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Analyzing Flexibility as a Risk Management Strategy in Agricultural Systems

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ANALYZING FLEXIBILITY AS A RISK MANAGEMENT STRATEGY IN AGRICULTURAL SYSTEMS

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Agricultural businesses deal with uncertainty of all kinds. Uncertainty arising from variability in resources, markets, human factors, and regulatory policy can be sources of significant risks. Acquiring or building flexibility in an operation is one of the ways suggested to manage risk and uncertainty—reducing the impact of negative outcomes and increasing the benefit of positive outcomes. Although flexibility has been repeatedly encouraged for businesses, the definition of flexibility and its value remains ambiguous after more than 80 years of research. Flexibility is often described as a multi-dimensional ability to effectively deal with change in the business operating environment. Flexibility can also be described as an ability to switch to alternative means that allow the same objectives to be reached. Thus, maintaining flexibility requires active and ongoing management to retain its effectiveness for mitigating risk. The goal of the first chapter is to present a compilation of literature discussing flexibility in general in an attempt to define, measure, and value flexibility in isolation. In the second chapter, flexibility in agricultural systems will be explored as a risk management strategy and, through a series

of applied examples, described both in isolation and together with other risk management strategies. The emphasis will be placed on agricultural scenarios, but non-agricultural cases will be visited as well. In the third chapter, the theory of flexibility will be illustrated in depth through a natural resource management example. Building on the framework of real options, different approaches for cross fencing a pasture for grazing will be used to identify the value of flexibility to alter land use.

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Chapter 1: Literature Review

Introduction

Businesses deal with uncertainty of all kinds. Variability in available inputs, output markets, supply chain functionality, and government policy can have significant impacts on the annual cash flow of a business and long-term profitability. Flexibility may be one of the ways businesses can deal with uncertainty. Most authors refer to flexibility as an ability or a capacity to effectively deal with change in the business operating environment and in the business itself (Slack 1987; TenDam 1987; Upton 1994; Weiss 1999; Cowan, Kaine, and Wright 2013; Brozovic 2018). Unexpected changes often create risk for a firm, which can have positive, negative, or neutral outcomes (Hewlett et al. 2019). Flexibility has been promoted as a hedge against risk by several authors (Yeo and Qiu 2003; de Neufville, Scholtes, and Wang 2006; Wang and Tang 2010; Sushil 2017; Mintah, K., Higgins, D. and Callanan 2018).

Flexibility may be viewed from different perspectives and in different contexts. Flexibility within the operational, tactical, and strategic contexts have been examined by a few authors (Carlsson 1989; Upton 1994; Shewchuk and Moodie 1998; Sharma, Sushil, and Jain 2010). Despite the discussion surrounding these flexibility context levels, there is some disagreement about defining the timeframe associated with each level. Alternative flexibility perspectives include active/passive or proactive/reactive approaches also (Upton 1994; Brozovic 2018). Some authors have discussed the use of flexibility to control the variability associated with the inputs (Shewchuk and Moodie 1998; Cowan, Kaine, and Wright 2013) and outputs (Slack 1987; von Ungern-Sternberg 1990; Weiss 1999; Mintah, K., Higgins, D. and Callanan 2018) of the business. Most authors acknowledge that flexibility is not generic, but has many dimensions (Shewchuk and Moodie 1998; Sharma, Sushil, and Jain 2010). Complexity is added to the discussion when the contributions of various authors regarding the processes, consequences, and methods of valuing flexibility are considered as well.

A few authors have described some means of measuring flexibility, and even fewer have attempted to quantify flexibility for the purpose of placing a value on it. While methods of measuring flexibility have been mentioned in the literature (Shewchuk and Moodie 1998; Brozovic 2018), the methods can be somewhat ambiguous and situation-specific. Given the uncertainty that still surrounds the quantification of flexibility, attempts to place a value on it are also challenging. Recently, authors have utilized the real options framework to determine the value of a flexible strategy over an inflexible one (Simmons 2019; Andalib, Tavakolan, and Gatmiri 2018; Mintah, K., Higgins, D. and Callanan 2018; Wang and Tang 2010; de Neufville, Scholtes, and Wang 2006; Yeo and Qiu 2003). Much of the work surrounding real options builds upon the methods of Black and Scholes (1973) and Margrabe (1978). Most of the efforts to place a value on flexibility, or define flexibility in general, have been within manufacturing systems or property investment settings. The goal of this literature review is to summarize relevant research to define, measure, and value flexibility.

Flexibility: A Historical Perspective

Flexibility has not been well defined. Flexibility is a derivative of the word ‘flexible’, defined by the Merriam-Webster Online Dictionary as “capable of being flexed”, “yielding to influence”, and “characterized by a ready capability to adapt to new, different, or changing requirements" (Merriam-Webster Online Dictionary n.d.). Part of the struggle to define flexibility is hinted at by TenDam (1987), who stated that flexibility is noticed when it is lacking; but flexibility can be described as stability when it is present. This agrees with De Leeuw and Volberda (1996), who describe flexibility as a stable state between the two unstable extremes—rigidity and over-responsiveness—a lack of flexibility on one hand and an excess of flexibility on the other. Most authors will agree that there is not a good singular definition for flexibility; rather, it is multi-dimensional (Upton 1994; Shewchuk and Moodie 1998; Sharma, Sushil, and Jain 2010). The multi-faceted nature of flexibility has led to numerous attempts to define flexibility for more than 80 years. Instead of becoming clarified by further research, conflicting views have developed, making it more difficult to understand this concept. For example, a recent review of the manufacturing industry literature identified 83 unique definitions for strategic flexibility alone (Brozovic 2018). A summary paper written by Shewchuk and Moodie (1998) developed and used a highly detailed classification framework, revealing that some of the same flexibility definitions offered by different authors were essentially identical, others were less similar, and some were very different. Shewchuk and Moodie (1998) suggest that the variety observed in flexibility definitions may be attributed to different authors' views of manufacturing systems, the operating environment, and the attributes needed for an accurate definition of flexibility. The proposition of extracting one or more uncontended definitions of flexibility from the literature is unlikely, but the research on this topic can serve as a basis for probing the crux of flexibility.

Flexibility is almost always discussed in association with change. Slack (1987) offers a simple definition: “Flexibility is about the ability to change.” Upton (1994) further defines flexibility as “the ability to change or react with little penalty in time, effort, cost or performance”; this definition is generally accepted by others. Upton (1994) clarifies that his definition incorporates both the ability to change (i.e., instigate or create change) or to react (i.e., adapt to change). These proactive and reactive perspectives of management are similar to those discussed by De Treville, Bendahan, and Vanderhaeghe (2007), Sharma, Sushil, and Jain (2010), and Brozovic (2018). The literature review performed by Brozovic (2018) revealed that authors have placed more emphasis on researching the reactive dimension of flexibility in the past, but there has been a recent shift to focus on the proactive aspect of flexibility. As an example, a case study completed by De Treville, Bendahan, and Vanderhaeghe (2007) suggested that the perspective of the manager and the subsequent response of the organization to uncertainty determined the outcome of flexibility to a large degree. The flexibility strategy resulted in higher performance when managers actively sought to capture value from market volatility and viewed product demand as unpredictable than when a managers took a passive outlook and used an ‘ad hoc’ response rather than establishing a flexibility strategy (De Treville, Bendahan, and Vanderhaeghe 2007). The literature discussing flexibility obviously revolves around change; the nature of change and how it affects a business will be examined now.

Change in the business environment is usually cited as a reason for flexibility, although a few authors clarify that changes can be external or internal to the business

(Shewchuk and Moodie 1998; Sharma, Sushil, and Jain 2010; Brozovic 2018). Some authors indicate that flexibility is part of the processes of the system or organization (Aaker and Mascarenhas 1984; Slack 1987; Sharma, Sushil, and Jain 2010; Brozovic 2018) while others refer to flexibility as a quality of management (TenDam 1987; Yeo and Qiu 2003). Depending on the context, ElMaraghy (2006) describes flexibility as being hard (physical) or soft (logical). Sanchez (1995) comments that strategic flexibility is a function of the inherent flexibility of resources available to an organization as well as the ability to coordinate those resources and utilize them in a flexible manner. The flexibility of technology has been discussed in regard to its effects on business functionality (Sharma, Sushil, and Jain 2010) as well as the implications it can have for firm ability and size (Acs, Audretsch, and Carlsson 1991). TenDam (1987) also states that capability and readiness are two dimensions of flexibility that determine how and when flexibility can be implemented successfully.

