual model of path dependence in farms.

2.3.2.1. Critical juncture

Path dependence can be described as a process of increasing sensitivity of a system to previous decisions which is reinforced by mechanisms such as feedback and externalities, leading to an outcome of lock-in or irreversibility (Antonelli, 2006; Bednar, Page, & Toole, 2011; David, 1994; Greener, 2002; Liebowitz & Margolis, 2000; Page, 2006; Schwartz, 2004; Setterfield, 2008; Vergne & Durand, 2011; Wilsford, 1994). Hence, path dependence is a description of the collective influences through time that lead a path to an irreversible state.

To understand the path dependent state of a system it is useful to consider how it begins: the ‘path origin’ (Vergne & Durand, 2011). Path dependence begins with a decision to make a change to a system at a ‘critical juncture’, which can also be described as a critical decision point (Pierson, 2000; Schwartz, 2004; van Driel & Dolfsma, 2009; Vergne & Durand, 2011). A critical juncture describes decision-maker perception of a threat or an opportunity to the system. The emergence of a critical juncture indicates that a perceived change in the system or environment has triggered a need to make a change to the current system configuration (van Driel & Dolfsma, 2009). A critical juncture can be described as resulting from an interaction between a perceived change in context and the current state of the system. This implies that the path dependent state of a system at the time a change in context occurs has an influence on the emergence, or not, of a critical juncture.

A critical juncture differs from a critical leverage point (see section 2.2.3). While a critical leverage point is an identified place in the system in which change can be orchestrated, a critical juncture is a change in context that indicates a need to make an alteration to the system. In a highly simplistic sense, a critical juncture is an identification of the problem and a critical leverage point is one way of describing a potential solution.

At a critical juncture a decision is made to follow one path from among those available within the current set of conditions or 'initial conditions' (van Driel & Dolfsma, 2009). The selection of a path here implies an identified link between the decision and a desired future or goal. Subsequent decisions support the initial decision, decreasing the likelihood of altering paths (Greener, 2002; Wilsford, 1994). These subsequent decisions are determined by the outcome from the sequence of previous decisions and current context, which includes reinforcement mechanisms (Greener, 2002; Wilsford, 1994).

If path dependence is present then a decision at a critical juncture cannot be the predominant determinant of the final state of the system. If the decision at the critical juncture has had a greater influence on the system than the collective effect of the reinforcing mechanisms then this is not path dependence. Instead, it represents structural determinism (Antonelli, 2006; Page, 2006; Schwartz, 2004; Tisdell, 2003; van Driel & Dolfsma, 2009). Structural determinism implies a predictive relationship between an initial decision about structure and the end state of the system (Mone, 2008). It is generally used within structural contingency theory to identify an optimal or preferred organisational structure, within a given context (Mone, 2008). Hence, structural determinism does not account for a role for reinforcing mechanisms in the path outcome. Nor does it consider the potential for equifinality in path options.

2.3.2.2. Reinforcement mechanisms

Reinforcement mechanisms play a key role in path dependence. There is an emphasis in the literature on the role of these mechanisms in amplifying the effects of relatively small, contingent or inconsequential decisions at a critical juncture (Arthur et al., 1987;

Cowan, R. & Gunby, 1996; Liebowitz & Margolis, 2000; Pierson, 2000; Ruttan, 1997; Schwartz, 2004; Vergne & Durand, 2011). Reinforcement mechanisms, described as feedback and externalities, ensure systems are “affected by a dose of unpredictability” (Vergne & Durand, 2011, p. 368). Antonelli (2006) argues that understanding the influence of feedback and externalities “paves the way to understanding the existence of multiple equilibria and hence multiple directions and intensities” of path trajectory (p. 8).

Feedback in the path dependence literature is described in a number of ways: as economies of scale, increasing returns, positive feedback and internal feedback (Antonelli, 2006; Arthur, 1989; David, 1994; Dobusch & Schüßler, 2013; Pierson, 2000; Schwartz, 2004; Sydow et al., 2005; Vergne & Durand, 2011). Regardless of the term used, the underlying mechanism being described is the reinforcement of the current trajectory towards a desired end state or goal.

Externalities can be broadly described as costs or benefits borne outside of the system, which are derived from system behaviour (Cowan, R. & Gunby, 1996; Holder & Lee, 2007). Externalities are often related to the notion of ‘the tragedy of the commons’ (Hardin, 1968; Holder & Lee, 2007). Externalities can be positive or negative. For example, farm development of technological innovations can be a positive externality in agriculture. Nutrient runoff is an example of a negative externality of relevance to agriculture (Kaine, Johnson, et al., 2008; Young & Kaine, 2009). In both cases, other entities than the farmer are impacted by the externality.

Externalities affect the environment rather than the farm system. This means that they do not have a direct effect on producer decision-making. A negative externality may lead to a change in public policy, thereby internalising the cost to the producer. If this happens, the policy change becomes a constraint on the farm.

2.3.2.3. Irreversibility

Path dependence can be viewed along a continuum, in which the set of decision options available to the decision maker becomes increasingly narrowed over time. As reinforcement mechanisms increase the degree of path dependence, the amount of change (and therefore resources) required to alter the path also increases (Cowan, R. & Gunby, 1996; Vanloqueren & Baret, 2008). The outcome of increasing path dependence is the lock-in of the path, in which the system is left in an irreversible state (Cowan, R. & Gunby, 1996; Greener, 2002; Liebowitz & Margolis, 1995; McGuire, 2008; Vanloqueren & Baret, 2008; Vergne & Durand, 2011; Wilsford, 1994).

Irreversibility can be thought of as a description of the degree to which a system has been locked out of options (Antonelli, 2006). All change comes at a cost to the system. As lock-in increases, the cost to change the path trajectory also increases. The degree of irreversibility that emerges can be so great that significant exogenous forces are needed to enable a change of trajectories (Arthur et al., 1987; Vanloqueren & Baret, 2008; Vergne & Durand, 2011). Arthur et al. (1987) describes this as "an ever widening…changeover gap" (p 302).

Irreversibility indicates that, while altering the path is desirable, the cost of doing so is too great. Costs to change trajectories, also called switching costs, include those associated with changing system components and opportunity costs from both imbedded investment (sunk cost) and efficiency gains due to high competency (Antonelli, 2006; Crouch, 1981; Vergne & Durand, 2011). For example, R. Cowan and Gunby (1996) identify the need for farm learning as a switching cost in the adoption of Integrated Pest Management, as it implies a period of lower revenue and higher uncertainty.

At times, while the benefit of change may outweigh the costs, a farm business may be so constrained that changing trajectories is not an option outside of system failure. This was found to be the case for a number of wine grape producers in northern Victoria, who did not have the resources needed to alter their production paths (Cowan, L. et al., 2011, 2012).

Table 2.5: Path dependence concepts

Path dependence term	Definition
Critical juncture	A decision point in which a change in the system or environment has triggered a need to make a change to the current system structure
Reinforcement mechanisms	Feedback and externalities that emerge from the outcome of previous decisions
Path dependence	A process of increasing sensitivity of a system to previous decisions which is reinforced by mechanisms, leading to an outcome of lock in or irreversibility
Irreversibility	A system state where the path is locked in and cannot be changed. Irreversibility indicates that while altering the path is desired, the cost of doing so is too great.

Citations relevant to the table are in the text.

2.3.2.4. Real options analysis

A model that appears relevant to the conception of path dependence is real options analysis (ROA). Associated with the original work of Myers (1977), ROA gained popularity in the 1980s and 1990s and has been used internationally in various manifestations over several decades (Borison, 2003). The use of ROA has included consideration of farm businesses (for example, see Hertzler, Sanderson, Capon, Hayman, & Kingwell, 2013; Ihli, Maart-Noelck, & Musshoff, 2013; Seyoum-Tegegn & Chan, 2013; Tauer, 2006).

Broadly, ROA is an approach for evaluating the value of current decision options to an organisation and business. 'Value' here is determined by the impact of these options on the capacity to respond to "future contingent events" (Kogut & Kulatilaka, 2001, p. 745).The capacity to alter the timing of decision-making in the face of uncertainty is central to analysis of value (Borison, 2003; Hertzler et al., 2013). Hertzler et al. (2013) describe this as "examining the trade-offs between acting sooner versus retaining the option to act later, by taking into account the value of flexibility and the value of new information that can help resolve uncertainty" (p. 1). Hence, ROA focuses on analysis of differences in value that could be derived from making a single decision, at different points in time. A typical example of ROA application in agriculture is industry entry and exit decisions (Hertzler et al., 2013; Seyoum-Tegegn & Chan, 2013; Tauer, 2006).

Similar to path dependence, irreversibility is encapsulated within ROA as a determinant of value. For example, in Kogut and Kulatilaka (2001) consideration of how organisational capability strategies influence the future options for the firm, the irreversibility of capabilities is identified as a key constraint. As well, in Bellalah's (2003) use of ROA he considers the influence of incomplete information on irreversible investment decisions. As such, ROA enables consideration of how the irreversibility of an option can affect a future state.

While ROA goes some way toward considering the complexity of business decisions, it necessarily simplifies the parameters that are defined as constraints to enable economic evaluation on a representative scale. This implies a narrow view of the sources of constraints for firms and organisations. For example, Seyoum-Tegegn and Chan (2013) define the relevant data points in their analysis of farm adjustment decisions in terms of "wine grape price, yield, planted area, discount rate, total estimated cost, and total variable cost", yet little detail is offered to justify why these are the most useful data for understanding constraints on farm business decisions (p. 90). While Ihli et al. (2013) consider socio-demographic and farm-specific variables in their analysis of the influence of timing of (dis)investment decision-making, there is no explicit rationale for variable selection.

ROA enables evaluation of "real-world investment practices" by enabling consideration of dynamics in the research approach (Seyoum-Tegegn & Chan, 2013, p. 86). For example, the timing of decisions is central to value analysis for Ihli et al. (2013) in their assessment of producer investment and disinvestment decisions. In the consideration of irreversibility and dynamics, what is missing in ROA is consideration of other influences, such as reinforcing mechanisms or other sources of constraints, on this future state.

ROA holds limited usefulness to my research for a couple of reasons. First, my focus is not on understanding the changes in values of a single decision at different points in time. I am interested in the interaction among multifaceted and cumulative sets of decisions through time. The complexity of this issue is beyond ROA.

Second, when considering a single decision at different points in time I suggest that there are others sources of constraints influencing farm decision-making that are not considered by ROA. For example, while Tauer (2006) suggests specific milk price triggers as motivators to enter or exit the dairy industry, he acknowledges the likelihood of "other financial and non-financial factors impacting on entry and exit decisions" (p. 345). On this face of it, these other constraints could relate, in part, to the close farm and family interrelationship, something not considered in ROA.

2.3.3. Implications from the path dependence literature

While the fundamental elements of path dependence have been presented, there are still a number of points that must be explored that would enable the development of conceptual model that includes the constraining effect of path dependence on farms. These include: a greater understanding of critical junctures; the degree of control a producer has over guiding the path; and how path dependence interacts with flexibility in the farm.

2.3.3.1. Identifying critical junctures in farms

It is at critical junctures in farms that the threat of variability is experienced and the capacity to respond is visible. However, greater clarity is needed regarding how critical junctures can be identified among the myriad of farm decisions. At a critical juncture a producer makes an initial key decision to alter the farm's path. Subsequent decisions tend to reinforce the initial decision. Distinguishing the initial decision from reinforcing decisions about the farm is necessary to this research. The initial decision at a critical juncture indicates an interaction between a constrained system state and a change in context that necessitates altering the path. Once the path is altered at a critical juncture, path dependence is lessened until, over time, subsequent decisions build path dependence along this altered path.

I cannot look to the notion of adaptation for clarity here. Decisions about the production system of farms are identifiable in the adaptations producers make to the farm system. However, adaptation may be associated with an initial decision at a critical juncture or reinforcing decisions. As well, change outside of the production system is not explicitly explored through the notion of adaptation. This means that adaptation alone does not provide the means for distinction between initial and reinforcing decisions.

Linking critical junctures to the hierarchy of plans and goals may offer some insights here. In a farm business context, a critical juncture occurs when a signal (from the farm or environment) indicates to the producer that the current organisation of the farm will not lead to the achievement of farm business goals. Practically speaking, a critical juncture is triggered when a producer sees threats to farm output value or risks associated with missing opportunities.

At a critical juncture, the producer assesses the hierarchy of plans to determine the level at which change is needed. When a change decision occurs at a higher level in the hierarchy of plans this may be easily identifiable as large-scale change in output or how the farm production system is organised to produce the output. Even so, care must be taken not to mistake the exercise of strategy flexibility for a change in farm strategy at a critical juncture (Cowan, L. et al., 2013).

Often decisions are made to alter lower-order plans and their associated structure. Such change may represent decisions that reinforce a previous decision at a critical juncture. It is also possible that what appears to be a small change in the farm may actually represent a critical juncture, which can lead to major consequences for the system down the track (Cowan, R. & Gunby, 1996; Liebowitz & Margolis, 1995; Ruttan, 1997). For example, the decision to drift lamb affects paddock design (fencing and shelter), pasture and supplementary feed production, lamb marking, mulesing and labour input (McNally, 2001; Tyrrell & Giles, 1974).

A critical juncture is often obvious when it leads to changes to higher level plans of the farm system. What is less apparent is when a small change indicates a critical juncture rather than a reinforcing decision. The determination that a small decision has stemmed from a critical juncture is based on the number and magnitude of consequential decisions that flow from that small change. Hence, this type of critical juncture is identifiable only after a sequence of reinforcing decisions has occurred.

What represents a critical juncture within one farm may not be so in another as it will be strongly embedded in farm context (Crouch, 1981; Kaine, 2008). For example, a decision to invest in technology may have very different impacts depending on how it influences commitment to scale and reduces resources. In this research an emphasis will be on identifying critical junctures and farm responses to critical junctures. Some of these critical junctures may only be identifiable by tracking back through the sequence of decisions made by producers. Consideration will emphasise the sequence of decisions within the farm context.

2.3.3.2. Different paths, different path dependence

A consequence of path dependence is that the path being reinforced by feedback and externalities may not be that which was desired by the decision maker at a critical juncture. Reinforcing mechanisms, as converging forces, can support the desired path trajectory (Antonelli, 2006). Alternatively, reinforcing mechanisms can push the path trajectory in an unintended and possibly undesirable direction as diverging forces (Antonelli, 2006). It is clearly possible that a current path may not be aligned with the desired path and original expectations of the producer at critical juncture, given the complex interplay between converging and diverging elements of feedback and externalities (Antonelli, 2006; Schwartz, 2004). Potentially compounding this divergence from the desired path is increased unpredictability and uncertainty.