Various authors have described flexibilities in a hierarchy, where the flexibility at higher organizational levels depends on that of lower levels (Slack 1987; Sethi and Sethi 1990; Sanchez 1995; Shewchuk and Moodie 1998). Slack (1987) illustrated how system flexibility (upper level) can be built upon, or limited by, the flexibility of resources such as labor, machinery, and technology (lower level). Sanchez (1995) offers a similar argument, stating that strategic flexibility of an organization is dependent on the flexibility of resources, but also the application of those resources by management. Slack (1987) observed that managers at different levels in the surveyed companies placed more emphasis on the flexibility needed at their respective level. For example, higher-level managers sought the flexibility of the system as a whole, while lower-level managers emphasized the need for flexibility at the resource level (Slack 1987). The definition of flexibility is far from straightforward as the examination of multiple authors' contributions makes plain. The true definition of flexibility might be approached through further consideration of other attributes, but it may be just as beneficial to consider what flexibility is not as well.

Misnomers of Flexibility

Flexibility is not without cost. In some of the earliest works concerning flexibility, Carlsson (1989) agreed with Stigler (1939) that a flexible firm will have higher costs than a firm that is not flexible (Figure 1.0). Stigler (1939) focused his discussion on short-run cost curves, emphasizing that a plant with a known output level will be more profitable but less flexible than a plant designed to optimize efficiency over a range of outputs that are most likely above and below the optimum. Aaker and Mascarenhas (1984) discussed how a general-purpose factory with greater flexibility to handle diverse inputs and outputs will be more costly than a specialized factory. Aaker and Mascarenhas (1984) also identified two costs linked with flexibility. First is the cost incurred for building flexibility that is not needed later on. Secondarily, there is a cost of withstanding uncertainty and change where the flexibility of having options has not been acquired (Aaker and Mascarenhas 1984). The dual-cost implication of acquiring or not acquiring flexibility is also explained by Sushil (2001), who suggested that flexibility could help reduce wasted efforts while a lack of flexibility could lead to waste. Slack (1987) reaffirms that flexibility has a cost associated with it, so efforts to improve flexibility should be made in areas that enhance firm competitiveness (i.e., flexibility efforts that do not enhance performance should be avoided). Upton (1994) reported that the cost of flexibility can be used to measure the *mobility* element of flexibility, with lower switching costs associated with higher flexibility. Sethi and Sethi (1990) also discussed flexibility as inversely related to the cost of making the switch i.e., the implementation of a change or response. Regardless of whether the cost of flexibility is high or low, Aaker and Mascarenhas (1984) held the opinion that flexibility was the least-cost approach for dealing with uncertainty in the operating environment. The exact cost of utilizing flexibility will most likely be determined by the circumstances particular to each firm.

More flexibility is not always better. Sushil (1997) offered a word of caution to the pursuit of infinite flexibility since it leads to confusion and instability. TenDam (1987) also supports the claim that instability can result from over-flexibility, while stability is the result of the proper level of flexibility. Brozovic (2018) alludes that an optimal level of strategic flexibility may be achieved between the two extremes of over-responsiveness and rigidity, which can be damaging to the firm. According to Stigler (1939), flexibility should be added until the marginal cost associated with flexibility equals the marginal savings. De Treville, Bendahan, and Vanderhaeghe (2007) illustrate with a real-life case example of how a highly flexible manufacturing plant struggled with confusion, regulation compliance, and accurate order processing because of the heightened flexibility. In fact, Slack (1987) observed that manufacturing managers actually tried to reduce the need for flexibility, either in the system as a whole or by isolating the need for flexibility to a portion of the system. Further, several authors agree that flexibilities can interact in a positive or negative way, resulting in antagonistic and/or complementary interactions (Aaker and Mascarenhas 1984; Slack 1987; Carlsson 1989; Weiss 1999; Cowan, Kaine, and Wright 2013). Weiss (1999) noted how tactical and operational flexibilities were inversely correlated for the surveyed farms, indicating that an increase in one type of flexibility could limit the other. Furthermore, Carlsson (1989) states that "there is a tradeoff between productivity and flexibility," indicating that increasing flexibility might not always be a win-win scenario, especially if the wrong type of flexibility is pursued within a company. This idea supports the work of Aaker and Mascarenhas (1984), who noted that increasing flexibility to deal with one type of change may simultaneously reduce the flexibility to effectively handle another sort of change in the environment. If flexibility is well-managed and meets a specific need, authors suggest it can result in positive outcomes for an organization.

Flexibility should not be a prize pursued for its own sake—a destination to be reached (Sushil 2001). Slack (1987) found that managers sought to be flexible for the advantages gained by the system, not because flexibility in itself provided an intrinsic value to the company. Sushil (2001) agreed with Slack (1987) and Sethi and Sethi (1990) that flexibility provides the *means* to accommodate uncertainty, but flexibility is not the end in itself. This idea was reinforced by TenDam (1987), who stated that flexibility is achieved and maintained by continuously accepting and responding to challenges, rather than training management and structuring the organization to be flexible. Ideally, flexibility should be a quality that is incorporated into the business structure and strategies, but requires ongoing evolution and revolution—at times—in order to be effective (Sushil 2001). Some authors clearly indicate that flexibility involves ongoing change, and flexibility cannot be obtained by a singular acquisition due to the constant fluctuations in the underlying business environment.

Flexibility is not generic, but has many dimensions, as several authors suggest (De Leeuw and Volberda 1996; Shewchuk and Moodie 1998; Sharma, Sushil, and Jain 2010). Shewchuk and Moodie (1998), who classified flexibility terms using six different attributes, begin by asking what the flexibility refers to. Upton (1994) agreed, suggesting that if flexibility is a problem, the source or cause of change should be identified so flexibility efforts can be prioritized appropriately. The reason being, Upton (1994) said, was “each dimension of change identified implies a different flexibility”. Sharma, Sushil, and Jain (2010) also discussed how firm competitiveness and performance could be increased through different kinds of flexibility. De Leeuw and Volberda (1996) describe flexibility as having two distinct dimensions: a task of management and a quality of the system design. ElMaraghy (2006) also holds that flexibility may be placed into two categories: the hard or physical components of the system and the soft or logical use of those components. Slack (1987) illustrated how the flexibility of resources like labor, technology, and infrastructure contributed to flexibility of manufacturing tasks, which in in turn increased the overall performance of the company. Other authors have also investigated how flexibility can have operational, tactical, or strategic attributes (Carlsson 1989; Upton 1994; Shewchuk and Moodie 1998; Sharma, Sushil, and Jain 2010). Slack (1987) discusses technology, labor, infrastructure, delivery, and product mix flexibilities. Sethi and Sethi (1990) provide a detailed evaluation of 11 flexibility types: machine, material handling, operation, process, product, routing, volume, expansion, program, production, and market flexibilities. Some of these flexibility types and others are discussed by later authors as well (Shewchuk and Moodie 1998). The flexibility of manufacturing, information systems, and finances are three more types presented later by Sushil and Stohr (2014). Accepting the multi-dimensional nature of flexibility is key to understanding and accurately describing flexibility for a business.

Rigidity is often perceived as the opposite of flexibility. Indeed, “non-rigidity” was mentioned as one of several connotations of flexibility by Sushil (1997). Authors often compared a flexible alternative to one that is “rigid” or “fixed” in the process of determining the advantage of flexibility (Kulatilaka 1986; Trigeorgis 2005; Wang and Tang 2010; Cowan, Kaine, and Wright 2013). Brozovic (2018) suggests rigidity as one of the barriers to flexibility which, he states, “should not be confused with robustness or stability”. Yeo and Qiu (2003) also warned against the rigid adherence to a long-term plan or strategy since it was unlikely to lead to success in a competitive environment. TenDam (1987) took a slightly different perspective, however, describing flexibility as the stability that lies between two unstable extremes: over-responsiveness and rigidity. De Leeuw and Volberda (1996) reinforce this idea, stating that instability results from an excess or defect of flexibility, but stability is the result of flexibility. Authors agree that flexibility involves an ongoing balance of change and preservation simultaneously (De Leeuw and Volberda 1996; Sushil 2017; Brozovic 2018). Farms were classified as rigid by Cowan, Kaine, and Wright (2013) if they displayed low strategic and tactical flexibility simultaneously, which was understood to mean that their options to adjust input use or output mix were limited. Past research seems to agree that flexible systems are not rigid, but that some balance must be found between continuity and change for flexibility to be effective.

Flexibility and Risk Management

Risk can result from uncertainty and challenges whether that be in the internal or external operating environment. A business faces risk in a situation when possible outcomes and their probabilities of occurrence are known, while uncertainty arises from a situation where the potential outcomes and their probabilities are not known (Kay, Edwards, and Duffy 2012). While risk is often viewed as the possibility of a negative outcome occurring, the outcomes of risk may be neutral or positive as well (Hewlett et al. 2019). Four primary strategies have been suggested for managing risk by previous authors, and three specific ways to control the impact of risk on an organization:

1. Avoid the risk
2. Transfer the risk
    i. Insurance
    ii. Contracting
3. Control the risk
    i. Control Probability
    ii. Control Impact
        1. Increase Reserves
        2. Maintain Flexibility
        3. Diversification
4. Accept the risk (Hewlett et al. 2019)

Kay, Edwards, and Duffy (2012), state that risk management tools in general either reduce risk or reduce the impact of a negative outcome. Risk management is defined by Hewlett et al. (2019) as "one or more strategies created with the goal of reducing the consequences of negative outcomes, or increasing the likelihood of positive outcomes." Insurance is one risk-transferring mechanism commonly used to limit losses with certainty in exchange for the payment of a premium (Aaker and Mascarenhas 1984; Hewlett et al. 2019). Contracts, such as those made in the futures market, are a way to eliminate price uncertainty, though the potential gain from an upward price movement is limited simultaneously (Debertin 2012; Hewlett et al. 2019). The way businesses utilize risk impact controls will be explored further.

Diversification is a common strategy to control the impact of risk on an organization. Aaker and Mascarenhas (1984) suggest that diversification creates external flexibility for the organization, enabling participation in multiple output markets or technologies. Debertin (2012) and Hewlett et al. (2019) agree that the good performance of one enterprise offsetting the poor performance of another enterprise is the goal of diversification, in spite of the costs incurred from non-specialization. Revenue stabilization is usually the goal of diversification, which is attested to by several authors. An empirical study conducted by Mcnamara and Weiss (2001) found that off-farm employment was closely related to on-farm diversification. Although the results were not significant, Mcnamara and Weiss (2001) concluded that diversification of activities both on or off the farm was perceived by farmers to be an effective way of reducing household income risk. On-farm diversification involved a multiplicity of enterprises, while off-farm diversification implied employment sourced from outside the farm. Debertin (2012) added that diversification may be more effective for revenue stabilization in the face of price risk than production risk. This would be true if the relevant markets were non-correlated. Wilmer et al. (2018) also found that ranchers in Colorado relied on diverse revenue streams for building greater flexibility. In a survey conducted by Weiss (1999), farm diversification was positively correlated with the ability to switch between a number of products (operational flexibility), but negatively correlated with the ability to easily adjust aggregate output (tactical flexibility). Diversification has been widely accepted as a risk mitigation strategy and often seen as being tightly linked with flexibility.

The risk-mitigating effect of flexibility has been discussed by several authors. Carlsson (1989) suggested that a flexible company has a different perspective on risk, where changes can be interpreted as opportunities, rather than threats. Commitment to general-purpose resources was mentioned by Aaker and Mascarenhas (1984) as a means to increase flexibility and risk protection in exchange for higher investment costs and poorer performance. On the other hand, specialized resources lead to improved performance along with decreased flexibility and increased risk (Aaker and Mascarenhas 1984). Torell, Murugan, and Ramirez (2010) observed that the flexibility to adjust animal stocking rate in the face of climatic uncertainty was improved through grazing yearling livestock but the increased number of livestock purchases introduced financial risk to the operation. A survey of ranchers performed by Kachergis et al. (2014) also found that shorter grazing periods and utilizing yearling livestock were associated with the flexibility to prepare for drought risk. Sushil (2017) proposes that acquiring the proper flexibility can mitigate risk, but the costs associated with unguided flexibility can introduce more risks instead. Incorporating flexibility into financial planning was discussed by Mintah, K., Higgins, D. and Callanan (2018), who proposed that a real options framework more accurately accounted for future risks and the flexibility to adjust investment than the traditional net present value method. Although there exists some dissent about flexibility as a risk management tool, authors tend to agree that flexibility has the potential to reduce risk for an organization.

It is likewise important to make a distinction between raw flexibility and the use of extra capacity to control the impact of risk. As defined by Hewlett et al. (2019), extra reserves refer to resources that are held in excess of need, such as cash, which can help mitigate the occurrence of poor revenues. Aaker and Mascarenhas (1984) describe that investment in extra capacity in manufacturing, distribution, or other areas are a means to building internal flexibility. Liquidity is thought to be synonymous with internal flexibility, increasing the business' potential to respond to either undesirable developments or positive trends (Aaker and Mascarenhas 1984). Bengtsson and Olhager (2002) view extra capacity as complimentary to flexibility, although risk management is not directly linked with these efforts. Extra capacity can promote product-mix flexibility; while at the same time, the marginal value of flexibility depends on the amount of extra capacity used in the system (Bengtsson and Olhager 2002). Incorporating flexibility to expand the capacity of a parking garage in the future is the focus of a study conducted by de Neufville, Scholtes, and Wang (2006). Both flexibility and resource reserves are used in tandem in this case. The flexibility to expand capacity later had to be incorporated during the planning phase, but building unneeded extra capacity initially was too costly and would have increased the risk of low financial performance (de Neufville, Scholtes, and Wang 2006). Similar to diversification, maintaining resource reserves is a tool for controlling risk, though extra capacity is often perceived as increasing flexibility.

Flexibility in Various Contexts

Context can have a major impact on how flexibility is perceived. This trait arises partly due to its multi-dimensional nature, as attested by several authors (TenDam 1987; Upton 1994; Sushil 1997; Sharma, Sushil, and Jain 2010). The concept that flexibilities can occur at various levels and areas in an organization is visited by Slack (1987), Sushil and Stohr (2014), and Brozovic (2018). Furthermore, authors describe how flexibilities can interact within an organization—building upon, limiting, or enhancing other flexibilities (Aaker and Mascarenhas 1984; Slack 1987; Sethi and Sethi 1990; Sushil and Stohr 2014). Kumar and Kumar (1987) described how different flexibilities are suited to address four potential sources of uncertainty: inputs, outputs, the production process, and the operating environment. Flexibility in the context of various time frames (Slack 1987; Carlsson 1989; Upton 1994; Shewchuk and Moodie 1998; Sharma, Sushil, and Jain 2010) as well as the internal and external perspectives of the business (Aaker and Mascarenhas 1984; Upton 1994; Sushil 1997; Sharma, Sushil, and Jain 2010) have received substantial attention in the literature. Flexibility as a feature of available resources as well as the flexible use of resources have been discussed also (Slack 1987; TenDam 1987; Upton 1994; De Treville, Bendahan, and Vanderhaeghe 2007). Flexibility in various contexts is expanded here for greater clarity.

Multi-Dimensional

Flexibility has been repeatedly acknowledged as a multi-dimensional concept (Sethi and Sethi 1990; Upton 1994; Shewchuk and Moodie 1998; De Treville, Bendahan, and Vanderhaeghe 2007; Sharma, Sushil, and Jain 2010). Sethi and Sethi (1990) reported finding at least 50 flexibility terms in their review of the literature and more recently, Brozovic (2018) identified 83 unique definitions for strategic flexibility alone. To determine various dimensions of flexibility, Upton (1994) suggested beginning with the identification of what change is needed or what needs to be adapted to. Some example dimensions given were machine flexibility, labor flexibility, mix flexibility, and operation flexibility (Upton 1994). These labels seemingly refer to the flexibility surrounding certain activities or aspects within an organization. However, some authors have discussed dimensions of a particular type of flexibility, such as managerial (TenDam 1987), strategic flexibility (Brozovic 2018), or operational flexibility (Sharma, Sushil, and Jain 2010), which adds ambiguity to the discussion about what is meant by 'flexibility dimensions'. It is clear based on this discussion that authors do not hold a generic view of flexibility, rather that it is related to something specific—even if investigation be required to discover it.