When a producer makes a decision at a critical juncture, it can be tempting to assume that some decision options are inherently better than others, leading to better paths. This may not always be the case. The emphasis in path dependence theory, on reinforcing mechanisms driving path trajectory, challenges the strategic management assumption that the producer purposefully drives the direction of the business (Vergne & Durand, 2011). Instead, the farm could be driven along a number of different paths leading to a number of different outcomes (Arthur et al., 1987). Practically speaking, this means that two farms can be organised the same way and achieve different results, due to factors outside of the producer's control, such as climate variability. It is also possible for a number of different paths to lead to the same outcome (Vergne & Durand, 2011). An example of this is the Dairy Australia classification of five types of feeding systems used by Australian dairy farmers (Little, n.d.). In reality, this means that a farm system can be organised in a number of different ways to create an output. This thinking aligns with the GST concept of equifinality (see Section 2.1).

A fundamental point here is that there is not one 'right path'; nor is there one determined outcome. The number of paths that are possible is limited by context: as context is constrained, so are path options (Antonelli, 2006; Liebowitz & Margolis, 2000; Vergne & Durand, 2011). Exploration of path dependence in farms needs to be embedded in consideration of farm context. Given differing farm contexts, an expectation in this research is that path dependence will differ across farms.

A potential consequence of path dependence is that the initial decisions upon which the path is founded may lead to a path that is suboptimal or inferior (Arthur et al., 1987; Cowan, R. & Gunby, 1996; Liebowitz & Margolis, 1995, 2000; Wilsford, 1994). Liebowitz and Margolis (2000) identify that “a part of the appeal of the path dependence literature is the implicit allegation that these lock-ins, these bad economic outcomes, are avoidable by small but prudent interventions” (p. 982). However, an inferior path is not necessarily due to poor decision-making. The initial conditions upon which decisions are made may make outcomes unpredictable (Arthur et al., 1987; Liebowitz & Margolis, 1995, 2000; Wilsford, 1994). There may be considerable uncertainty regarding future states of the task environment, which means unknown degrees of convergent and divergent mechanisms guiding the path.

Roe (1995-1996) offers a typology of path dependence to understand the reason for inefficiencies in American national institutional and infrastructure. He describes three different forms of path dependence as ‘weak’, ‘semi-strong’ and ‘strong’ forms of path dependence. In weak path dependence “several satisfactory [path options] were available and path dependence explains the one we got” (Roe, 1995-1996, p. 648). Given the lack of a preference for one over the others in weak path dependence, with little difference in outcome, there is insufficient need to change the existing system. Semi-strong path dependence means that a path was selected which resulted in a less efficient path (Roe, 1995-1996). However, the cost of significantly changing the path is more inefficient than maintaining the existing path. Strong path dependence within Roe’s typology entails an inefficient path decision that would be worth changing, but still is not changed due to other factors that impede the change: “information and public choice” (Roe, 1995-1996, p. 651).

Liebowitz and Margolis (1995) suggest that there are different types of path dependence, reflecting the nature of the information available at the time the initial decision was made. Within ‘first degree’ path dependence, initial decisions put the business along a path that cannot be left without cost, but the path is optimal, though perhaps not uniquely so (Liebowitz & Margolis, 1995). This aligns with what Roe (1995-1996) describes as ‘weak’ path dependence. In ‘second degree’ path dependence, imperfect foresight at a critical juncture leads to the selection of a suboptimal path (Liebowitz & Margolis, 1995). While regrettable and costly to change, a better path choice was not known at the time the initial decision was made (Liebowitz & Margolis, 1995). ‘Third degree’ path dependence is indicative of a path choice that is suboptimal and avoidable at the time the initial decision was made, because sufficient knowledge and alternatives were available to make a better path decision (Liebowitz & Margolis, 1995).

Given better path decision options are available within third degree path dependence, this tends to be the focal point of path dependence research (Liebowitz & Margolis, 1995, 2000). Both second and third degree path dependence are relevant to this research as they both represent threats to farm viability. “Decision making under uncertainty” is studied within second degree path dependence (Liebowitz & Margolis, 2000, p. 986). There is considerable uncertainty regarding better path options for producers in adapting to climate change, making it likely that path dependence emerging from climate variability will be second rather than third degree. Policy options in supporting primary industries may look very different in response to second versus third degree path dependence. For example, while research in relation to third degree path dependence may usefully focus on identifying and correcting poor decisions, such an approach in relation to second degree path dependence would not yield useful results.

2.3.3.3. The constraint of technical efficiency

Every decision to organise a production system in a particular way, along a particular path, knocks out a set of alternatives that do not align with that path. The path dependence resulting from this is not inherently negative. Path dependence is intrinsically linked to technical efficiency and is necessary for managing complexity in business (Greener, 2002; Liebowitz & Margolis, 1995; Ruttan, 1997).

Businesses often seek high short-term productivity, to which technical efficiency is key (Collinson, 2001; Rosenhead, Elton, & Gupta, 1972). Enhancing technical efficiency within the farm production system is important as it enables the producer to more efficiently transform inputs into a product flow. The importance of technical efficiency and productivity enhancement has driven much of the emphasis in agricultural research (Dillon, 1976). For example, Villano, Fleming, and Fleming (2010) suggest that optimising the farm system by integrating ‘functional complementarity’ will maximise profit.

Maximising production output along a path is not always possible nor desirable. Farms may produce a range of outputs and need to meet a number of goals simultaneously. This will likely make it impossible to invest limited resources to maximise short-term productivity across all outputs (Collinson, 2001; Gross, 1965; Spedding, 1979).

Maximising production output also comes at a cost to the business. Increasing technical efficiency implies a narrowing of the range of acceptable system behaviours. This includes a reduction in more costly forms of system regulators (e.g. aggregation) or flexibility built into the system to manage variability (Cowan, L. et al., 2013; Kaine & Cowan, 2011). This has implications for the capacity of the farm to manage variability, increasing the risk that variability poses to business stability.

Kerr and Mooney (1988) suggest that as a farm business approaches peak productivity it becomes finely balanced, with little flexibility to manage disruption. An example of this is the consequence of short-term droughts on intensive dairy farms in the Waikato region of New Zealand (NZPA, 2010). Given that farming is fraught with disruption, achieving enduring optimisation within a given path does not seem likely in viable farm systems. For example, highly integrating diversified outputs may put the viability of the farm business at risk if the integrated components are ones that are disrupted.

The loss of capacity to manage variability is identified in the work of Tisdell (2003) which emphasises the trade-off made by livestock producers when selecting breeds for maximising productivity. As is evident in the figure (below), the choice of breed I over breed II entails a high productive output, with a much narrower set of environmental conditions that can be tolerated (see Figure 2.5). Tisdell (2003) argues that pushing livestock production down paths that are dependent on “high-yielding environmentally-sensitive breeds will create serious problems for the sustainability of livestock production” (p. 373).

The volatile reality of farming means that producers need to be able to take advantage of the ‘good’ productive and profitable times to make up for ‘bad’ times of poor production and profitability. Taking advantage of the good times can mean consuming expanded financial resources to reduce debt, investing in infrastructure and saving financial (or other storable) resources for potential bad times ahead. This implies that maximising profit and technical efficiency have some role in managing variability in the medium-to-long run.

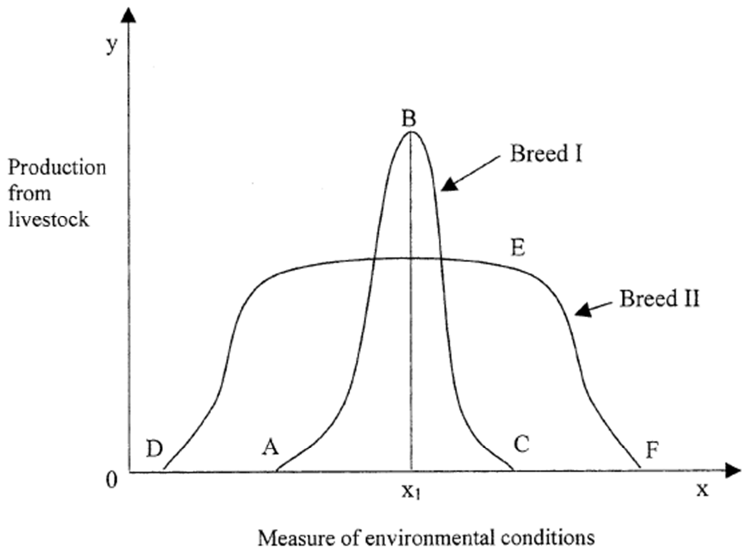

Figure 2.5: An example of trading-off the capacity to manage variability for maximising production in the selection of livestock breeds, from Tisdell (2003)

Practically, producers make decisions about their farm systems in which they have to make trade-offs between technical efficiency and flexibility. Logically, producers will emphasise technical efficiency on elements of the farm that are at less risk of being impacted by variability. Importantly, circumstances can change, altering the elements of the farm that are exposed to variability.

2.3.3.4. Farm finance

What is apparent in this discussion of technical efficiency and maximising profit is that the state of farm finances is a major factor in considering the capacity of producers to manage variability. Put another way, the state of farm financial reserves is a determinant of the sensitivity of a farm to variability in inputs.

Managing variability comes at a cost. For example, the activation of tactics uses farm resources. Changing production system structure to increase the capacity to manage variability also uses farm resources. When variability cannot be managed, the negative effect on output and profit translates to a reduction in farm finances. As variability wears away at farm finances it also wears away at the farm's flexibility and capacity to adapt to further variability (Cowan, L. et al., 2013; Cowan, L. et al., 2011).

It can be very difficult to disentangle farm finances from family finances in a family farm. The family finances can be a source of extra resources for the farm business, increasing the capacity of the producer to manage variability. However, family goals can compete with the farm business for resources; this may decrease the capacity to manage variability.

The interconnection between the farm and family is an important element that influences constraints on managing variability. The point of connection here may be best understood through consideration of the producer, who has goals regarding the farm and the family.

2.4. Framing consideration of the producer in constraints on decision-making

In this research constraints have been described in relation to their influence on decision options for producers. The phrase ‘decision options’ here refers to the set of choice alternatives that the producer considers to be possible for the farm, related to a specific decision problem. Constraints reduce the feasible options that are within that set.

The producer, through his or her management decisions and day-to-day operations, is a part of the farm business. A producer is more than his or her role on the farm. The producer’s decision options are underpinned by a number of factors including personality attributes, capabilities, locus of control and the farm family (Ajzen, 2006; Barr, 2009; Crosthwaite & Malcolm, 2000; Nalson, 1964; Wright, 2011b). A challenge in this research is bounding the relevant aspects of the producer as an individual to enable meaningful and useful analysis of constraints on decision options. This is the aim of the next section.

As we begin to discuss the producer as decision-maker it must first be acknowledged that an individual’s decisions are not simply based on objective rationality (von Bertalanffy, 1968). At times individuals will adopt and continue to follow a strategy or practice that may not be the best option (Egidi & Narduzzo, 1997). Perceptions are influenced by a non-rational escalation of commitment to previous decisions an individual has made (Bazerman, Giuliano, & Appelman, 1984; Staw, 1976). Perceptions are limited by the models of learning they employ (Argyris, 1995). Perceptions are also influenced by “path revision”, by which an individual changes how past decisions are currently perceived to justify the current outcome (Bednar et al., 2011, p. 4); a form of post hoc rationalisation. This is also referred to as ‘hindsight bias’ (Christensen-Szalanski & Willham, 1991).

Instead, there is an assumption within this research that producers who manage viable farm businesses have sufficient objectivity to make reasonable decisions about their farms. Grossly irrational behaviour will lead to poor performance and ultimately failure of the business (Antonelli, 2006). This does not imply, however, that business failure is necessarily an indicator of insufficient rationality in decision-making. There are other factors that can lead to poor business performance, including increased uncertainty (Antonelli, 2006; Chhetri et al., 2010).

As argued earlier, a farm can be described as entailing a hierarchy of goals and plans, with decisions about the farm existing within this hierarchy (see section 2.2.1). Decision-making may differ depending on where within the hierarchy the decision is being considered, as higher-order decisions constrain the set of decision options in lower-order decision-making. Additionally, the decision-making process itself may add to constraints regarding what producers view as feasible options for their farms.

Consideration of how decisions at different levels within the hierarchy are made by individuals is important to this research as it offers useful insights into the analysis of constraints on decision options for producers and how this can be identified in the analysis process. Image theory (Beach, 2010; Beach & Connolly, 2005; Beach & Mitchell, 1987; Beach & Potter, 1992; Beach & Strom, 1989; Nelson, K. A., 2004) is a conceptual model that enables such consideration. Image theory will now be described, including fundamental elements and how the theory may be useful to this research.

Image theory was originally developed by Beach and Mitchell (1987) as a descriptive theory for considering different types of decision-making by individuals (Beach & Potter, 1992; Beach & Strom, 1989). Image theory was extended to consider decision-making within organisations (Beach & Connolly, 2005; Beach & Mitchell, 1990). While the underlying theory is the same, whether considering organisations or individual decision makers, the language and emphasis differ between the two versions (Beach & Connolly, 2005). Hence image theory as it relates to individual decision makers will be drawn upon more heavily. The attention to the individual decision-maker aligns with the focus within this research on micro businesses in agriculture, where an individual producer makes most, if not all, of the farm management decisions.

Image theory describes the decision-making process of individuals when the decision is "of more than routine importance" (Beach & Mitchell, 1987, p. 201). Routine practices are those that occur automatically or as a matter of course, in the present context, within the day-to-day operations of the farm; hence, the routine is in the realm of regulatory mechanisms rather than management decisions. Routine practices are not the central focus of this research.

2.4.1. Images

Image theory describes the reality of decision-making from the perspective that people partition elements of our individual 'store of knowledge' so that we can selectively access from this store based on relevance (Beach & Connolly, 2005). This reduces the effort needed to make a decision. An individual's store of knowledge is partitioned within three images: value, trajectory, and strategic image. Knowledge from the relevant image can be drawn upon when needed and bypassed when it is not.

The value image consists of an individual's values, morals and ethics. These are described collectively as 'principles' (Beach & Connolly, 2005). An individual's principles drive what goals and plans are appropriate in the trajectory and strategic images. This store of principles is called a value *image* because "it represents his or her vision about the state of events that would conform most closely to his or her beliefs, values, and ethics" (Beach & Connolly, 2005, p. 161).

The trajectory image represents an individual's "agenda of goals to achieve" (Beach & Connolly, 2005, p. 161). It comprises goals as defined by principles. The trajectory image also comprises goals that are identified through the need to respond to problems in the environment in a way that aligns with principles (Beach & Connolly, 2005).The collective goals are termed the trajectory *image* because it represents an individual's "vision about how the future should unfold and therefore sets standards for what is and is not appropriate behavior" (Beach & Connolly, 2005, p. 162).