a. Interactions Between Flexibility Types

Since different types of flexibility have been understood to exist, some authors have also investigated how particular flexibilities may interact within an organization. Aaker and Mascarenhas (1984) caution that increasing the flexibility to handle one potential change may simultaneously reduce the flexibility of the business to handle another potential change. Similarly, Slack (1987) relates an example where a company effectively increased the flexibility to quickly respond but lost flexibility to produce a wide range of products. In his empirical analysis of Austrian farms, Weiss (1999) found that operational and tactical flexibility to be negatively correlated as well. Apparently, farms with the ability to easily adjust output of a single product had less capacity to adjust product mix, and vice versa (Weiss 1999). In the "Flexibility Maturity Model" illustrated by Sushil and Stohr (2014), flexibility in the interaction between processes is the second level, which is built upon the flexibility in individual processes. The potential interaction between flexibility types is an important consideration for managers seeking to increase flexibility in a business.

b. Levels and Hierarchies of Flexibility

Some authors have delineated the flexibility they discussed based on the level of the organization where it can be observed. In the analysis of the overly-flexible manufacturing company, De Treville, Bendahan, and Vanderhaeghe (2007) broke down the analysis based on the questions at the strategic, tactical, and operational levels. Strategic problems involved a long-term outlook to match flexibility efforts with the demands of the environment; the choice of equipment and technology were listed as problems at the tactical level; and process consistency was a major issue at the operational level (De Treville, Bendahan, and Vanderhaeghe 2007). The strategic, tactical, and operational perspectives have been discussed by other authors (Carlsson 1989; Shewchuk and Moodie 1998; Sharma, Sushil, and Jain 2010), but these will be explored later since they are generally linked with time in some way. Slack (1987) illustrated a four-level flexibility hierarchy for a company, indicating that higher levels were enabled or constrained by lower levels. The lowest level is that of production resources; second, the production tasks; third, the overall performance of the production system; and fourth, the competitive performance of the company (Slack 1987). Sushil and Stohr (2014) also illustrate a hierarchy of flexibility for an organization, where strategic flexibility is facilitated by financial flexibility, marketing flexibility, manufacturing flexibility, organizational flexibility, and information systems flexibility at the lower levels. Sethi and Sethi (1990), Shewchuk and Moodie (1998), and Brozovic (2018) also mention how the flexibility of the whole system is dependent on the flexibility of the components, processes, or actors at lower levels. It should be understood, based on these highlights, that various flexibilities can increase or decrease other flexibilities and the flexibility of the system as a whole.

Time

Flexibility has been associated with time to some degree. In the classification framework created by (Upton 1994), the time horizon relevant to the change was an important factor in determining what type of flexibility was needed. Upton (1994) also proposes that the mobility aspect of flexibility can be measured in terms of time or cost, with flexibility associated with low switching costs or changeover times. Short-term and long-term flexibility were also mentioned as distinct categories of manufacturing flexibility (Upton 1994). Yilmaz and Davis (1987) categorize the association between the flexibility of a manufacturing system and time as: flexibility at times, flexibility after a time, and flexibility over time. The machine and routing flexibilities are characterized as short-term (at times), followed by product, process, and process sequence flexibilities that occur ‘after a time’, and volume, expansion, and production flexibilities considered to be longer term or ‘over time’ (Yilmaz and Davis 1987). Slack (1987) identified that flexibility could be viewed from two perspectives with respect to the portfolio of options: range and response. The former was typically seen as a long-term flexibility, since a wide range of alternatives is important over time, but the latter was considered a short-term flexibility because an effective and timely response was more important for uncertainties that do not endure (Slack 1987). Some authors have made a distinction between strategic, tactical, and operational flexibility (Carlsson 1989; Upton 1994; Shewchuk and Moodie 1998; Sharma, Sushil, and Jain 2010), the main differentiating factor being long, intermediate, and short time horizons, respectively. Shewchuk and Moodie (1998) acknowledged others’ efforts have included the delineation of flexibility based on absolute/relative timeframes, or by the activities involved in the manufacturing process. Shewchuk and Moodie (1998) also clarified that one or more flexibility terms may be described at a given point in time or over time, depending on the range of options available. TenDam (1987) emphasizes the need for readiness in managerial flexibility—what he calls “when-flexibility”—referring to the ability to respond in a timely manner. The timeframes associated with flexibility merit further review since this concept has received considerable attention from past researchers.

Strategic Flexibility

Strategic flexibility is one of the most commonly mentioned flexibilities in the literature. In a recent literature review, Brozovic (2018) identified 83 unique definitions for strategic flexibility, indicating that a number of diverse perspectives exist amongst authors. A question may arise as to the meaning of this flexibility. Does strategic flexibility mean that one strategy is flexible, or there is flexibility to switch between multiple strategies? First, the concept of strategy should be clarified. Hewlett et al. (2019) describe a strategy as a plan of action to utilize available resources in order to accomplish a particular goal or end. Decisions are viewed as strategic if they determine or affect what the business does in the big-picture sense (Hewlett et al. 2019). Shewchuk and Moodie (1998) summarize other works that describe strategic-level decisions as those regarding the definition of products, production volume, and utilization or change of infrastructure. According to Cowan, Kaine, and Wright (2013), strategies are “decisions about what is going to be produced and how the business is going to be organized to produce it.” There is apparent agreement regarding the wholistic outlook of strategy; the incorporation of flexibility with business strategy will now be explored. Carlsson (1989) holds that strategic flexibility belongs to the long-term planning horizon, it being linked to the organization’s ability to make choices in the future regarding product offering, geographical location, R&D efforts, and threats to be mitigated. Both the style of management and the structural features of the organization are thought to control how much strategic flexibility may be exercised (Carlsson 1989). Aaker and Mascarenhas (1984) did not directly link strategic flexibility to a specific timeframe but acknowledged that strategic flexibility allows the organization to adapt to changes in the operating environment that would have persisting implications for business operation. Strategic flexibility is described by Sharma, Sushil, and Jain (2010) as the ability to react to urgent and dynamic changes that affect the performance of the organization on the strategic level. However, the conflicting perspectives of other authors are also related, and the lack of consensus in defining strategic flexibility by others is recognized as well (Sharma, Sushil, and Jain 2010). The flexibility of resources available to the business has been cited as one determinant of strategic flexibility (TenDam 1987; Sanchez 1995; Brozovic 2018) as well as the ability to utilize resources in a flexible manner (Sanchez 1995). In his description of strategic flexibility, TenDam (1987) included both the ability to adapt to changes in the operating environment as well as the ability to enact change—which allows for the exploration of new operating environments and new goals. In agreement with Carlsson (1989), Upton (1994) described strategic flexibility as the ability to make long-term changes which typically occur infrequently and have greater significance due to the level of commitment or capital involved (Figure 1.1). Higher strategic flexibility is associated with a greater ability to easily change products, markets, or technology, as well as expand or withdraw from business ventures as performance dictates (Sharma, Sushil, and Jain 2010). Cowan, Kaine, and Wright (2013) state that the ability to change the strategy of the farm is not the concern of strategic flexibility, as that implies a fundamental change in farm structure, or more properly called an ‘adaptation’ of the system. Instead, strategic flexibility describes the ability of the farm business to vary the composition of the output mix—a subset of the total set of outputs possible for a given strategy—in order to be less dependent on a critical input (Cowan, Kaine, and Wright 2013). In order to retain strategic flexibility, (Brozovic 2018) suggests that a business must not only respond swiftly in a given situation but also allow the development, reframing, and changing of strategies over a longer period of time. In general, it is difficult to find agreement on the subject of strategic flexibility, except that many authors have acknowledged that flexibility can influence the strategy used by a business in some discernable way.

Tactical Flexibility

What is the meaning of tactical flexibility? Cowan, Kaine, and Wright (2013) illustrated business strategy being highest in the hierarchy of business plans, while tactical decisions are the lowest (Figure 1.2). This implies that well-guided tactical decisions are informed by, indeed preceded by, some strategic vision. Hewlett et al. (2019) support this view, relating that decisions that are tactical in nature determine how the business strategy is put into practice. According to Cowan, Kaine, and Wright (2013), tactics relate to the translation of inputs to outputs through the production process. Contrary to the common method of distinguishing strategic and tactical flexibility according to time, Cowan, Kaine, and Wright (2013) delineate between the two based on the aforementioned hierarchy. It is pointed out that decisions which are tactical in nature may appear to be strategic due to the long production cycles typically found in agricultural systems (Cowan, Kaine, and Wright 2013). Thus, timeframe may not be the best sole measure for describing the flexibility at the strategic and tactical levels.