The strategic image is the store of plans in use to achieve goals in alignment with principles (Beach & Connolly, 2005). A plan is described as comprising two parts, tactics and forecasts. Tactics are the concrete collection of activities or behaviours employed to achieve a goal. Some plans require tactics to manage “local environmental conditions and constraints” (Beach & Connolly, 2005, p. 162). This aligns with the conception of tactics described in relation to farm system regulation (see section 2.2.1).

The second part of a plan within the strategic image is forecasting. Forecasting is an individual’s perceptions of possible future states given the current plan (Beach, 2010). Forecasting entails monitoring of the system state compared with possible future states to highlight any misalignment with goals. The degree of alignment between the forecast and a goal determines the success of the related tactics. Forecasting, as described here, is proximal to the notion of feedforward control, which relies on predictions of deviations from plans before they occur (Anderson,C., 1984). Collective plans are called the strategic *image* as they entail “the decision maker’s vision of what he or she is trying to do to achieve the goals on the trajectory image and sets standards for what is or is not appropriate behaviour” (Beach & Connolly, 2005, p. 163)

An individual will have multiple plans, based on multiple goals. An important consideration in the strategic image is coordination of plans to minimise interference across plans (Beach & Connolly, 2005). Implicitly, here, forecasting includes consideration of the interaction between concurrent plans on the perception of possible future states. A perceived discrepancy between the possible future state and goals triggers the need for a decision process to assess whether changes are required to plans or goals. A perceived discrepancy in a plan can emerge out of changes in the environment, changes in an interacting concurrent plan, or changes in the forecasting element of the strategic image.

An influence on forecasting is what the decision maker defines as relevant knowledge, which is determined to some degree by the individual’s ‘frame’. A frame describes the subset of an individual’s store of knowledge that is drawn upon to consider a particular decision (Beach & Connolly, 2005). What is recognised as relevant knowledge to be drawn upon emerges through a process of identifying contextual memory that has similar features to the current context. The frame defines the relevant image elements and previous experience with similar goals and plans to be drawn upon in the current decision-making process.

2.4.2. Types of decisions

Image theory describes two types of decisions: progress decisions and adoption decisions (see Figure 2.6). Progress decisions are those concerned with assessing whether a plan of action is progressing toward achieving goals (Beach & Connolly, 2005; Beach & Mitchell, 1987). Progress decisions are made through the forecast element of plans in the strategic image (Beach & Connolly, 2005). Progress decisions are an assessment of whether the current plan is aligned with a forecasted attainment of goal in the projected future. If the attainment of the goal is deemed plausible then the plan is maintained. If the forecasted future does not reflect goal attainment then the plan needs to be replaced or altered.

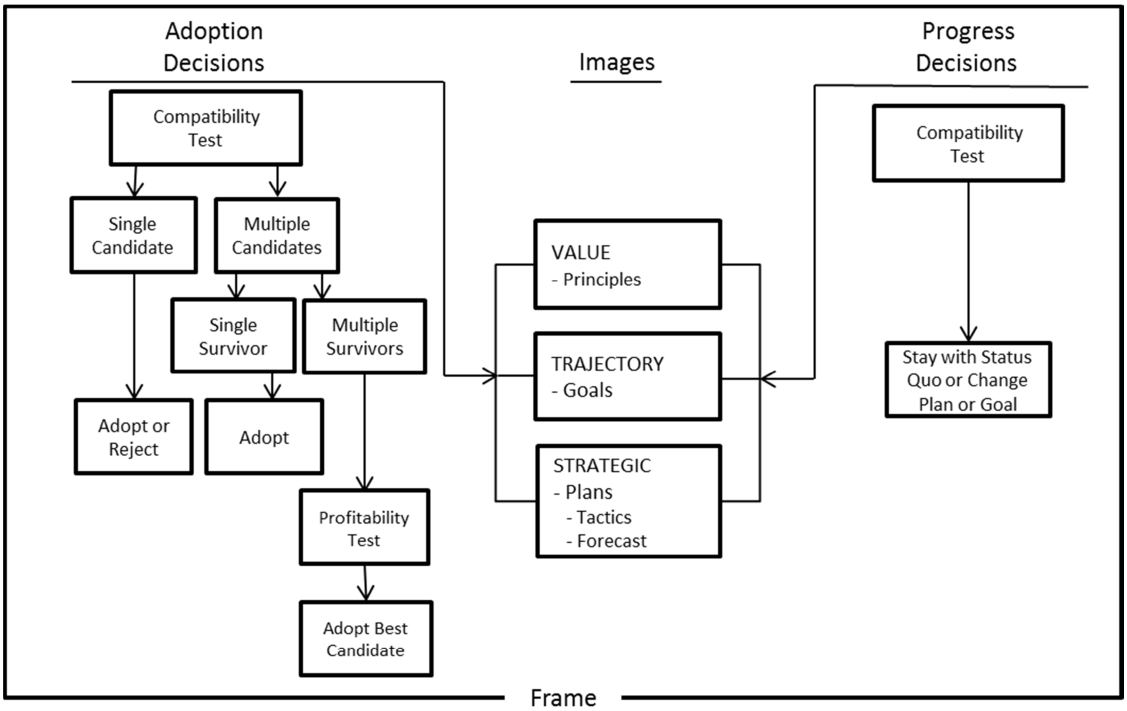

Figure 2.6. Elements of decision-making in image theory, adapted from Beach and Connolly (2005)

Progress decisions can be described as elements within the control process. This differs significantly from the second type of decision described in image theory, adoption decisions. Adoption decisions are responses to progress decisions that signal the need for intervention and are concerned with the adoption or rejection of decision options for images (Beach & Connolly, 2005; Beach & Mitchell, 1987). Adoption decisions at an image must be compatible with the other elements within that image and with the image above in the hierarchy.

2.4.3. Decision-making process

The type of decision, progress or adoption, determines the decision-making process. Within image theory, decision-making is described as a two-step process. The first step involves assessing options for compatibility (Beach & Connolly, 2005), which has also been called screening (Beach & Potter, 1992; Beach & Strom, 1989). The object of this step in decision-making, for both progress and adoption decisions, is to reject options that are not compatible with images. For example, an alternative being considered as a plan of action will be rejected if it does not align with principles and goals. Simply put, a decision option must be acceptable to all images to be included in the set of decision options. Compatibility is non-compensatory. Rejection due to misalignment with a principle, goal or plan cannot be compensated for by alignment with other principles, goals or plans (Beach & Mitchell, 1987; Beach & Strom, 1989). This is governed by a rule of sufficiency and a rejection threshold that determines how many violations to compatibility within an image will be allowed before the decision is rejected due to incompatibility (Beach & Connolly, 2005; Beach & Mitchell, 1987). Compatibility testing has been the focus of most research using image theory (Beach & Connolly, 2005).

In adoption decisions, when more than one adoption option makes it through compatibility screening the second step in decision-making is employed: an assessment of profitability. 'Profitability' has been defined as the expected utility, or the quantity of outcomes expected with the associated adoption options (Beach & Connolly, 2005; Beach & Mitchell, 1987). In this stage of decision-making, positives and negatives are compensatory and profitability is assessed as an overall sum of utility and compared across adoption options.

2.4.4. Implications from image theory

Image theory is relevant to research on the constraints in farm management as it provides a model for considering the individual producer, as primary decision-maker, within a comprehensive set of possible sources of constraints. Fundamentally, image theory describes how the decision-making process itself constrains the decision options for individuals. Some of this constraining influence comes from path dependence. Beach and Mitchell (1987) highlight path dependence in decision-making when they describe the role that repeated adoption of practices has in building constituents within images, reinforcing subsequent decisions. This can be seen in Beach and Connolly's (2005) description of framing, in which previous experience influences the subset of knowledge that is accessed for decisions.

It is possible to broadly view path dependence as a highly constrained form of the trajectory image, in which the producer's perceptions of how they will pursue their values through the farm business narrow. Hence, path dependence constrains decision-making. As decisions are made regarding business structure, increasingly reinforcing previous decisions, these constrain the decision options available to the producer. This means more options are deemed incompatible with the producer's images. This translates into an increasingly narrowing set of plans and goals available which may lead to higher-order critical junctures. There are a number of implications that emerge when image theory is applied to the analysis of constraints on producer decision options. These implications relate to how the images interact with the hierarchy of the farm, identifying profitability and compatibility, and the constraining effect of doubt on decisions.

2.4.4.1. Hierarchy

The description of images offered by Beach and Connolly (2005) implies a hierarchy of images, with the value image influencing the trajectory image, which influences the strategic image. The reality may be less tidy, as the flow of influence across images may not run unilaterally from principles to goals to plans. Given the farm is a hierarchy of interrelated goals and plans, it is possible that higher-order plans influence lower-order goals. This implies that there may be circumstances in which strategic image change to higher-order plans may influence lower-order goals.

Importantly, image theory is about the images of an individual. The goals for the farm are those of the producer. They are interwoven with the myriad of other goals held by this individual and underpinned by his or her principles. These goals and principles determine the manifestation of the strategic image, visible in the day-to-day operations of the farm. The hierarchy of images in image theory offers a way clearly to locate higher-order constraints, such as the principles of the producer, in the decision-making process.

Principles relate to many facets of the producer’s life beyond the farm, including the farm family (Gasson, 1973; Gasson et al., 1988; König et al., 2013; Nalson, 1964). In the same vein, goals of the producer will relate to the farm as well as other aspects of life. Essentially, image theory enables the researcher to consider how producer evaluation of decision options may intersect with multiple domains of life, including the farm family. An example here is the consideration of how family and business goals interact to influence the use of family and farm finances.

Hierarchy has implications for adoption decisions in image theory. If a need for change is triggered through the forecast element of the strategic image and the related progress decision, an adoption decision can occur at either the trajectory or strategic image in the hierarchy. However, change is likely to be assessed at the strategic image before moving to the trajectory image (see Figure 2.7). This is because changes to goals will necessitate changes to subordinate plans to align with the new goal. Such change is likely to have a much greater impact across the system.

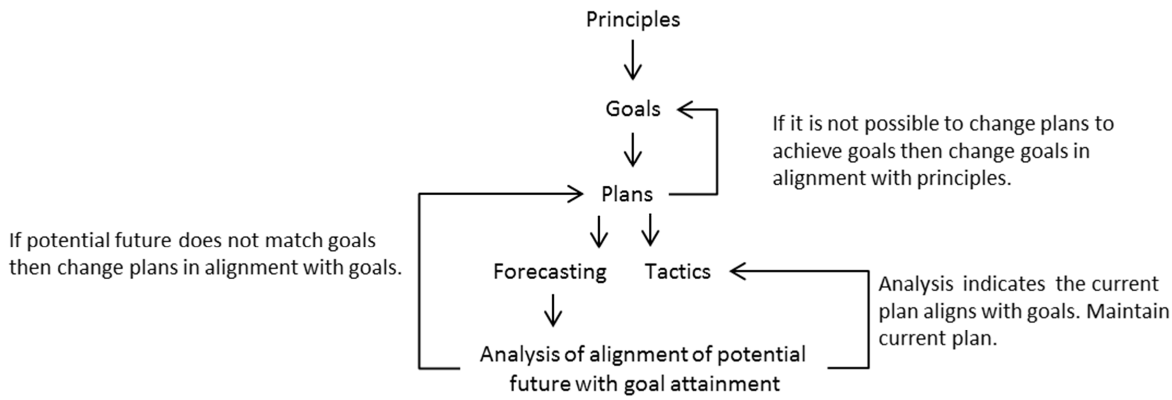

Figure 2.7. Simple example of a decision hierarchy

2.4.4.2. Profitability and compatibility

Compatibility and profitability are very different types of analysis in decision-making and will appear as such within a producer’s decision-making process. When deciding about the adoption of an innovation, for example, a producer is typically able to describe the elements that were considered when making the decision and is likely to be able to describe the discrete process that was followed. An approach to predicting the adoption of innovations in Australian and New Zealand agriculture is grounded in this thinking (see Bewsell & Kaine, 2006; Bewsell, Monaghan, & Kaine, 2007; Kaine & Bewsell, 2008; Kaine, Lees, & Wright, 2007). Such decisions about the adoption of innovations are being evaluated for profitability and have already avoided rejection due to incompatibility.

Often, when a decision-option is rejected due to incompatibility with images, this is done unconsciously, via intuition (Beach & Mitchell, 1987). Hence, individuals may not be able to readily describe why an option was rejected beyond ‘gut feel’. This can create some challenges when analysing decisions. It can appear that an option has been excluded from a producer’s decision options because of a lack of knowledge regarding the option, when it may be due to fundamental incompatibility with the producer’s principles, goals or plans. This has implications within this research when identifying sources of constraints.

2.4.4.3. Changing signals and increased uncertainty

Forecasting is the key to identifying whether change needs to be considered in the farm business. This requires the timely identification of signals (threats and opportunities) among the background noise. What is classified as a signal is reinforced by previous successful identifications of the signal, which is path dependence. With increased climate variability, some producers may need to alter their use of signals to consider whether their farms are on the right trajectories.

Increased climate variability is linked to increased uncertainty (see Section 2.4.4.3). With increased uncertainty the signals for change may be increasingly difficult to identify. This uncertainty leads to doubt. Beach and Mitchell (1987) identify doubt as a constraint in profitability assessment of decision options. Evaluating profitability requires that the decision-maker judge the degree to which a decision option may aid in goal achievement. People recognise that such judgements in their own decision assessments can be imprecise, which attaches doubt to profitability assessments (Beach & Mitchell, 1987). Doubt diminishes the positives and negatives within a calculation of profitability. This, in turn, influences an individual’s perception of the utility of a decision option. The implication here is that increased doubt can constrain an individual’s decision-making by reducing their capacity to assess the profitability of a decision option. Consideration of doubt among the constraints on adaptation to climate change may be useful to this research.

2.4.4.4. Learning

Given this is a study of decisions being made through time in a farm system, it is expected that an evolution in perceptions of reality and self-efficacy[8] will emerge. As well, it is likely that there will be differences in the rates that different farmers move toward understanding changes in their farm circumstance that require a response. This is due to learning. It is worth briefly contemplating how learning may interact with the hierarchy of images.

Learning is “the detection and correction of errors” that lead to ineffective action (Argyris, 1976, p. 365) . Learning is limited by the information regarding consequences of the action (Argyris, 1976). It is also inhibited by the receptivity of the decision maker to feedback indicating an error has occurred (Argyris, 1976)

Argyris (1976) has suggested that there are two types of learning, single-loop and double-loop (see figure 2.8). Single-loop learning is the dominant learning practice and entails a narrower set of evaluative behaviours, focusing on satisfying the governing variable that initiated the need for action. Put another way, single-loop learning employs a logic to close a gap in performance (Gates & Cooksey, 1998). Gates and Cooksey (1998) identify single-loop learning as a “common form of problem solving in organisations particularly in times of scarce resources and stress” which they align with crisis management (p. 7).

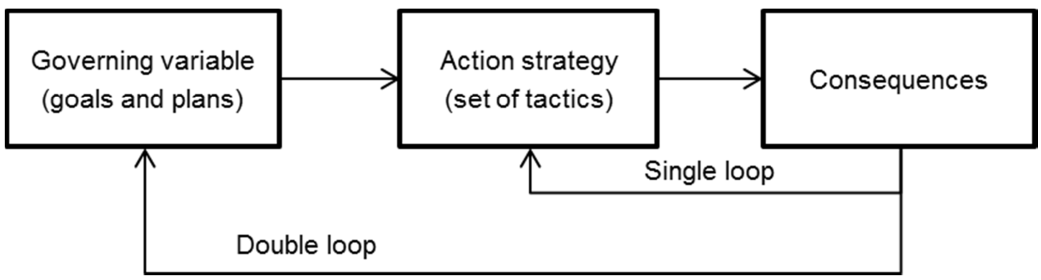

Figure 2.8. Single and double loop learning, adapted from L. Anderson (1997)

[8] Self-efficacy is an individual’s belief in his or her ability organise and execute a course of action successfully (Bandura, 1977).

Double-loop learning entails a deeper degree of scrutiny in evaluating actions, which includes consideration of the governing variables that underpinned the need for action (Argyris, 1976, 1995). Whereas single-loop learning is used to close a gap in performance, double-loop learning is used to question whether the correct gap in performance is being sought (Gates & Cooksey, 1998). Double-loop learning is identified as more effective in the longer term, but more stressful, uncomfortable and destabilising in the short-term (Gates & Cooksey, 1998).

Learning behaviour as described here offers another perspective for considering how producers make and evaluate decisions about their farms. The constraints on learning, in terms of information and receptivity, are likely to influence forecasting and perceptions of the need to alter plans and goals. These constraints are relevant for understanding the constraints on producers to adapt to climate variability and its related uncertainty.

Additionally, double-loop learning aligns with higher-order changes in image theory's hierarchy of principles, goals and plans. Such learning is likely to be apparent through the historical sequence of decisions described by producers. Some of this learning may be reflected in changes to principles and goals.

2.4.4.5. Other constraints on decision-making

There are other theories of decision-making which predominantly focus on what image theory classifies as profitability assessment in adoption decisions. For example, Pennington and Hastie (Pennington & Hastie, 1986, 1988) offer explanation-based decision-making as a model for considering complex decisions; Kaine (2008) considers the adoption of agricultural innovations using complex decision-making framed around farm context; Bagozzi (2006) presents a consumer decision-making model that Wright (2011b) suggests is applicable to farm businesses. As well, Janis (1992) offers a constraints model of strategic decision-making that is applied to organisations and individuals and Lord and Hanges (1987) use control theory to consider individual and interpersonal motivation through integration of goals, feedback and decision-making. Importantly, while these approaches may acknowledge the distinction between low-effort and high-effort decisions, they do not offer an explicit framing of the cognitive processes undertaken with different types of decision-making.

The constraints model of strategic decision-making (Janis, 1992) is worth further attention, as it offers insights regarding constraints on adoption decisions that are not explicit in image theory and are relevant to this research. While the constraints model is fundamentally concerned with maximising vigilant decision-making by policy-makers by increasing their capacity to manage salient constraints in an organisational context, Janis (1992) suggests that the underlying constraints described within it are useful for considering individual decision-making.

Janis (1992) argues that decision-making is constrained by every individual's limited knowledge and capabilities, which impede objective rationality from ever being achieved in human decision-making. Such constraints are categorised as cognitive constraints. Other cognitive constraints include impediments to contributing sufficient cognitive effort to problem solving; such as lack of time, complexity, limitations in resources and the need to consider multiple tasks (Janis, 1992). The constraints from ambiguous and incomplete information that is associated with uncertainty also align with the notion of cognitive constraints (Janis, 1992).

Cognitive constraints are clearly relevant to considering producer decision-making. Maintaining sufficient knowledge and skills to manage multiple tasks simultaneously are perennial elements of farming, and complexity and uncertainty are issues that are becoming increasingly relevant given increased climate variability.

Janis describes constraints relating to social standing on decision-making as affiliative constraints. Affiliative constraints include the need for power, standing, compensation, social support and acceptability (Janis, 1992). This has relevance for this research given the intergenerational nature of farming. It may help reveal an element of influence that the family may have on producer decisions.

The third set of constraints that Janis describes comprises egocentric constraints. These constraints relate to an individual's emotional needs and stress. Emotional stress is an internal constraint that acts "at the preconscious level" (Janis, 1992, p. 21). Farms in Australia are often more than a business and include elements of family history that may spark egocentric constraints on producer decisions. Over the past decade, producers in Victoria have had to manage a decade of drought, and quite possibly other sources of stress. Hence, it is important to acknowledge that emotional stress may appear as a salient egocentric constraint.

While the constraints model was designed to evaluate policy development, the cognitive, affiliative and egocentric constraints described in the model are clearly relevant to understanding producer decision-making. Constraining factors such as knowledge, capability, stress, uncertainty and time are all relevant to understanding how producers can respond to increased climate variability. Importantly, many of these constraints on the decision-making process are outside the domain of the farm, stemming from the producer and the farm family. There is a need to approach this research with mindfulness of these sources of constraints.

What is apparent in the literature on decision-making is that there are a number of factors constraining the decision-making process itself. Framing these constraints as a hierarchy of images provides a practically useful way of identifying critical junctures and path dependence. Changes in plans or goals within the hierarchy of images that require changes to the production system should also align with the concept of adaptation being explored in this research.

2.5. Developing a model of a firm

To analyse the influence of path dependence on managing variability in inputs it is necessary to first construct a model of a farm in which such analysis is possible. The model needs to enable consideration of constraining elements at levels of the hierarchy of decisions in which inputs are managed. Hence, disaggregation of the farm to the level at which production decisions are made is a priority within this model. The dominant construct in production management and operational management literature is that of a firm as a value chain (Walters & Rainbird, 2007). In the following section this model will be described to access its appropriateness for use within this research.

2.5.1. Firms as value chains

Constructs of firms as interconnected collections of components for analysing the flow of physical inputs through production processes to product distribution has links in primary industries back to origins in the 1950s and 1960s. This includes the emergence of agribusiness, analysis of mineral-export development options and the French ‘filière’ approach for studying vertical integration and contract manufacturing in agriculture (Hartwich & Kormawa, 2009; Kaplinsky & Morris, 2001).

Porter (1985) developed these constructs into a model that depicts an individual firm as a collection of activities and interactions between activities. The model is represented as a value chain (see Figure 2.9). The value chain model is used within an approach to analyse the competitiveness of the firm, described as value chain analysis[9]. Porter's value chain analysis highlights the importance of managing firm activities and linkages when maintaining a profitable business and seeking competitive advantage.

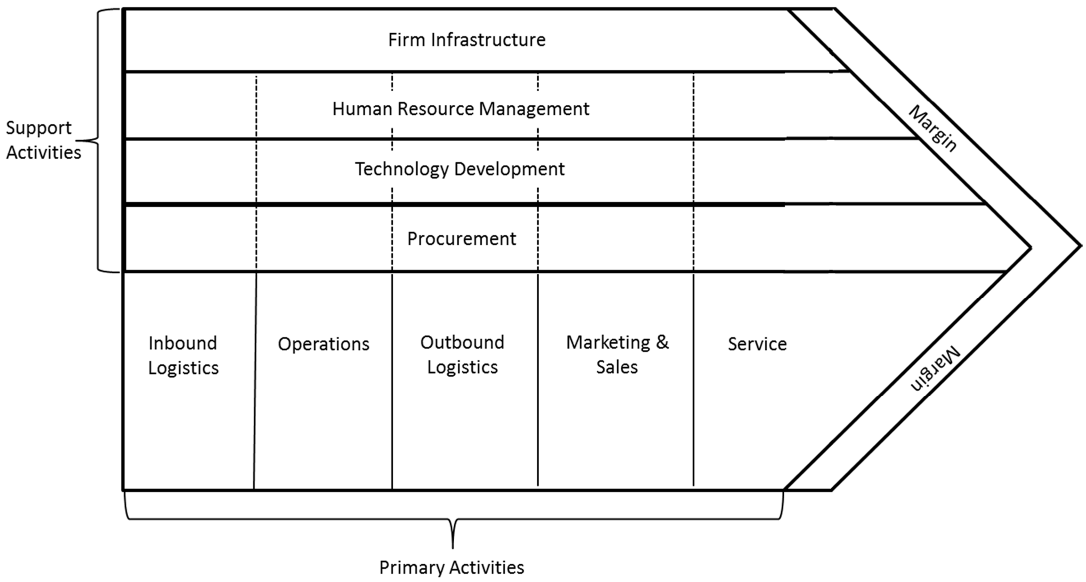

Figure 2.9: A value chain, adapted from Porter (1985)

When using value chain analysis, an individual firm is disaggregated to individual categories of activities, and linkages between them, according to their functions within the firm to produce a product (Porter, 1985). The notion of function as a taxonomy for firm structure aligns with the organisational design research conducted by Gresov and Drazin (1997) in which function is defined as "the way in which a component part of a subsystem (i.e. a structure) contributes to the maintenance of the system and its ability to be adaptive to its environment" (p. 406).

If a firm has multiple enterprises then these are represented as distinct value chains within the business. This aligns with Storper and Harrison's (1991) concept of an

[9] The distinction between value chain as a model of a firm and value chain analysis as an investigative process is quite important.

‘input-output’ system. The individual activities and linkages within a value chain are then analysed to consider the part they play in the firm’s competitive advantage. When there are multiple value chains activities and linkages are identified separately and are then analysed collectively to assess the firm's competitive advantage.

The value chain, at a business level, exists within a value system: the sequence of interconnected firms that, together, create the final product (Porter, 1985). In more recent times the value chain approach to analysis has been extended to include analysis of value systems, from supply chains to global commodity chains (Al-Mudimigh, Zairi, & Ahmed, 2004; Antràs & Chor, 2013; Dries, Germenji, Noev, & Swinnen, 2009; Hartwich & Kormawa, 2009; Kannegiesser, 2008; Raikes, Friis Jensen, & Ponte, 2000; Taylor, 2005). At times the term value chain is now defined in terms Porter associated with the value system (Humphrey, 2006; Innovation Center for U.S. Dairy, 2013; Kaplinsky & Morris, 2001). In this research, my interest is in analysis at the firm level and therefore Porter’s original conception of a firm as a value chain is of relevance here.

Porter’s (1985) value chain analysis focuses on strategic competition among oligopolists or imperfect competitors. This means that comparison between competing firms is an essential element of analysis. This is not the case for near-perfectly competitive situations such as farming. Hence, analysing the competitive advantage of farms is not the focus of my research. Instead, I am focused on analysing the constraints on a farm business to produce outputs; it is production rather than profit that I am exploring here, since producers tend to be unable to set output price. This means that value chain analysis, as such, is not of core interest to this research.

Even so, useful concepts can be derived from the notion of value chain as a model for developing a conceptual understanding of path dependence in farms. Of predominant usefulness is the characterisation of a firm as an interconnected collection of activities that are classified according to function within the firm. The usefulness of the value chain in this research is aided by its alignment with concepts in GST such as open systems and hierarchy.

2.5.2. Adapting the value chain model

Next, I am going to describe Porter's classification of firm activities and linkages. From there I will highlight specific implications for agriculture. I will then build on the concepts to consider how the model can be integrated into an analytical framework for analysing path dependence in farms.

Within the model, Porter (1985) defines five categories of primary activities that every business performs. Primary activities are those "involved in the physical creation of the product and its sale and transfer to the buyer as well as after sale assistance" (Porter, 1985, p. 38). The five primary activities are: inbound logistics, operations, outbound logistics, marketing and sales, and service.

- *Inbound logistics* are "activities associated with receiving, storing, and disseminating inputs to the product" (Porter, 1985, p. 39). In agriculture, some examples of this include receipt of purchased inputs such as fuel, storing purchased feed grain in farm silos and filling up dams that are used for farm irrigation.
- *Operations* are "activities associated with transforming inputs into the final product form" (Porter, 1985, p. 40). In agriculture this includes many of the day-to-day farm practices, for example: stock grazing practices, irrigation practices, sowing and harvesting crops.
- *Outbound logistics* are the "activities associated with collecting, storing, and physically distributing the product to buyers" (Porter, 1985, p. 40). Examples of outbound logistics in agriculture include packing fresh fruit for market, storing milk for collection by the milk factory and transporting stock to the saleyard.
- *Marketing and sales* are "activities associated with providing a means by which buyers can purchase the product and inducing them to do so" (Porter, 1985, p. 40). Selling fruit directly from the farm's fruit shed to the public or marketing and selling farm produce at a local Farmers' Market are examples of this kind of activity in agriculture.
- *Service* describes "activities associated with providing service to enhance or maintain the value of the product" (Porter, 1985, p. 40). A fodder producer liaising with local dairy farmers about their feed input needs is an example of a service activity in agriculture.

The degree of emphasis a firm places on these categories of primary activities will differ, depending on the industry (Porter, 1985). For farm businesses, the greatest emphasis is placed on primary activities associated with inbound logistics and operations, the elements of the farm business in which they have the greatest influence. Given agricultural businesses exist within commodity markets and near-perfect competition, producers typically have no control over their product beyond the farm gate.

In addition to primary activities, Porter's model describes four kinds of support activities. Support activities are those that "support the primary activities and each other by providing purchased inputs, technology, human resources and various firm-wide functions" (Porter, 1985, p. 38). The four support activities are: procurement, technology development, human resource management and firm infrastructure.

- *Procurement* is "the *function* of purchasing inputs used in the firm's value chain" rather than inputs themselves [emphasis in original] (Porter, 1985, p. 41). Procurement is a business-wide function, as inputs are used all along the value chain. It is the design of the way inputs are procured. A producer's business practices relating to purchasing feed to fill seasonal feed gaps is an example of a procurement activity. Another example is a producer's practices for obtaining access to irrigation water through the use of a combination of temporary water, irrigation entitlement, a farm dam and groundwater bores.
- *Technology development* is a description of the system support activities that are employed to improve the product and the process of product creation (Porter, 1985). Technology development encompasses research, development and adoption of physical technologies as well as relevant knowledge, processes and procedures. Technology development can support specific activities or multiple activities across the business. In agriculture, examples of technology development include the adoption of a new grain variety for cropping, shifting from rotational to strip grazing, and the installation of a rotary dairy.
- *Human resource management* is a description of activities related to "recruiting, hiring, training, development, and compensation of all types of personnel" across the entire value chain (Porter, 1985, p. 42). Examples of human resource management on farms are hiring and training staff and contractors, managing a share farming relationship and succession planning for the family business.