Tactical flexibility belongs to the medium-term according to Carlsson (1989), who described it as the ability to accommodate changes in product mix, production rate, or moderate design changes in the course of a business cycle. This view of strategic flexibility is shared by Shewchuk and Moodie (1998). Interestingly enough, Carlsson

(1989) said that at the tactical level, this ability to deal with change was based on the equipment used by the firm. Flexibility built on the physical elements of the organization is discussed by others as well (TenDam 1987; ElMaraghy 2006). Upton (1994) agrees with Carlsson (1989) that tactical flexibility is related to changes that occur occasionally, still requiring some commitment and effort (Figure 1.1). Shewchuk and Moodie (1998) categorized flexibility terms from past literature based on the organizational level affected. Hence, they determined that flexibility definitions that affect tactical-level decisions describe tactical flexibility. Although there was some disagreement between authors as to the definition of some terms, product flexibility, product-mix flexibility, volume flexibility, and sequencing flexibility were some examples of terms categorized as being tactical in nature (Shewchuk and Moodie 1998). Weiss (1999) follows the work of Carlsson (1989) and Stigler (1939) and defines tactical flexibility as "the ability of a single-product firm to adjust output to exogenous shocks at relatively low costs." In his empirical analysis of Austrian farms, Weiss (1999) found that tactical flexibility was inversely related to farm size and participation in off-farm employment. Tactical flexibility seemed to be higher for farms with well-educated operators that were married and had family members living on the farm as well (Weiss 1999). Similar to other authors, De Treville, Bendahan, and Vanderhaeghe (2007) proposed that flexibility at the tactical level involved the structures, systems, and technologies of the business that provided the realization of strategic flexibility. Cowan, Kaine, and Wright (2013) define tactical flexibility as a farm's ability to adjust the use of a critical input while holding the output mix constant. Tactical flexibility allows the farm to alter the use of a critical input in one of three ways: 1) altering the time when the input is used, 2) reducing the use of that input, or 3) substituting another input for the variable input (Cowan, Kaine, and Wright 2013). The core of tactical flexibility seems to be related to the business components and operations and their ability to enable flexibility at higher levels.

Operational Flexibility

Flexibility on the operational level has been expanded by several authors. Hewlett et al. (2019) state that decisions at the operational level are related to the activities that enable and accomplish the tactical and strategic objectives. Carlsson (1989) describes the operational level as being associated with the short-term and the commonly observed fixity in the hardware and software used for company operations. Operational decisions are usually related to the day-to-day activities such as scheduling, sequencing, deliveries, and procedures (Carlsson 1989). Therefore, the firm demonstrating operational flexibility will be capable of permitting high variation in these areas (Carlsson 1989). “Operational flexibility is the ability to change day to day, or within a day as a matter of course” is the definition given by Upton (1994), reemphasizing the short-term nature of operational considerations. Similar to others, Shewchuk and Moodie (1998) and Sharma, Sushil, and Jain (2010) link operational flexibility with the real-time system operation and adjustment. Weiss (1999) describes operational flexibility as a firm’s ability to change output between multiple products, which aligns with the definition of strategic flexibility given by Cowan, Kaine, and Wright (2013). The integration of flexibility and diversification of outputs is also noted by Carlsson (1989), who stated that the ability to switch between products was important for operational flexibility. There seems to be nearly universal agreement surrounding the definition of operational flexibility; namely that it refers to the business's ability to alter the method or mode of operation. In so far as the alterations occur with greater frequency, this flexibility may also be considered short-term.

Internal vs. External

Another perspective discussed by authors is whether flexibility is considered internal or external to the business. Aaker and Mascarenhas (1984) discuss internal flexibility created by liquidity and external flexibility created by diversification. In the first case, liquidity can provide a business the means to quickly respond to negative or positive trends in the operating environment through investment in slack resources, such as extra manufacturing or warehousing capacity (Aaker and Mascarenhas 1984). On the other hand, diversification provides alternatives external to the business through participation in multiple markets, technologies, or R&D areas so that fluctuations in the operating environment do not have a severe impact on the business (Aaker and Mascarenhas 1984). In his discussion of internal and external flexibilities, Sushil (1997) describes an interaction between the situation and the actor. The external flexibility of the manager depends on the freedom of choice allowed by the situation, while the manager's own strengths and limitations likewise determine the amount of internal flexibility that can be realized (Sushil 1997). These two flexibilities must be appropriately balanced to maintain system viability (Sushil 1997). Similarly, Upton (1994) describes two views flexibility: internal capabilities of the business to be flexible and the competitive advantage realized by external flexibility. He states that the flexibility of the business to accommodate changes in the external operating environment and foster competition is fundamentally dependent on the internal operating strategy and abilities developed within the business (Upton 1994). In his discussion of flexibility and risk, Sushil (2017) associates business and managerial risks with the external and internal operating environment, respectively. While business risks can arise from the introduction of new products, diversification, or the obsolescence of technology, managerial risks can result from internal changes and practices such as reengineering, process automation, and procedure innovations (Sushil 2017). Sharma, Sushil, and Jain (2010) took a slightly different perspective, describing internal flexibility as a capacity of the organization to adapt to changes in the operating environment while external flexibility describes the organization's ability to influence the operating environment. In the first case, the organization's ability may be either reactive or pre-emptive, while in the second case it is assumed that the organization must act voluntarily to reduce threats from the operating environment (Sharma, Sushil, and Jain 2010). While not addressing the internal and external aspects of flexibility specifically, the literature review written by Brozovic (2018) relays that most of the past research has been focused on the organizational response to changes in the operating environment (i.e., external to the business). Care should be taken to understand if flexibility will affect the internal or external operating environment of a business, since several authors have acknowledged this distinction.

A Systems Perspective

What is required for the realization of flexibility in a business? Carlsson (1989) stated that "in order to have a flexible organization, one needs a flexible structure, not only flexible people." According to Sanchez (1995) and ElMaraghy (2006), flexibility is dependent on both access to flexible resources and the flexible use of those resources through managerial actions. ElMaraghy (2006) refers to flexibility as being a feature of the "hard/physical" or "soft/logical" elements of the system. In other words, an organization needs a combination of either flexible resources, flexible management, or both in order to be characterized as flexible. Sethi and Sethi (1990) categorize flexibility types as pertaining to either components or the system as a whole. Several authors have been interested in the flexibility to switch the output produced by the business (Carlsson 1989; von Ungern-Sternberg 1990; Weiss 1999; Cowan, Kaine, and Wright 2013). Works that discuss the flexibility associated with management, inputs, and outputs will be investigated further.

a. Managerial Flexibility

According to several authors, managerial flexibility is an important determinant of the flexibility of the business. Sushil (1997) notes the general trend in management seems to be "toward greater flexibility" as business managers shift away from the traditional and relatively rigid approach. It has been mentioned that "top management attitudes and practices may be the single largest obstacle to increasing flexibility" (Carlsson 1989). In his discussion, TenDam (1987) states that managerial flexibility is just as important as having a flexible structure and resource base. An individual's resourcefulness and ability to handle challenges are a function of their experience, pragmatism, and innovative attitude (TenDam 1987). As was already stated, TenDam (1987) clarifies that an organization does not attain or maintain flexibility by simply training managers to be flexible (increasing experience), but rather by recognizing and responding to challenges. Sanchez (1995) relates that a strategic manager is challenged with defining the business's product strategies, then coordinating and deploying resources to support the chosen product strategies. In the case of a dynamic environment, flexibility in coordinating resources involves the ability to adjust pre-defined product strategies, locate alternative resources, and reorganize them for effective use (Sanchez 1995). Although not specifically labeled as a managerial trait, ElMaraghy (2006) describes the "soft/logical" aspect of manufacturing system flexibility that allows for systematic reconfiguration without modification of the physical elements in the system. Soft or logical flexibility is realized in areas such as product-mix, routing, production planning, and operations (ElMaraghy 2006). A case study found that flexibility efforts paired with active management were associated with a positive outcome, while the outcomes from flexibility paired with a passive management style were neutral to negative (De Treville, Bendahan, and Vanderhaeghe 2007). In his general definition of flexibility, Upton (1994) notes that flexibility can be viewed as an adaptive response to, or a proactive action taken to change, the dynamic operating environment. Similarly, the flexibility of western ranchers in responding to drought through proactive and reactive approaches was evaluated by Kachergis et al. (2014). A proactive approach would include actions taken to prepare for drought, while reactive measures would be those taken in response to drought conditions (Kachergis et al. 2014). In the area of finance, the theory of real options has been shown to be advantageous over the traditional NPV technique in valuing investments primarily because it accounts for the flexibility of the project manager to alter the investment at a later time (Yeo and Qiu 2003; Trigeorgis 2005; Wang and Tang 2010; Andalib, Tavakolan, and Gatmiri 2018). The topic of managerial flexibility has received attention from numerous authors, and now the flexibility of resources will be reviewed.