- *Firm infrastructure* is the group of support activities that generally support the entire value chain, not individual activities (Porter, 1985). Firm infrastructure includes the physical infrastructure as well as "general management, planning, finance, accounting, legal, government affairs, and quality management" (Porter, 1985, p. 43). In farms, examples of firm infrastructure are elements of the biophysical production system such as irrigation channels, hay sheds, and grain silos. Firm financial planning and resources and farm business strategy are also examples of firm infrastructure activities.

Both primary and support activities can be described as either direct (value creating), indirect (continuously make value creating possible), or quality assurance (assessing quality of other activities) (Porter, 1985). Porter (1985) argues that distinguishing among the types is crucial in analysing firms as indirect activities can often be ignored, which means "tradeoffs between direct and indirect activities" are not well understood (p. 44).

How the activities within a firm are disaggregated is determined by the purpose of the application of the framework and the identification of discrete activities that influence the firm (Porter, 1985). Activities may be relevant to more than one classification, and assignment of activities is determined by where it will best aid analysis of the firm in the research; hence, researcher judgement is embedded within the classification process (Porter, 1985).

Activities in a value chain are interconnected by linkages, which Porter (1985) describes as "relationships between the way one value activity is performed and the cost or performance of another" (p. 48). This aligns with the concept of relationships from GST. Linkages within farm businesses can be seen in the day-to-day decisions about flood irrigation scheduling and grazing rotation management. For example, flood irrigation may be scheduled to ensure that it does not overlap with the stock grazing rotation to reduce the risk that stock might damage pasture in newly-watered paddocks.

Linkages can be used within a firm to optimise activities and to coordinate activities (Porter, 1985). In agriculture for example, a horticulturalist may link fertiliser with irrigation to maximise fertiliser uptake by the fruit trees (optimisation). This same producer may seek to time irrigation to align with the need to get onto the orchard for other activities (coordination).

2.5.3. Priority functions in farming

Porter's (1985) value chain constructs are being used in this research because of the relevant focus on the physical flows of a firm. While Porter's interest is on value flows and how this influences competitiveness, this value flow is underpinned by the physical flows in the production system itself. It is this physical model of a firm that is being used here, integrated with farm control, image theory and path dependence, to consider farm constraints.

Fundamentally, a farm business is dominated by a production system used to transform inputs into outputs; hence, emphasis is placed on managing this transformation process within the farm. Given that unchecked variability in inputs translates into variability in outputs, a producer seeks to exert control over elements of the farm to manage the flow of inputs and the operations of the production system to achieve desired output quality and quantity. However, a producer's capacity to control the flow of inputs and the operating system is limited by the historical sequence of farm business decisions.

Producers exert the greatest degree of control within the inbound logistics and operations functions of the farm, with support from procurement activities. A producer's degree of control is also influenced by farm infrastructure, human resource management and technology support activities. These are the functional areas of the farm which this research emphasises.

2.5.4. Accessing farm inputs

Producers can access inputs by either purchasing them from suppliers in the value system or generating them within the firm. Given the importance of inputs, suppliers can have considerable influence on a farm's performance (Porter, 1985). The relationship between a firm and supplier is described as a vertical linkage, in which the supplier is a separate value chain from the firm, with a separate bargaining power for negotiating with the firm (Porter, 1985). When a firm internally generates an input for a primary function of the firm it is classified within the firm's support or primary activities rather than as a supplier.

A firm's decision to obtain inputs from a supplier or create it internally may be based on efficiencies associated with specialisation and/or scale: whether it is more efficient for the firm to make it or buy it. Another influencing factor on a firm's choice between buying or creating an input relates to managing risk regarding access to the input. Farms face considerable variability in relation to significant farm inputs, due to their degree of openness. This means that in agriculture there is often an emphasis on enhancing reliability of access to variable inputs in producer supply decisions. For example, a producer may decide to install a groundwater bore to increase the reliability of access to irrigation water, even if this is more costly than buying temporary water on the market.

In reality, producers often obtain farm inputs from a combination of internal and external sources. A producer's capacity to choose between various means of access to inputs may be crucial in managing variability in inputs. This aligns with Porter's (1985) notion of tradeoffs and L. Cowan et al.'s (2013) concept of tactical flexibility. Understanding the capacity of producers to alter how they access inputs, and how this relates to inbound logistics and operations, is of importance to this research.

2.5.5. Support systems

An important element of the value chain model that offers relevant insights to this research is the fundamental distinction between support activities and primary activities within the model of a firm. The insights offered here are grounded in the hierarchy it introduces within the model of the firm. Primary activities are those involved in the physical creation and distribution of a firm's product.

Support activities are functions that have the potential to influence all of the primary activities; hence they are likely to be higher order activities when compared to the primary activities within a firm. A support activity that is a higher-order activity is likely to incur a higher-order source of path dependence for a firm. Hence, changes at the higher order are likely to indicate a critical juncture within the firm.

Finance is an example of a support activity within farm infrastructure. A producer will only have access to a certain amount of finance within the farm business. As well, impacts of change on the farm can have a cumulative negative financial effect on the business. Cumulative negative financial consequences from historical decisions within the firm reduce the current and future decision options available to the producer.

2.5.6. Higher-order objectives

A key point of analysis in the research is linking a farm's current constraints to future options for the business. A producer pushes his farm down a particular path, driven by current business strategy and objectives for the future. Boehlje (1999) builds on Bromley and Reis's (1999) notion of 'final cause' when suggesting that analysing implications for the future requires consideration of these future objectives.

The set of decision options that are available to the producer will be determined by this overarching strategy and objectives for the future, which can be seen in the producer's implicit and explicit hierarchy of plans. A practical example of an objective in a family farm might be the desire to pass the farm onto the next generation.

Porter's value chain approach implicitly contemplates a single objective relating to maximising return on investment. Farming differs from many firms in that producers often have a number of higher-order objectives that do not relate to maximising return on investment. These objectives emerge out of the close interrelationship between the farm business and the family (Gasson, 1973; Gasson et al., 1988). This research will include consideration of how the relevant higher-order hierarchy of objectives leads to constraints on the farm value chain.

This is not to suggest that all producers will have highly formulated objectives for the future. The further into the future a producer is looking, the broader an objective will appear. This means that the set of current decision options for achieving that objective is likely to be large. However, higher-order objectives will knock out misaligned lower-order decision options within the farm business. As well, when future objectives become untenable, this may signal a critical juncture for the farm business. For example, a producer who has based farm business decisions on a child coming home to take over the business will rethink the future of the business if his or her children all decide to embark on different careers.

It is important to acknowledge here the strong interconnection between the farm business objectives and their associated hierarchy of plans with the producer's principles and goals, as described in image theory. The producer's principles and personal goals dictate what objectives will be contemplated for the farm. As well, the hierarchy of plans in the business must be sufficiently compatible with all other plans, goals and principles. There are likely to be more far-reaching implications when changes occur in higher-order images. In the example above, the producer’s need to rethink the future of the business may stem from a crisis relating to a threat to fundamental principles due to the strong link between the farm and family.

2.5.7. Developing a conceptual model of path dependence

My research differs from value chain analysis in that I am not seeking to use the value chain model to identify all current activities and linkages within a business. Identifying all current activities within a farm and the sequences of decisions that led to them would be an enormous task and largely unnecessary.

Instead, this research is about identifying current constraints as described by producers, and the historical sequence of decisions that led to them from a critical juncture. Existing constraints within farm activities are at the forefront of producers’ minds as the sources of risks for the business and within the options that they identify as available to them. By identifying a current concern for a producer it is possible to then peel back the layers of interrelated decisions that have led to that concern. Linking farm control theory grounded in GST, image theory, as well as core concepts of path dependence to the value chain model offers an approach for understanding these constraints described by producers.

3 Developing and testing a conceptual model of constraints on farm decisions

3.1. Introduction

In the Introduction I highlighted a gap in knowledge regarding the capacity of producers to manage the increased variability in farm performance that is expected with climate change. Central to understanding this capacity and filling this gap is clarity regarding the constraints on decisions producers make about their farms. In the preceding chapter I described several bodies of literature that offered relevant concepts for framing variability and constraints on managing variability in farms. In this chapter, these concepts are drawn upon and integrated to develop a conceptual model of constraints on decision-making in farm businesses. Following discussion of the conceptual model, the research design and methods are described.

3.2. Developing a conceptual model

While the various domains of research described in Chapter Two offered useful insights for considering constraints on decision-making on farms, the insights offered in each domain were limited when considered separately. I propose here that a conceptual model integrating relevant concepts from across these domains provides a landscape for more complete investigation of potential constraints.

When developing a conceptual model of the constraints on producers to manage variability there are two key steps. First, the farm needs to be defined in a way that enables meaningful contemplation of how variability is managed. Second, the constraints on managing variability need to be identified. These two key steps will now be described, drawing from the perspectives of farm control theory, path dependence, image theory and value chains.

3.2.1. Defining the farm and variability management in farms

Defining the farm system in a way that enables meaningful contemplation of how variability is managed entails consideration of both static and dynamic elements. This includes consideration of farm structure and how this structure works, in interaction with the task environment, to generate a product flow. Towards this end, farm control theory has been drawn upon to describe the farm as a purposeful hierarchy of interrelated components in this conceptual model. Farm control theory, grounded in GST, introduces the notion that how a farm production system is organised is a determinant of its capacity to manage product flow of the business.

While a systems metaphor offers many useful concepts for describing a farm as a production system, it falls short of providing definitional clarity regarding the purpose of farms and how this purpose governs the management of farms as businesses. Such clarity is important here as it enables contemplation of how system structure at the farm business level has been organised to achieve particular business functions and outcomes. Porter's (1985) value chain fills this need, as it offers a construct of the farm as a functional hierarchy of primary and support activities that create and manage product flow to enable the achievement of a profit[10]. The functional hierarchy in a value chain holds significance in the proposed model, as changes to support activities, by definition, are more likely to lead to farm-wide consequences. Hence, framing farms as value chains, in the sense used by Porter, enables consideration of the interaction between primary and support activities and the influence of this interaction on the farm as a whole.

[10] Recall here that other purposes of the farm (e.g. family legacy) rely on the achievement of long-run profitability.

When defining the farm and its characteristics it is important to ensure that the description of the farm enables consideration of variability management. The notion of value chain highlights the importance of the relationship between inbound logistics and procurement in managing input variability in farms. However, it does not in itself describe how variability is managed beyond acknowledging a relationship across functional activities, highlighting the importance of farm control theory in this model.

I have defined the farm as a hierarchy of functions with a purpose of profit attainment that is achieved by managing the farm production system to maintain a product flow. I can now use farm control theory to guide consideration of how farms are managed in relation to variability. Farm control theory offers a useful framing of the dynamic interaction between the farm and the task environment to maintain system stability. From this perspective variability is managed by using tactics (or system regulators) and strategies to absorb variability and by making adaptations in the production system (see section 2.2.4.1). Framing variability management in this way enables identification of farm responses, through the identification of adaptations in the farm system as changes to production system structure.

3.2.2. Identifying constraints on managing variability in farms

Following consideration of how variability management in farms is framed within the proposed model, it is necessary to consider the constraints on managing variability. Constraints, in a general sense, are referred to as limitations on decision options to respond to variability. The relevant domains of literature described in the previous chapter offer different dimensions of constraints that can be integrated into a conceptual model defining the impact of constraints on farms. In this section I will briefly describe the different dimensions of constraints on managing variability offered by the four domains.

3.2.2.1. Dimensions of constraints from farm control theory

Within the domain of farm control theory, constraints on farms are contemplated in relation to the interaction between the farm and the task environment. From this perspective, constraints limit the set of system behaviours available to the farm in steady state (i.e. absorption) and limit the capacity to make alterations to the production system (i.e. adaptation). This becomes an issue when variability threatens to push farm behaviour away from steady state or unexpectedly shocks the system out of steady state. Hence, the constraints of concern here are those that impede the capacity of the producer to respond to variability, as they represent limitations to absorption and adaptation.

These constraints are evident in poor performance in current or projected farm output. When a producer perceives that variability may alter farm output in an undesirable way, tactical and strategic flexibility are employed to absorb the variability. Logically, limitations in absorption lead to adaptations in the system. Adaptation in this context is indicative of a constraint on absorption. Hence, understanding constraints on absorption can be revealed through the identification of adaptation.

There can also be constraints on adaptation. Constraints on adaptation indicate that the decision options available to the producer to make alterations to system structure in a way that maintains system purpose are limited. This may require that the producer revisit higher-order goals and plans of the farm business, increasing the degree of adaptation that is necessary to return the farm to a stable state. A higher degree of adaptation generally implies higher costs to the business associated with the adaptation when compared to lower degrees of adaptation Constraints on adaptation reduce the capacity to return the farm to a stable state and will be evident in poorer-than-desired farm performance. Continued constraints on adaptation will lead to adjustment: withdrawal from agriculture (see section 2.2.4.1).

3.2.2.2. Dimensions of constraints from the value chain

Within the value chain domain, constraints are approached in relation to the planning hierarchy of the farm. This offers a way to frame the distinction between lower-order and higher-order constraints in farms. An implication of the functional hierarchy in value chains is that the support activities are higher-order constraints on primary activities. Additionally, value chain functions enable consideration of constraints on accessing inputs through the procurement function and the intersection between the farm and family, through the human resource management and infrastructure (notably finance) functions. These dimensions of constraints are missed within the farm control theory focus on the production system.

3.2.2.3. Dimensions of constraints from image theory

An element underlying the dimensions of constraints from farm control theory and value chain functions is the importance of the producer as decision-maker for the business. It is the producer who generates the hierarchy of plans and the associated structure for the farm. It is the producer who identifies the need to alter structure in response to a change in context. Hence, a conceptual model about the constraints on farms must include consideration of constraints that stem from the decision-making of the producer.

Image theory (Beach & Connolly, 2005) contemplates constraints on farms in terms of the objectives and perceptions of the producer as the system controller. Image theory describes the constraints on individual decision-making within three images. Image theory suggests that images constrain the decision-making of individuals by filtering out options from consideration that are not compatible with images. From this perspective, principles influence goals which influence plans of the individual.

When considered in light of the planning hierarchy of farms, the influence of images is somewhat messier than is suggested in the previous paragraph. Higher-order farm goals and plans constrain decision options for lower-order goals and plans in farms. This means that higher-order changes to the strategic image can influence lower order changes to goals. Consideration of the relationship between the trajectory and strategic images needs to include awareness of this hierarchy in farm planning.

In a practical sense, the value image and higher order goals in the trajectory image determine the producer's framing of farm business goals and perceptions of goal achievement through forecasting. These lead to the set of farm plans implemented in the farm. Distinguishing change to principles in the value image, to higher-order goals in the trajectory image and to farm plans in the strategic image can offer key insights as regarding differences in dimensions of constraints across images. Implicit here is the notion that incompatibility of options within images, described by where change occurs, is reflective of constraint.

Importantly here, these higher order image constraints may relate to all aspects of an individual's life. This notion injects consideration of other influences on producer decision-making, such as family and personal aspirations and values, which fall outside of the farm business but may impact on it nonetheless. It is expected that where goals have altered, due to changing personal or business circumstances, this would lead to alteration of business plans and activities, to some degree. Image theory offers a mechanism for describing how the principles, as well as higher order goals, of the producer give purpose to, and interact with decisions about, the farm system.

3.2.2.4. Dimensions of constraints from path dependence

The domain of path dependence captures the constraining effect of the historical sequence of decisions through time. It reports the evolution in constraints on a farm. Path dependence describes the degree of constraint imposed on a system by the interaction between the historical sequence of decisions and reinforcing mechanisms that enhance lock-in. Path dependence offers a way of characterising farms as a sequence of decisions, through time, about farm business structure, from sets of decision options that are increasingly shaped and delimited by previous decisions and reinforcing mechanisms. In a practical sense, path dependence reduces the decision options available to the producer; such as narrowing the range of acceptable behaviours within the system as technical efficiency increases. It also locks out options for altering the overall path of the farm business, such as adaptation to components of the production system and changes within value chain functions.

I expect that path dependence in farms is most visible at a critical juncture, in which the producer perceives a threat or opportunity to the business that generates a decision to alter the farm business path. A critical juncture stems from the interaction between the current constrained state of the business and a perceived change in context. From a critical juncture, it is possible to identify subsequent changes to the farm system that reinforce the initial decision.

Critical junctures may vary in immediate visibility as path dependence can emerge from what seems to be an apparently relatively small decision about the farm. Such critical junctures are identifiable by the number and magnitude of decisions that flow from the original relatively small change. It is possible that tracking back through a sequence of decisions most easily identifies these critical junctures. This is a hallmark of the sensitivity to initial conditions in complex systems, which is typified in chaos theory by the ‘butterfly effect’ (Hilborn, 2004; Liebowitz & Margolis, 2000).

Path dependence provides a lens for describing the manifestation of the dynamic and cumulative impact of constraints defined within farm control theory, value chain and image theory (see Figure 3.1). Hence, path dependence derives its meaning from these domains of constraints. As well, the impacts of the dimensions of constraints described within farm control theory, value chain and image theory can only be practically and meaningfully understood through the lens of path dependence. Considering constraints in isolation, such as through a comparative statics approach, does not reveal the influence of cumulative impacts from different sources of constraints that can be considered within this model.

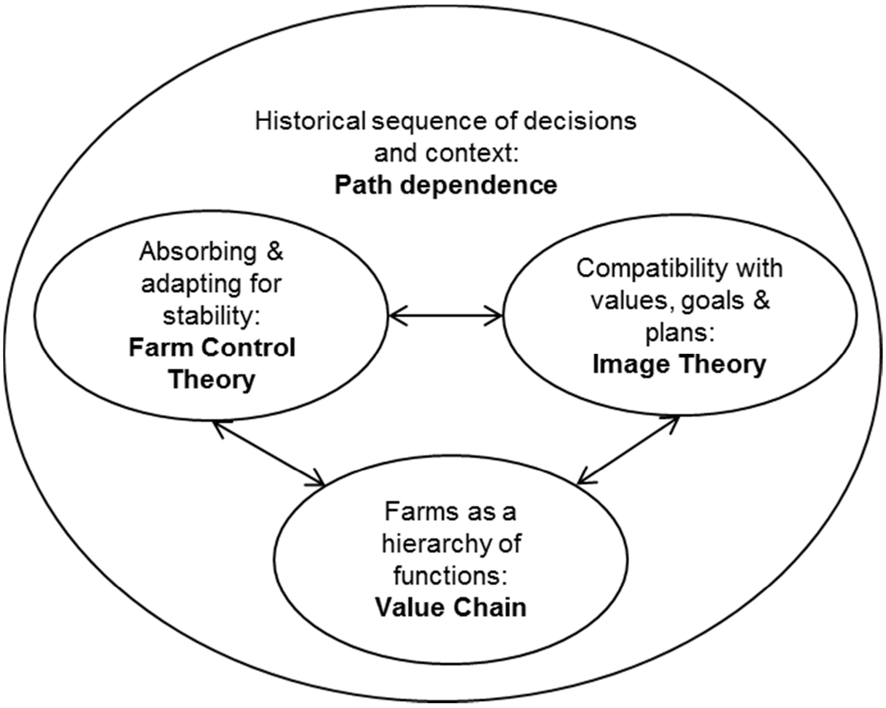

Figure 3.1. A conceptual model for understanding the constraints on farm management of variability

3.2.3. An integrated model

While the four domains of literature considered in this research each frame constraints differently, they reflect different dimensions of a constrained state. By identifying the relationships across different dimensions of constraints, greater clarity may be possible in analysing the practical reality for producers. Relationships among dimensions of constraints can be described in terms of the influence one dimension of constraint has on another, such as when a critical juncture necessitates a change to farm business plans. Relationships among dimensions can also relate to intersections of multiple dimensions, such as when a producer's experience is simultaneously linked to adaptation, a change in plans and the technology development function. Hence, the analysis here emphasised identifying these relationships across the four domains.

Intersecting relationships across domain constructs could indicate synergies across theories regarding the dimension of constraints. Simply put, different theories may be describing the same phenomenon in different ways. For example, the adoption of a new farm management practice is both an adaptation (change in structure) and a change in the strategic image (change in plans or activities). Alignment of such constructs would indicate a degree of compatibility across the theories.

Intersections across dimensions of constraints could also indicate a multifaceted hierarchy of constraints in a particular circumstance. Simply put, multiple dimensions of constraints may be influencing the producer at a particular time. For example, a decision to switch from purebred to crossbred cows may be infused with issues relating to personal beliefs (value image) about maintaining a purebred herd, infrastructure (value chain) consequences through changes in herd value, and implications for the breeding practices (adaptation). In such cases identifying the multiple dimensions of constraints would enable a deeper understanding of the constrained state.

Given the differences in meaning that can be derived from intersections between theory constructs, more is needed than simply identifying intersections. Revealing patterns of intersections and explanations for these patterns was crucial in this research. Implicitly this means that where dimensions of constraints do not intersect may indicate differences in evaluating constraints across the four domains. While consistent congruence between the dimensions of constraints may imply the theories are describing the same constraints in different ways, some dissimilarity implies genuine differences among the dimensions of constraints. Divergences and uniqueness that emerges in analysis offers a way to differentiate the value added by each theory. This highlights a benefit of using an integrated model.

Identifying relationships in which one dimension of constraint influences another implies consideration of sequences of decisions through time. This is where the dynamic and compounding influences of constraint dimensions interact to generate an existing constrained state. Consideration of critical junctures is central to this, as the most likely manifestations of a constrained state as well as the origin of a new sequence of path decisions. Path dependence is the lens through which this can be understood.

3.3. Research design

The purpose of this research is to reveal the effect that path dependence, as a manifestation of compounding constraints in farms, has on the capacity of producers to manage the increased variability expected with climate change. I suggested in the previous section that application of an integrated model of constraints would offer significant insights regarding compounding influence of different dimensions of constraints. The broad questions being addressed in this research toward this aim are:

- What effects does path dependence have on the capacity of the producer to manage variability in the farm system?
- What does this reveal about the capacity of producers to manage the increased variability expected with climate change?
- What implications can be drawn for appropriate agricultural public policies in response to the emergence of climate change?

Embedded in these questions is the assumption that commonalities do exist across the experiences of producers regarding the dimensions of constraints that influence their management of farms. It is through the identification of commonalities that useful information could be derived for policy makers[11]. The application of the conceptual model was expected to be theoretically generalisable (Stake, 1995) to all commercial farms managing variability. However, it was not assumed that the model would have uniform predictive power across farms because of localised contextual sensitivities.

Central to the approach used in applying this conceptual model to farms was the philosophical basis I brought to the research, making this a crucial starting point for describing research design. This research sits broadly within the post-positivist paradigm (Clark, 1998). I approached it from a critical realist ontology. While I acknowledge an objective reality (Crotty, 1998), I consider how this reality can be seen or known is imperfect because of subjective experience (Boeree, 1999; Guba & Lincoln,

[11] In`terestingly, while the commonalities may inform the core of policy, identifying where the dimensions of constraints do not align is also expected to offer useful insights for policy. Idiosyncrasies may expose the limits of policy, which cumulatively may shape any changes to policy extent and reach.

1994; Healy & Perry, 2000; Lincoln & Guba, 2000; Magee, 1985; Patomäki & Wight, 2000; Yeung, 1997).

An application of the conceptual model to farms required the collection and analysis of farm-specific data. Due to the influence of subjectivity on perceptions of reality, I conducted this research from a modified dualist epistemological approach (Guba & Lincoln, 1994; Lincoln & Guba, 2000). Hence, I viewed the most reliable source of knowledge about the historical sequence of decisions on the farm to be the producer[12]. This means my focus in gathering data was on eliciting information about producer experiences. Given this, the qualitative research methods I adopted centred on using the producer as the chief data source and undertaking procedures to monitor and safeguard against undue subjective influences of the researcher on the data. Thus, continuous care was taken to ensure both transparency of research process/analysis/interpretation and authenticity of participant voice and meanings. Methods for data collection and analysis will be described next.

3.3.1. Scope of the study

This research can be described as exploratory and qualitative. The objective was to explore the constructs from the different constraint domains to identify if useful insights about farms could be derived through integration of these constructs. The constructs derived from the theories were the drivers of the data being sought and analysed in the research, adding a deductive focus to the research (Miles, Huberman, & Saldana, 2014; Patton, 1990). Given the exploratory nature of the research, care was taken in the research process to ensure there was openness to emergence of the unexpected in the data gathering and analysis, as is found in inductive research (Miles et al., 2014; Patton, 1990).

The model was applied to existing farm systems, rather than to a simulated model of a farm or through the use of a representative farm. There are two main benefits of

[12] Other sources of knowledge about the history of farm management could arise from third party observers. Underpinning the view that the producer is the most reliable source of knowledge about the farm is a guiding assumption that primary producers who successfully manage viable farm businesses have veridical perceptions of reality. This means that data gathered in interviews with primary producers about their farm businesses should reflect the biophysical reality of their farms. Reliability of data also relies on the establishment of an appropriate level of trust and rapport between the producer and the researcher.

applying the model to farms. First, it enabled examination of the proposition that considering domains of constraints across multiple constructs offered a deeper understanding of both shared and idiosyncratic constraints on farm decisions. Second, it enabled deliberation over the usefulness of this conceptual model for characterising the practical reality of farms in a way that highlighted meaningful policy implications.

The irrigated dairy industry of north-central Victoria was selected as the focal point for this research (see Figure 3.2). Focusing on the dairy industry enabled consideration of farming in the context of a single output (milk). Given the research, in part, considered the capacity to change outputs, focusing on a single output industry minimised the potential for complexity that would characterise farms with a mix of enterprises. This approach also eased the impact of budget and time constraints on the research.

Figure 3.2. Map of Victoria highlighting region where interviews were conducted, adapted from Net Resources International (2012)

Irrigated dairy producers in north-central Victoria had experienced multiple years of drought and a policy change regarding access to the public irrigation system (Crase, 2010; HMC Property Group, 2010). I expected that these obviously substantial changes in context would likely interact with farm businesses and offer relevant data regarding constraints on farms, such as creating critical junctures. As well, I considered producers who had moved out of dairy into other enterprises, based on the view that changing enterprises was likely to indicate significant constraint to the successful alteration within dairy production relative to shifting out of dairy production.

3.4. Methods of data collection

Producers were selected as the primary source of data in this research as these individuals were presumed to be the most knowledgeable about their farm businesses. Importantly, it was the producer's perceptions of issues (e.g. threats and opportunities) pertaining to the farm that mattered, given that this person made the decisions about responding to these issues. That is, the producer's hierarchy of images determined the perceived compatibility of decision options for the farm business.

The qualitative data gathered in this research were drawn from personal interviews. Prospective participants in the interviews were sought using a purposive, theory-based sampling approach in which the constructs in the conceptual model were used to define the parameters for the sampling (Patton, 1990). This was useful given the need to interview a small number of farmers who fit specific criteria.

3.4.1. Sampling criteria

My aim in this research was to interview between 12 and 14 producers in the north-central Victoria irrigation region (see Table 3.1). Given data were gathered through personal interviews that could take one to two hours, willingness to participate in an extended interview was a fundamental criterion for all interviewees.

Table 3.1 Sampling criteria for interviews

# of participants sought	Sampling criteria
~ 10 participants	• Manager of an irrigated a dairy farm in the north-central Victorian irrigation region • Actively managing that dairy farm for a minimum of 20 years* • Willing to participate in the research
2-4 participants	• Manager of a farm in the Northern Victorian irrigation region that had been a dairy farm for a large portion of the farm history • Actively managing the farm for a minimum of 20 years* • Changed from dairy farming into a different type of farm enterprise • Willing to participate in the research

Interviews were sought with at least 10 individuals who were managing a dairy farm or had managed one for a minimum of 20 years. This 20 year minimum criterion related to an interest in ensuring the interviewee had sufficient experience on that particular farm to have a sound understanding of the history of decision-making regarding the farm business.

Participants who had changed their farm enterprises were targeted because it was thought that consideration of the constraints to changing outputs could offer additional different insights. As a consequence of this interviews were also sought with two to four producers who had managed a dairy farm for a minimum of 20 years but had altered the farm business to produce a different output. Again, the 20-year minimum criterion ensured the prospective interviewee had enough experience of the farm to have a sound understanding of decisions through time.

3.4.2. Process for inviting participation

Local industry and government officials, who worked directly with dairy farmers in the region, were asked to provide names of producers who might fit the interview criteria. These names were then looked up in the telephone directory to obtain contact details. Prospective participants were contacted by telephone to inform them that an invitation to participate in the research was going to be sent to them. The invitation included an introductory letter, consent form and researcher contact list (see Appendix A). This information clearly outlined their rights as interviewees, in line with the University of New England ethics guidelines. Respondents who contacted the researcher and returned signed consent forms were then offered interview times that best suited them.

3.4.3. Interview process

Semi-structured interviews were employed in this research. This means that the interview was designed as a conversation guided by a broad structure and purpose (Kvale & Brinkmann, 2009). This interview approach was deemed the most appropriate as it helped to guide the interview to ensure a broad range of topics were discussed. Semi-structured interviewing also enabled the interviewee to guide the direction and specific content of the interview, providing space in the conversation for unexpected data to emerge and allowing for the voice of the participant to assume primacy.