b. Resource Flexibility

The flexibility of resources was addressed as early as 1930's in microeconomic literature. According to Stigler (1939), a pioneer in discussing flexibility in economics, the divisibility and adaptability of a plant (i.e., the production unit) determine, to a large degree, how much flexibility a company can utilize. Aaker and Mascarenhas (1984) point out that flexibility can be increased by avoiding heavy commitment to specialized resources, which often present exit barriers, and investing in general-purpose assets instead. Slack (1987) relates that the individual resources of a business, like labor, technology, and infrastructure, each have flexibility associated with them and each contributes to the flexibility of each other and the system as a whole (Figure 1.3). Furthermore, Slack (1987) observes that the flexibility of physical processes cannot be realized without the structure and system being likewise flexible to handle change. Kumar and Kumar (1987) also acknowledge that uncertainties can affect the standards and availability of inputs used by a business, and these can be accommodated by machine flexibility and material flexibility. Sanchez (1995) explains the flexibility of resources in three respects: 1) Resources are more flexible when they have more alternative uses, 2) Resource flexibility is higher where the cost or difficulty of switching a resource from one use to an alternative use is low, and 3) Resources are considered more flexible where the time required to switch them from one use to an alternative use is low. In other words, resources may be considered more flexible where they can be quickly and easily repurposed for multiple needs. Continuing, Sanchez (1995) explains that a firm's strategic flexibility depends on the flexibility or inflexibility of all the resources utilized by the firm. The flexibility of a manufacturing system to scale capacity and capability is considered "hard/physical", according to ElMaraghy (2006), since this is achieved through the addition, replacement, or modification of hardware in the system. This agrees with Shewchuk and Moodie (1998), who describe the capacity and capability envelope of the system as being partly determined by the machines and equipment in place. Focusing on input resources, Cowan, Kaine, and Wright (2013) define tactical flexibility as the ability to alter the use of a critical input to adjust for variability of that input. Furthermore, it is understood that a farm may have higher tactical flexibility with regard to the use of some inputs than others (Cowan, Kaine, and Wright 2013). The link between flexibility and some specific resources such as finances and technology has received attention by other authors (Sharma, Sushil, and Jain 2010; Brozovic 2018). It has been demonstrated that the common understanding is that flexibility is a fundamental feature of resources, either individually or collectively. Similar attention has been given to the flexibility of outputs also.

c. Output Flexibility

The flexibility of the business to change outputs has received significant attention in the literature. Aaker and Mascarenhas (1984) categorized diversification in product markets as an external flexibility, since it relates to how the business participates in the external operating environment. Kumar and Kumar (1987) state that product-mix flexibility, quality flexibility, and design-change flexibility are particularly important to handle uncertainty in the area of outputs. Slack (1987) found that interviewed managers emphasized three flexibilities associated with outputs: product flexibility, mix flexibility, and volume flexibility. These corresponded with the ability to introduce new or different products, alter the range of products manufactured in a given period, or adjust the volume of output, respectively (Slack 1987). von Ungern-Sternberg (1990) developed an economic model to analyze flexibility as “the ease of switching to the production of a different commodity.” Based on the assumption of perfect competition in the marketplace, von Ungern-Sternberg (1990) concluded that the market will not usually encourage a similar degree of flexibility to be adopted by all firms; some will either specialize in the production of one output and be non-flexible or diversify output in response to fluctuations in demand and thus maintain flexibility. Carlsson (1989) and Weiss (1999) both discuss the ability to switch between output products as ‘operational flexibility’. More recently, Mintah, K., Higgins, D. and Callanan (2018) evaluated the flexibility to switch between alternative building configurations (outputs) using a real options approach. Although the original non-flexible design was an acceptable investment based on a positive NPV, Mintah, K., Higgins, D. and Callanan (2018) proved that the flexible building design had the potential to earn more revenue, especially considering that the demand for the original design might decline over time. Cowan, Kaine, and Wright (2013) discuss the flexibility of a farm business to alter output as well, calling this ability ‘strategic flexibility’. The context used to examine flexibility matters tremendously in identifying how flexibility may be at work in a business. Once identified, the amount of flexibility present may be sought by way of measurement. The methods suggested for measuring flexibility are presented now.

Measuring Flexibility

The goal of measuring flexibility is to quantify the various flexibilities that may be present in a business. Few attempts have been made to accomplish this task because of its intimidating nature. One of the first ways of measuring flexibility was suggested by Aaker and Mascarenhas (1984), who provide an extensive list of qualities to assess the level of flexibility in various aspects of the business. Aaker and Mascarenhas (1984) stated that “it is unrealistic and unduly restrictive to expect the measurement to be limited to objective quantitative measures”, and therefore propose a number of subjective means of measuring flexibility as well. In the area of marketing, the number of markets that the firm participates in is suggested as an objective measurement, while the strength of customer loyalty is offered as a subjective measure in this area (Aaker and Mascarenhas 1984). Using the theory of uncertainty, Kumar and Kumar (1987) suggest that individual flexibilities should be identified and measured in response to specific uncertainties facing the business, like variability in inputs, outputs, the manufacturing process, or the operating environment. Chryssolouris (1996) proposes several methods of measuring flexibility including operational statistics, time required for change, manufacturing indices, and the number of choices (options) available and the amount of freedom to choose from those choices. However, Chryssolouris (1996) gives greater effort to the development of a mathematical measure of flexibility describing the system’s sensitivity to change as a function of the probability and penalty associated with a potential change of states. In their paper discussing flexibility and decision making, Mandelbaum and Buzacott (1990) propose that flexibility may be measured as the number of alternatives that remain available in the second period after a choice has been made in the first period. Sethi and Sethi (1990) suggest methods of measuring specific flexibility types, such as machine flexibility and product flexibility. In both cases, the time or cost required to make a switch is proposed as a means to measure flexibility. Upton (1994) also suggests the time or cost required to make a change as a method to measure the 'mobility' element of flexibility. However, Upton (1994) also acknowledges that a metric successfully applied to one case may be irrelevant in another case, so further efforts should be made to understand how to measure flexibility. Shewchuk and Moodie (1998) report a total of six measures for flexibility from two previous authors. In the first case, flexibility may be measured either as absolute, simply defined as the number of choices available and the decision maker's ability to choose them, or as relative, defined by the number of choices available after one choice has been made (Shewchuk and Moodie 1998). In the second case, absolute and relative attributes remain, but the desirability of choices and the ability of the choices to meet a predetermined criteria were considered (Shewchuk and Moodie 1998). The method suggested by Upton (1994) and others for measuring flexibility are mentioned by Brozovic (2018), but little elaboration or explanation is given. The concept of measuring flexibility has been attempted by a few authors, but remains elusive in the current literature, which proves problematic when attempting to assign a value to flexibility in an objective manner.