An interview guide was developed in alignment with the broad structure and purpose of the research. This guide was used by the researcher to ask open ended questions relating to: farm context/history; current circumstances regarding farm viability; sources of variability and how they were managed; changes that have been made to/considered for the farm system relating to the use of inputs; and changes considered for/made to the mix of outputs (see Appendix B). An emphasis, when gathering data across these topics, was in gaining insights into the underlying reasoning for decisions and eliciting chains of causation, where possible[13].

Interviews were conducted at a location that was convenient to the participant, which in all cases was at the participant's residence. The intention was to ensure the participant was relaxed and comfortable for the duration of the interview. Interviews were expected to take approximately one to two hours. As well, participants were asked if they were interested in being contacted again to review narratives that were to be generated from the interview data. Eliciting the interest of participants in follow up was built into the conclusion of the interview design.

Interview data were captured on a digital voice recorder, with the informed consent of the participant. The audio recordings were then transcribed for meaning through a transcription service. This meant that the words used by the interviewee and me as the interviewer were recorded, but generally the pauses and tone of voice not noted (Kvale & Brinkmann, 2009). Interviews were transcribed and returned to me within a week of each interview. I reviewed all transcripts to ensure that they matched with my memory of the interview.

During interviews I took field notes. These notes helped me to track elements of the producer's story within the interview, which was useful when asking clarifying questions to understand linkages within the story. I later used these field notes to aid my review of the transcriptions.

In the transcription process, any unclear words or phrases were identified in the transcription document, along with a time signature indicating where they were located

[13] However, it was expected that data quality issues were likely to arise regarding the underlying reasons for decisions and details regarding the chain of causation when considering historical decisions. This is especially the case when decisions may have been made by a previous farm manager, such as the producer's father or grandfather.

in the audio file. Lack of clarity identified in the data related to the use of technical terms and sound quality associated with background noise and accents. I reviewed the audio to fill in gaps, where possible, identified in the transcription.

3.4.4. Developing farm narratives

A total of 16 interviews were conducted, 12 with dairy producers and four with producers who had converted from dairy to another enterprise. A total of 24 hours and 22 minutes of interviews were audio-recorded. The recorded interviews ranged from 42 minutes to 209 minutes, with a mean of 91 minutes (see Table 3.2). The transcripts totalled 1139 pages ranging from 27 to 155 pages, with a mean of 71 pages.

Table 3.2 Data collected through interviews

Number of Interviews:	**Total**	**Current dairy farmers**	**Current farmers who were ex-dairy**
	16	12	4
Interview time:	**Total**	**Mean**	**Range**
	1462 min.	91.4 min.	42 to 209 min.
Transcript pages:	**Total**	**Mean**	**Range**
	1139 p	71.2 p	27 to 155 p
Farm Narratives pages:	**Total**	**Mean**	**Range**
	195 p	12.25 p	7 to 20 p

The raw data in the interview transcripts were converted into narratives about each farm. The creation of narratives enabled me to organise the historical sequence of decisions about the farm into a whole that conveyed the significance of events within the whole (Elliott, 2005). Emphasis was placed within the narratives on interviewee perceptions about the contextual basis for their decisions.

The generation of farm narratives was important for enabling analysis given the open-ended nature of the interviews, in which data did not necessarily emerge in a sequential way. The conversion of transcript data into a narrative enabled me to combine interrelated data into historical sequences, a form of data that was amenable to coding. The narratives were my accounts of the stories told to me by the producers, based on my need to make sense of their complex set of experiences (Elliott, 2005). Hence, the farm narratives were "second-order"[14] transcripts that anchored all subsequent data analysis (Elliott, 2005, p. 12).

The process of writing the narratives highlighted any gaps, conflicts or confusions in the data. If required, I contacted interviewees to clarify any missing information. This occurred in relation to six interviews. Interviewee comments through this process were recorded manually and then transcribed as follow-up interviews. The new data were then incorporated into the farm narratives. Overall, the farm narratives totalled 195 pages and ranged from 7 to 20 pages in length, with a mean of 12 pages. The full set of farm narratives are in Appendix C.

The creation of farm narratives can be described as a preliminary form of analysis. Narratives that were developed were my perceptions of interviewee experiences. I sought to minimise the imposition of my reality on the experience of the producers by using low-inference descriptive language as far as possible. This included using direct quotes from interviewees where emotive or inferential language was used by the interviewee. With an aim to minimise my influence on the data, all farm-related topics discussed in an interview were incorporated into the narrative. This meant that I did not filter out topics for inclusion based on a judgement of irrelevance. This allowed the unexpected concepts that had emerged in the interview to be preserved in the narratives.

The anonymity of interviewees was preserved in generating the farm narratives by excluding any details that would have made the interviewees identifiable. In all of the farm narratives personal names and town names were excluded, as were data relating to changes in water allocations associated with recent water use efficiency grants[15]. The exclusion of these data from the narratives did not influence subsequent interpretations of the data.

Given the farm narratives were my interpretation of the data from the interviews, it was important to ensure the narratives preserved the integrity and authenticity of the data provided by the interviewees. With this aim in mind, I used quotes where possible to preserve the producer's voice in the narrative. As well, I sought respondent validation[16]

[14] Elliott (2005) also refers to this as representational narratives, citing Somers and Gibson (1994).
[15] Specific details regarding water exchanged for farm works associated with the grants were stipulated under a non-disclosure clause of a contract and were excluded from all narratives as an added precaution.
[16] This has also been called 'member checking' (Miles et al., 2014)

(Gibbs, 2007) of their narratives. Interviewees were sent a copy of their farm narrative within one month of the interview. They were given an opportunity to check the narrative for any missing or incorrect information as well as identifying anything that they were not comfortable having in the narrative. I followed up with a telephone interview to discuss the narrative. The follow up telephone call was initiated two to four weeks after the narrative was sent to the interviewee. Fourteen of the 16 interviewees were willing and able to provide feedback regarding their farm narrative.

The farm narratives associated with the two interviewees who did not provide feedback were included in the analysis. In the process of developing the narratives no gaps or problems with the data were identified that would have precluded use of them in the research. The lack of follow up involvement by these interviewees was not due to their lack of agreement with the summary but a reflection of their personal circumstances.

The feedback from the fourteen who did review their farm narratives was overwhelmingly confirmatory. There were only minor changes requested by interviewees, as follows.

- One interviewee provided clarifying data on specific volumes in an irrigation entitlement.
- One interviewee clarified details regarding the war in which he fought.
- Two interviewees requested the removal of colourful or strong language from specific quotes.
- One interviewee added detail regarding a bank overdraft issue.
- One interviewee requested that some financial information be removed.
- One interviewee requested some details regarding his recent herd and land area be excluded because he was concerned that it would make him identifiable.

These minor changes were not materially relevant to the analysis as they were not essential to understanding the history of farm business decisions. Given the nature of the feedback received, I was confident that the process of creating the narratives had preserved the integrity of interviewee experiences.

3.5. Process of analysis

The farm narratives were the primary data for the analysis because they described the sequence of decisions about the farm business. In the process of developing farm narratives, there was the need to capture ideas that were emerging about the individual farm story. These details were developed as word processed documents described as 'farm notes' and maintained for each individual interviewee. This was another source of data used in analysis.

Using the integrated conceptual model as the guiding framework for the analysis, a multiple step process was employed (see Figure 3.3). The first step of the analysis was the coding of narratives using qualitative data analysis (QDA) software, NVivo 10 (QSR International, 2013). This initial coding aligns with what Saldana refers to as "first cycle" activities in coding (Saldana, 2013). In the second step, the coded data were used to manually analyse relationships among the dimensions of constraints. This included consideration of patterns of intersections across constructs and mapping sequential decisions stemming from critical junctions. This aligns with what Saldana calls "second cycle" activities in coding (Saldana, 2013). Following these two steps of analysis I contemplated the usefulness of the conceptual model for understanding farm constraints. Overall, unexpected insights on constraints that emerged from the data were identified and actively incorporated into the analysis and interpretation.

3.5.1. Congruence and dissimilarity across dimensions of constraints

There were two clear objectives for the analysis which both centred on consideration of relationships between dimensions of constraints. The first objective was to identify intersections across dimensions of constraints by categorising producer experiences according to theory-derived constructs. This enabled meaningful contemplation of patterns of congruence across the domains of constraints. The second objective was to use path dependence as a lens for understanding the dynamic and compounding influences of constraints by mapping critical junctures and subsequent sequences of decisions through time according to theory constructs.

3.5.1.1. Organising and coding data for analysis

The majority of the coding employed in this research was deductive, predefined by the researcher (Miles et al., 2014). My coding approach was driven by my intention to identify dimensions of constraints as theory constructs as well as relationships across constraints. Hence, a simultaneous concept-driven coding approach was used. Using concept-driven coding I was able to derive categories for coding based on the theoretical constructs being considered in the research (Gibbs, 2007). Simultaneous coding refers to coding of a simple qualitative datum at multiple codes (Miles et al., 2014; Saldana, 2013). Using simultaneous coding enabled me to identify intersections across constructs.

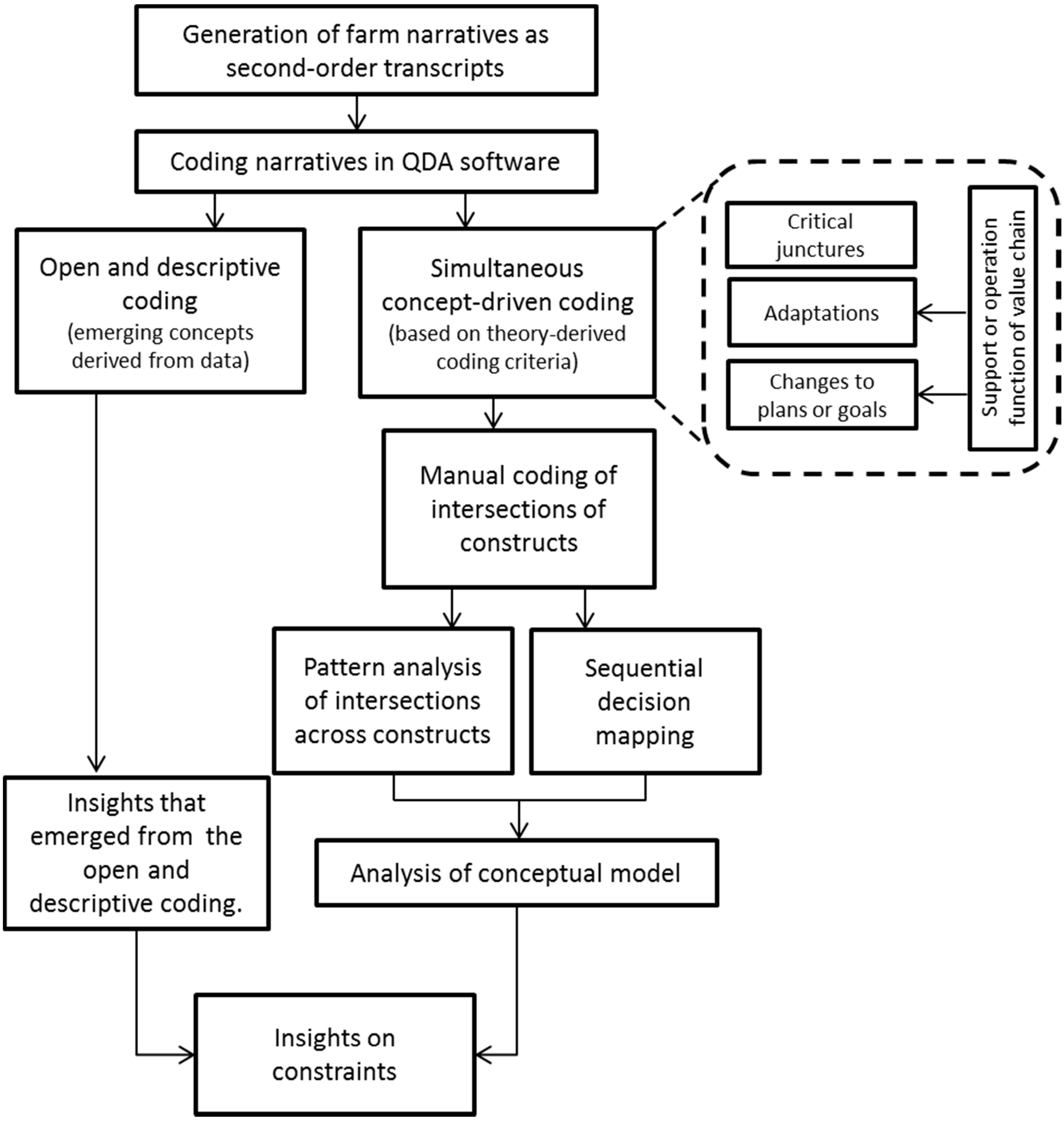

Figure 3.3 A simple diagram of the analysis process used in this research

Toward this aim, the farm narratives were coded at each point in the data where constraint constructs from each of the theories were apparent (see Table 3.3). From path dependence theory, critical junctures were coded in the narratives as decision points where changes in the state of the farm or environment triggered a need to make a change to the farm. From farm control theory, adaptations were coded in the narratives as performance-preserving changes to farm production system structure. Identifying adaptation enabled consideration of constraints on absorption and constraints on adaptation options.

Table 3.3 Constructs defined for coding

Theoretical origin of constraint construct	Constraint construct used in coding	Description
Path dependence theory	Critical juncture	A decision points where changes in the state of the farm or environment triggered a need to make a change to the farm structure.
Farm control theory	Adaptation	Changes to farm production system structure to preserve performance when absorption appears inadequate.
Image theory	Strategic image	Changes in tactics or activities on farm
	Trajectory image	Changes to higher-order farm business or personal goals
	Value image	Changes in values and beliefs
Value chain	Infrastructure: Support	Changes to infrastructure, human resource management, procurement or technology development
	HRM: Support	Changes to infrastructure, human resource management, procurement or technology development
	Procurement: Support	Changes to infrastructure, human resource management, procurement or technology development
	Technology: Support	Changes to infrastructure, human resource management, procurement or technology development
	Inbound: Primary	Changes in how inputs were received, stored and distributed within the farm system
	Operations: Primary	Changes to the day to day business practices, including the activation of tactics.
	Outbound: Primary	Changes to how outputs were collected, stored and physically distributed to product buyers.
	Marketing & sales: Primary	Changes to how the farm output was marketed and purchased by product buyer
	Service: Primary	Changes to services provided to enhance or maintain the value of the product'

From image theory, changes in the strategic image were coded in the narratives where changes in plans or activities were evident within the farm. Changes to the trajectory image were coded where changes to farm business or personal goals were evident. Changes to the value image were to be coded where there was evidence of a change in value or belief. Identifiable differences in constraints were expected to emerge through consideration of change associated with the three images. Using value chains, changes to support functions were classified where there were changes to infrastructure, human resource management, procurement or technology development. Also from value chains, changes to primary functions were coded as changes to inbound logistics, operations, outbound logistics, service, or marketing and sales. The changes to the support and primary functions were coded as changes in the component functions (rather than collectively as 'support' or 'primary' functions), as it was thought that distinguishing across functions may offer insights.