Valuing Flexibility

Beyond the efforts to measure how much flexibility is present in a system, some authors have attempted to determine the worth of flexibility as well. As mentioned before, several authors have indicated that there is a cost of some sort associated with flexibility (Stigler 1939; Slack 1987; Carlsson 1989; Sethi and Sethi 1990). While obtaining flexibility may have a cost, authors have acknowledged that circumstances can exist where it may likewise be costly to not have flexibility (Aaker and Mascarenhas 1984; Sushil 2001). Following the theory of real options written by Black and Scholes (1973) and Margrabe (1978), and the economic modelling performed by von Ungern-Sternberg (1990), authors have endeavored to determine the value of flexibility in various business sectors (Bengtsson and Olhager 2002; de Neufville, Scholtes, and Wang 2006; Mintah, K., Higgins, D. and Callanan 2018; Simmons 2019). Similar to financial options, real options can be described as "the mechanisms for building flexibility into projects; they are the right (but not the obligation) to sell/buy an asset in the future" (Andalib, Tavakolan, and Gatmiri 2018). Flexibility in the use of inputs was investigated by Kulatilaka (1993) in the case of steam boilers capable of burning either a single fuel source or two fuel sources. The trade-offs between the use of dedicated vs. automated machines used to manufacture automobile engines was the subject of a case study by Bengtsson and Olhager (2002). Property management is another area where flexibility has been analyzed through the use of real options theory. A parking garage project with flexibility to expand with future demand was analyzed by de Neufville, Scholtes, and Wang (2006). It was determined that the expansion option resulted in a higher expected

NPV than the non-flexible design, despite the additional investment at the beginning of the project (de Neufville, Scholtes, and Wang 2006). Mintah, K., Higgins, D. and Callanan (2018) evaluated a multi-use building project with the flexibility in floorplan design obtained through movable walls and floorplates, new technology, etc. The analysis showed that despite the extra investment cost, the option to switch could be profitable if it was exercised at the right time in the future (Mintah, K., Higgins, D. and Callanan 2018). Simmons (2019) evaluated a ranch's opportunity to install a fence and so acquire the option to utilize the land resource for either grazing or hay production and the flexibility to choose the highest value enterprise the following year. Using linear programming as a means of optimization, Simmons (2019) found that the annual expense of installing the fence was compensated by the option value created by the ability to switch to an alternative enterprise if market conditions dictated. As several authors have attested, the flexibility to alter an investment or project in the future can be estimated using a real options framework. Cases where authors have attempted to value flexibility will be concisely presented here.

Case Examples

i. Flexibility with the Use of Inputs

Kulatilaka (1993) used a real options framework to analyze the value of flexibility associated with a steam boiler capable of burning only oil or natural gas exclusively, compared with a dual-fuel boiler that could switch between these fuel sources. The dual-fuel boiler was likened to a call option which allowed the user to obtain fuel at the cheaper "strike price" or at the more expensive "market price". Further, the author pointed out that the dual-fuel boiler represents a compound option for cases when it might be attractive to reverse the switch, since this could be likened to a put option. Based on the price assumptions for each fuel type, the value of flexibility offered by the dual-fuel boiler was found to be $26,000, which far exceeded the incremental cost of purchasing the dual-fuel boiler for $5,200.

ii. Machinery Flexibility and Volume Flexibility

An electric motor manufacturing plant was used for a case-study by Bengtsson and Olhager (2002) to analyze the economics of adding flexibility and extra machine capacity through fully automatic or semiautomatic machines. When a single machine was the only resource dedicated to the production of a specific motor type, the system was viewed as inflexible compared to a machine capable of producing any variation of motor. The analysis revealed that the option of having machine flexibility proved to be worth more than 20,000 SEK (Swedish Krona)/week over the alternative dedicated system, but there was negligible benefit from adding extra machines beyond what was necessary to meet demand. Indeed, decreasing marginal returns were associated with adding semi-automatic machines to the system to obtain flexibility in production capacity.

iii. Flexibility to Expand Investment

A parking garage planning exercise was completed by de Neufville, Scholtes, and Wang (2006) through the use of the real options framework and spreadsheet analysis. Due to the uncertainty of demand for parking spaces in the future, the optimum capacity of the parking structure was the main question to be answered. The authors found that the most optimal solution was to build the parking garage smaller to meet the prevailing demand for parking spaces but reinforce the structure to allow for future expansion if demand increased as expected. The authors suggested that if demand exceeded capacity for two consecutive years, then another floor would be added to the garage. By investing an additional five percent at the outset of the project, the owners paid the "premium" for the right without the obligation to expand capacity in the future. This approach not only shifted the distribution of possible outcomes to be more positive, but it also provided cost savings when compared to the deterministic case. Despite the extra expense involved with this strategy, the value estimated for the option to expand was found to exceed the deterministic case (i.e., building larger in expectation of rising demand) by $2.25 million.

iv. Flexibility to Switch Output

Mintah, K., Higgins, D. and Callanan (2018) investigated the value of flexibility in a property investment project for a mixed-use building then under construction in the city of Melbourne, Australia. The original design included apartments with retail space on the ground floor. An alternative design proposed by the authors was for student dorm accommodations with co-working office spaces on the ground floor. Mintah, K., Higgins, D. and Callanan (2018) used real options analysis to determine the value of the original and the alternative design, and found that both were positive and thus, satisfactory investments. However, the authors evaluated a third option that provided flexibility in the floorplan (output) of the original design through the use of movable walls, flexible floorplates, and new technology. Despite the higher initial investment costs required for the flexibility option, the authors showed that incorporating flexibility into the building design and switching the floorplan at the right time in the future yielded a NPV of $AUD3,881,445, which was greater than either of the other “non-flexible” alternatives. Mintah, K., Higgins, D. and Callanan (2018) noted that the market conditions did not justify immediately switching the floorplan of the building, but value could be gained in the case of a significant reduction in demand for apartments in the future.

v. *Flexibility to Switch Enterprises*

Simmons (2019) evaluated the opportunity for a ranch to build a perimeter fence around a hay meadow and thereby create the option to use the land for cattle grazing or hay production. Since the market prices of cattle and hay were out of the control of the ranch owner, the ability to switch enterprises as these prices fluctuated was thought to create valuable flexibility for the ranch owner. Essentially, Simmons (2019) views the cost of installing the fence as the fee that must be paid for the freedom to choose one enterprise or the other without the obligation to change in the future. Based on the linear programming results, Simmons (2019) shows that the net present value of the “flexibility option” for one year is sufficient to cover the cost of the fence installation. Furthermore, since the fence is a durable investment, the value derived from the fence is even greater when the installation cost can be spread out over the life of the fence. The option increases in value as the correlation of cattle and hay returns move from positive and steady to negative and volatile. The minimum value of the option was found to be $45,834 when the correlation of returns was 0.80, whereas the “strike price” for this option (installation cost of the fence) was $42,240.

Summary

In conclusion, flexibility is a concept that has received significant attention in the field of business management. Despite numerous attempts to define flexibility, Kumar and Kumar (1987) stated that flexibility was not well understood. This deficiency in understanding seems to persist, given that several authors have paid such great attention to classification schemes and frameworks (Sethi and Sethi 1990; Upton 1994; Shewchuk and Moodie 1998; Brozovic 2018). Part of the reason for this may be in the fact that it is multi-dimensional in nature, which can make flexibility appear differently based on the situation (TenDam 1987; Sethi and Sethi 1990; Upton 1994; Sushil 1997; Shewchuk and Moodie 1998; Sharma, Sushil, and Jain 2010). Many authors agree that flexibility is best understood in the face of uncertainty (Kumar and Kumar 1987; Mandelbaum and Buzacott 1990) or change (Slack 1987; TenDam 1987; Upton 1994; Weiss 1999; Cowan, Kaine, and Wright 2013; Brozovic 2018). In other words, the fact that conditions in the operating environment do not persist through time gives reason for the adoption of flexibility. Just as different changes may occur in the short or long-term, several authors have discussed flexibility in relationship to time as well (Slack 1987; Yilmaz and Davis 1987; Carlsson 1989; Upton 1994; Shewchuk and Moodie 1998). The flexibility can be viewed from different perspectives within a business; some authors agree that flexibility is a characteristic of management (TenDam 1987; Sanchez 1995; Sushil 1997; Yeo and Qiu 2003; Sharma, Sushil, and Jain 2010), while others view it as a feature of resources (Slack 1987; Sanchez 1995; ElMaraghy 2006; Cowan, Kaine, and Wright 2013) in the business. Various attempts have been made to measure flexibility in one aspect or another

(Aaker and Mascarenhas 1984; Mandelbaum and Buzacott 1990; Sethi and Sethi 1990; Upton 1994; Chryssolouris 1996; Shewchuk and Moodie 1998) and a few authors have sought to place a value on flexibility (de Neufville, Scholtes, and Wang 2006; Mintah, K., Higgins, D. and Callanan 2018; Simmons 2019). The importance of flexibility for handling uncertainty in the operating environment has been stressed numerous times. Due to the high level of uncertainty which affects agriculture, flexibility has the potential to be highly valuable for businesses in the agricultural sector. The relative lack of attempts made to define, measure, and value flexibility as a risk management strategy in agricultural systems offers plentiful opportunities for current research to advance in this area.

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Figures

Figure 1.0 Costs associated with a flexible firm (A) and an inflexible firm (B) as portrayed by Carlsson (1989).