Inductive coding was also employed given the exploratory nature of the research. Inductive coding resulted in codes that emerged out of the data themselves[17] (Miles et al., 2014). The inductive coding used in this research was descriptive coding, in which underlying topics in relation to the data were described (Patton, 1990; Saldana, 2013). Using inductive descriptive coding helped me to maintain openness to emergent data.

A significant benefit of using QDA software was in the organisation and management of research data, an important factor in maintaining research quality (Bazeley & Jackson, 2013). Hence, NVivo 10, was used to organise data prior to coding. This started with the uploading of 16 farm narratives (see Figure 3.4). These were the sources of data used in coding. In addition to the narratives, the original transcripts, six follow up interviews and interview audio files were also uploaded to NVivo. These were linked to the relevant farm narratives, which eased cross checking and clarification of data to maximise consistency in my chain of reasoning throughout the research process. The series of farm notes were also uploaded to NVivo, and linked to the relevant farm narrative. These farm notes were viewed as 'living documents', growing and evolving as research progressed. This is similar to the use of memos in NVivo (Bazeley & Jackson, 2013; Saldana, 2013).

I maintained a journal throughout the research process. This journal was kept in digital form and as such was able to access it regularly across multiple electronic devices. This journal was useful in capturing my thoughts and experiences with the research process.

[17] This is also called data-driven coding or open coding (Gibbs 2007).

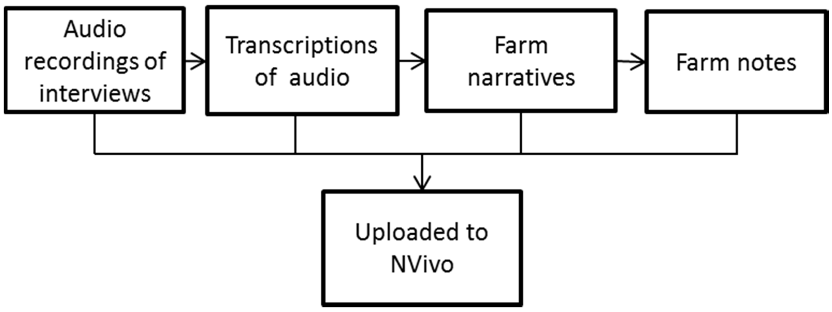

Figure 3.4: Data uploaded to NVivo

Approach to coding

Once the data sources were uploaded into NVivo, a specific coding process was undertaken to code farm narratives (see Table 3.4). Each narrative was coded separately for each theory (i.e. path dependence, farm control theory, image theory and value chains) during my first pass of coding. Additionally, coding rules were developed during the first pass of coding (see Appendix D). The aim of developing coding rules was to ensure consistency in coding and transparency regarding the coding process. The first pass of coding was iterative. Annotations were often used in the narratives to describe the reasoning for a particular code. I then returned to these annotations in the process of developing coding rules. As rules were developed I sometimes found the need to revisit previously coded data to refine coding based on the developed rules.

Table 3.4 Coding process employed in the research

1. Code critical junctures 2. Code adaptations 3. Code changes to goals or plans 4. Code data that were identified as adaptations and goal or plan changes as either changes to support or primary value chain functions

The developed coding rules were used during the second pass of coding. This helped protect against inconsistency or "definitional drift" in the coding process (Gibbs, 2007, p. 98). During the second pass of coding all codes were considered together, as opposed to the single construct approach in the first pass of coding. Given coding was revealed and considered across constructs, I was able to consider points of intersection. Findings regarding intersections were captured in my digital journal as early analysis thoughts.

Through the process of first and second pass coding, I also employed inductive descriptive coding for any relevant topics that stood out as of particular interest. What emerged from the data as relevant here was the notion of ‘guiding principles’ as a reflection of the producer’s value image. This was identified as a gap in the concept-driven coding process, which identified changes within images, rather than the images as constraints. Given value image change is highly unlikely, coding the existence of guiding principles seemed the best approach for including this image in the data. I found differences among these guiding principles and was able to refine coding to characterise this difference in terms of values, guiding principles and beliefs. This was incorporated into the analysis and is discussed in detail in section 4.3.3 of the thesis.

3.5.1.2. Analysing data for patterns across dimensions of constraints

Once the narratives were coded in NVivo I created matrices in Excel to enable analysis of patterns in the intersections across constructs. Excel was chosen because it enabled a simple visual representation of intersections across constructs. Coded data from a farm narrative were copied into a matrix, with the multiple codes identified. This was done for each farm narrative (full matrices can be seen in Appendix E). These matrices were then used to identify patterns regarding the intersection of constructs in the coded data.

3.5.2. Decision mapping to reveal path dependence

The second aim of this analysis was to reveal path dependence by mapping, where possible, critical junctures followed by sequences of reinforcing decisions. The farm matrices developed to enable pattern analysis, combined with the original farm narratives, were used in this step of the analysis. I added a rationale column to the farm matrices in which I briefly described the reasons for identified linkages between critical junctures and reinforcing decisions. Data coded as adaptation, image and function changes indicated decisions in farms. Hence, these were the potential sources of reinforcing decisions in the narratives. A manual coding approach was employed to identify whether these changes could be linked to critical junctures as reinforcing decisions. In a practical sense, critical junctures were given a code that included the narrative number and the number of the critical juncture in the series of critical junctures in the narrative. For example, the first critical juncture in the 15th farm narrative was coded as 15.1.

Reinforcing decisions were then coded as linked to a critical juncture where it was clear that the reinforcing decision reflected the path as defined by the response to the critical juncture. For example, if a perceived need to increase the rate of milking acts as a critical juncture and leads a producer to build a new dairy this entails an altering of the path. Subsequent decisions to install automatic cup removers and extend yard associated with the dairy to enable supplementary feeding are building on the new path derived from building a new dairy.

The coded data on their own were not necessarily sufficient to identify whether the data reflected a reinforcing decision. It was necessary to return to the farm narrative to understand the context around the coded data. A column was added to the narrative matrix to enable explicit identification of the rationale for the coding. Where data were not identified as reinforcing critical junctures this was also noted (full matrices can be seen in Appendix E).

Following the pattern analysis and decision mapping, the comprehensiveness of path dependence as a model for characterising constraints was evaluated. This centred on identifying the extent to which the model leaves producer decisions unexplained. The usefulness of the conceptual model in light of the practical reality of farm management was also assessed. This included reflections on the farm as a micro business and perennial constraints in dairy production. Findings were then applied to the problem of increased variability associated with climate change to derive insights and implications regarding public policy.

3.6. Quality criteria for the research

There are numerous, conflicting views regarding ways to approach the issue of quality in qualitative research (Hammersley, 2009; Simons, 2009; Sparkes, 2001). While a number of approaches may be valid, logically, analysis of quality is best aligned with the research approach employed (Golafshani, 2003; Healy & Perry, 2000). Given this research was exploratory that was grounded in the post-positivist paradigm, quality was considered in relation to two key dimensions: validity and reliability (Lincoln & Guba, 2000). Internal validity is about research credibility while external validity considers the generalisability of the theory and findings. Internal reliability focuses on reducing unacknowledged bias and external reliability considers the degree to which the research could be reproduced to achieve similar results. The techniques used to ensure validity and reliability are summarised in table 3.5.

Table 3.5 Tools to manage quality employed in this research

Tool employed	Internal Validity	External Validity	Internal Reliability	External Reliability
Use of adequately "thick description" of relevant farm context in relation to constraints, to enable assessment of transferability		✓		
Semi-structured interview process that enabled the interviewee take control over much of the interview direction	✓			✓
Narrative verification	✓		✓	✓
Addressing rival explanations	✓			✓
Explicit rationale to manual coding (in narrative matrices)	✓		✓	✓
Development and application of coding rules in NVivo coding	✓		✓	✓
Use of open coding to reveal unexpected insights	✓			✓
Identification of patterns in decision mapping	✓		✓	
Identifying where patterns or findings did not fit and considering why this is so	✓			✓
Inclusion of narratives, coding rules, narrative matrices in the thesis appendices		✓	✓	✓
Use of quotes in representation of data analysis			✓	
Development of a clear coherent explanation in the thesis: linking research question (underpinned by paradigm) to conceptual model, to methods, to analysis, to discussion, to conclusion	✓	✓	✓	✓
Theory triangulation	✓			
Consistent with existing theory		✓		
Identifying frequencies of occurrences in analysis		✓		

Central to managing validity and reliability is the development of a coherent explanation in the thesis. This requires explicitness in the research process. I used coding rules in the NVivo coding and described an explicit rationale for coding employed in the manual coding in aid of this. Due to the richness of the data and the analytical approach used here, there are significant amounts of material associated with this research process (including farm narratives, matrices and coding rules). With an aim of ensuring the research process is explicit and coherent these materials have been included as appendices to the thesis.

3.6.1. Internal validity

Internal validity focuses on the extent that the findings can be judged to be authentic or credible (Miles et al., 2014). Fundamentally, this is about ensuring that the research represents a credible argument based on a true account of the producers who were interviewed. Managing internal validity can be broadly done through coherent explanation building, triangulation, member checking, the identification of uncertainty and addressing rival explanations, replication of findings and pattern matching (Miles et al., 2014; Patton, 1990; Yin, 2009). In this research internal validity was managed in a number of ways.

First, internal validity was managed through the interview process and follow-up procedures with interviewees. The semi-structured approach to interviews meant that the interviewee largely determined the content of data collected. The generation of narratives from transcripts enabled consideration of their plausibility and coherence, as it enabled organisation of interconnected sequences of decisions (Beach, 2010). As well, the narratives derived out of the interview data were validated by interviewees (Gibbs, 2007; Lincoln & Guba, 2000; Miles et al., 2014). The interview process and narrative validation ensured the content was an authentic representation of interviewee experiences rather than an inferred reality imposed by the researcher (Yin, 2009).

Second, the conceptual model used in this research incorporates several theories regarding constraints. The use of multiple theories enabled the use of theory triangulation where constructs across theories aligned (Gibbs, 2007; Patton, 1990; Simons, 2009; Stake, 1995). This enabled consideration of different interpretations of the data through the different theories increasing the credibility of findings (Gibbs, 2007). It also reduces the chance of missing relevant data about constraints.

Third, the identification of patterns in relationships across theory constructs was a central element of my analysis process. The use of these patterns strengthens internal validity (Yin, 2009). Where patterns did not hold in the data explanations were sought regarding the lack of conformity. It was in these anomalies that I sought to identify dimensions of constraints that were not captured by the conceptual model. This was one way that I sought rival explanations for the findings.

There were other mechanisms employed in this research that ensured I considered rival explanations. The inclusion of an inductive open coding process in the research ensured a degree of openness to rival explanations. Semi-structured interviewing also supported consideration of rival explanations, as it enabled the interviewee to drive the content from which rival explanations could emerge.

3.6.2. External validity

External validity relates to how transferable or generalisable the conceptual model used in the research and the conclusions of the research are to other contexts (Miles et al., 2014). While theories and research findings can have differing degrees of generalisability, it is critical to be explicit about this. Generalisability of the conceptual model and of the results will be considered separately.

The focus of this research was on analysing the usefulness of path dependence as a framing of constraints in farms in Australia. Usefulness was determined, in part, by the generalisability of this framing. Hence, the generalisability of the model to other contexts was considered in the final section of the analysis (see section 5.5). Importantly, an indicator of generalisability is the degree to which this model conforms with existing theory (Miles et al., 2014). The generalisability of this model is supported by the fact that the path dependence lens draws on multiple existing theories and emphasises the identification of congruence across concepts.

A focus in the interpretation of research findings was in identifying implications for the development and implementation of policies that influence agriculture. Hence, the degree of generalisability of research findings was addressed in relation to policy. Aiding generalisability was the use of explicit referencing to the frequencies of occurrences within the pattern analysis. This helps guard against “selective anecdotalism”, in which generalisations are drawn from extreme of anomalous events (Gibbs, 2007, p. 100). Another mechanism for ensuring generalisability is through the use of adequately “thick description” of the relevant farm context in relation to constraints, as this enables the “reader to assess the potential transferability and appropriateness” in the reader’s context (Miles et al., 2014, p. 314).

3.6.3. External reliability

External reliability, also called objectivity or confirmability, focuses on reducing the degree of unacknowledged bias in research (Lincoln & Guba, 2000; Miles et al., 2014). Broadly, external reliability is managed through explicitness in the research process, self-awareness of bias and consideration of rival explanations in the research analysis (Miles et al., 2014). There are two elements to managing external reliability: minimising bias in the research and being explicit about any bias that did occur.

I sought to minimise researcher bias through the process of data gathering, analysis and development of implications. In my data gathering I minimised bias by allowing the interviewee to drive much of the interview content through the use of semi-structured interviews. As well, narrative verification ensured that data derived from the interviews reflected interviewee experience. Within analysis, bias was managed through consideration of rival explanations and the assessment of anomalies in patterns. As well, the open coding process enabled the revelation of concepts that had not been considered in the research design.

While all care has been taken to minimise bias as much as possible, I acknowledge it cannot be excluded entirely. Hence, I have been explicit about biases that I have brought to this research by clearly describing the guiding assumptions brought to the work. These guiding assumptions indicated the biases that I brought to the research, such as, my assumption that a producer's perception of reality is likely to be the most reliable source of knowledge about the history of the farm (see section 3.3).

3.6.4. Internal reliability

Internal reliability ensures the consistency and dependability of the research process (Miles et al., 2014). From internally reliable research, it should be possible for another researcher to follow the same process and achieve similar results. Internal reliability is largely managed through an explicit documented research process, parallelisms across sources of data and data quality checking (Miles et al., 2014).

To aid internal reliability I have documented the research process, from data collection through analysis in as much detail as possible so that another researcher could replicate the research. The significant amount of supplementary material in the appendices supports this aim.

Recording the decisions being made as I developed and employed my coding process helped me to build the case for the reliability of my approach, analysis and conclusions (Bazeley & Jackson, 2013). I did this through the use of a digital journal, annotations in NVivo and the development of coding rules.

Explicitness in the patterns I found in the analysis was also critical to ensuring internal reliability. Matrix displays that included coded data from the narratives were used to provide explicit examples justifying the rationale for findings. Additionally, summaries of experiences with direct quotes were used within the representation of analysis as indicative examples.

The quality of the data used in this research was checked to ensure they reflected the experiences of interviewees and were free from bias by the researcher. This was done by having the interviewees verify that the narratives adequately reflected their experiences. The process employed and the outcome of the process was clearly described in section 3.4.2.