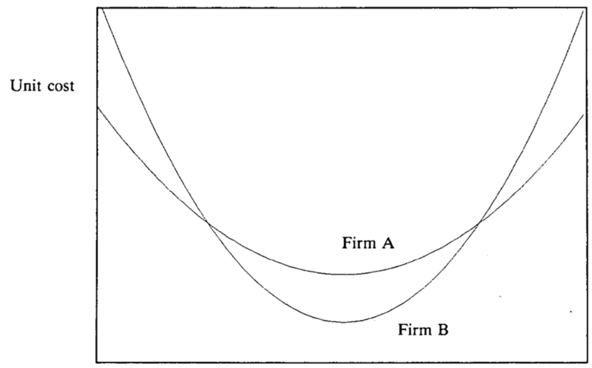


Fig. 1

Figure 1.1 Time, effort, and commitment associated with different levels of flexibility as described by Upton (1994).

Figure 3. Operational-Tactical-Strategic Flexibility

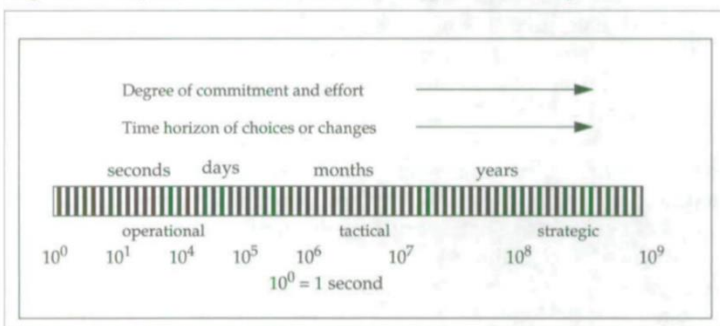


Figure 1.2 The hierarchy of business plans and goals as proposed by Cowan, Kaine, and Wright (2013).

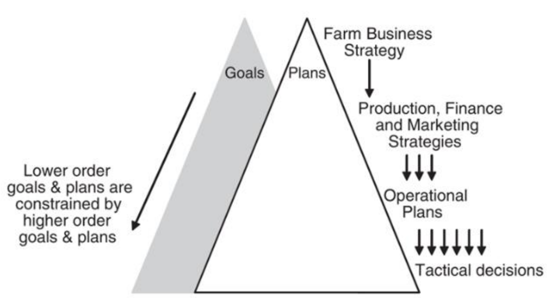
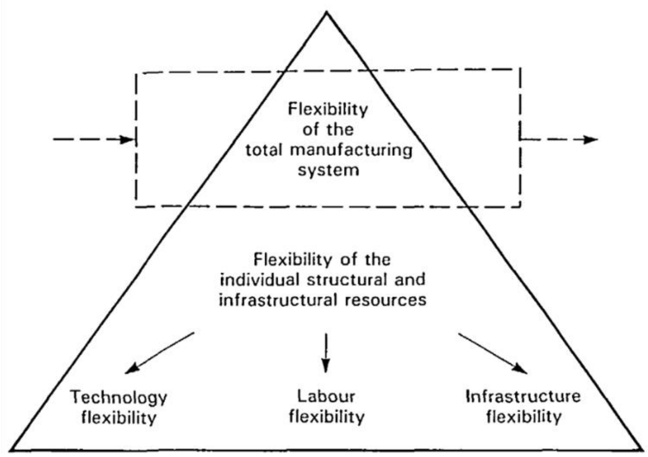


Figure 1 Example of the hierarchy of plans and goals in a farm business

Figure 1.3 Hierarchy of flexibility as illustrated by Slack (1987).

Figure 1.



Chapter 2: Flexibility as a Risk Management Tool for Agricultural Systems

Introduction

Flexibility is one of the most frequently used and least defined concepts in agriculture. Almost without exception, it is mentioned as a desirable attribute of the business, system, or decision-making outcomes. Kumar and Kumar (1987) mentioned over 30 years ago that flexibility was not well understood. Unfortunately, ambiguity persists in the discussion of flexibility in general, but notably in the agricultural sector. With the exception of a few authors (Weiss 1999; Cowan, Kaine, and Wright 2013), little has been done to define flexibility in agriculture, although others have written about it with more or less generality (Torell, Murugan, and Ramirez 2010; Kachergis et al. 2014; Simmons 2019). Without a clear understanding of what contributes to or limits flexibility in agriculture, it is difficult to assess if one system or decision provides more flexibility than another, or if flexibility would be desirable in different situations. Several authors have associated flexibility with increased costs (Stigler 1939; Aaker and Mascarenhas 1984; Carlsson 1989; Sushil 2001; Kulatilaka and Trigeorgis 2001; de Neufville, Scholtes, and Wang 2006), which might introduce financial uncertainty to an agricultural business already operating on small margins. Measuring flexibility is a task attempted by only a few authors (Aaker and Mascarenhas 1984; Mandelbaum and Buzacott 1990; Chryssolouris 1996; Shewchuk and Moodie 1998) because of its intimidating nature. Several attempts have been made to assign a value to flexibility in specific cases (Bengtsson and Olhager 2002; de Neufville, Scholtes, and Wang 2006; Mintah, K., Higgins, D. and Callanan 2018; Simmons 2019), largely through the use of a real options framework described by Black and Scholes (1973) and Margrabe (1978), and the economic modelling performed by von Ungern-Sternberg (1990). However, attempts to value flexibility in a production agricultural setting has been limited to an enterprise switch examined by Simmons (2019). The three-fold objective of this research is to define, measure, and value flexibility as it functions as a risk management strategy for an agricultural system.

Defining Flexibility

Flexibility is a concept that has appeared in peer-reviewed literature for at least 80 years. One of the first authors to discuss flexibility in economics was George Stigler (1939), who approached this topic through an examination of short-run cost curves. His work focused on the flexibility to adjust output quantities ranging from below to above some optimum. Authors have furthered the discussion of flexibility, either in general (Slack 1987; Upton 1994), or in more specific contexts (Carlsson 1989; Sethi and Sethi 1990; Shewchuk and Moodie 1998). Several authors have acknowledged that flexibility is multi-dimensional in nature (Upton 1994; Shewchuk and Moodie 1998; Sharma, Sushil, and Jain 2010), making it difficult to define. Flexibility is usually always discussed with regard to a change (Slack 1987; TenDam 1987; Upton 1994; Weiss 1999; Cowan, Kaine, and Wright 2013) or uncertainty (Kumar and Kumar 1987; Mandelbaum and Buzacott 1990) of some kind. The importance of this feature will be discussed later.

One of the simplest definitions of flexibility was offered by Nigel Slack (1987), who stated “flexibility is about the ability to change.” The definition written later by David Upton (1994) describes flexibility as “the ability to change or react with little penalty in time, effort, cost or performance”. This latter definition encompasses both the proactive (creating change) and reactive (reacting to change) perspectives of flexibility in management also discussed by De Treville, Bendahan, and Vanderhaeghe (2007), Sharma, Sushil, and Jain (2010), and Brozovic (2018). The penalty imposed by flexibility has been presented either as an indirect cost attributable to lower efficiencies (Stigler 1939; Aaker and Mascarenhas 1984; Carlsson 1989; De Treville, Bendahan, and Vanderhaeghe 2007) or a cost imposed by making the switch from one option to another (Sethi and Sethi 1990; Sanchez 1995; Kulatilaka and Trigeorgis 2001; de Neufville, Scholtes, and Wang 2006; Cowan, Kaine, and Wright 2013). For this analysis, flexibility will generally be defined as the ability to switch, acknowledging as Upton (1994) did, that a "switch" may include either a proactive or reactive effort, and that greater flexibility is associated with a lower penalty in time, cost, effort, or performance associated with the switch. Therefore, the formal definition proposed for flexibility can be stated as:

"Flexibility is the ability to switch without incurring large penalties of time, cost, effort or performance."

It should be understood that this definition provides a general guide to understanding what flexibility is. However, it lacks an inherent specificity that is often crucial for understanding what flexibility refers to and how it is helpful. To further define specific flexibilities, it would be helpful to follow the suggestion of Upton (1994) and answer the questions, "what exactly is changing?" or "what is being switched?" The reason a switch is valuable is another topic which will be addressed later.

Specification of Flexibility for Agriculture

Although a general definition can be helpful for formulating a general understanding of flexibility, it does not provide enough context for managing a specific type of flexibility. Since an intentional approach is recommended to gain a competitive advantage from an investment in flexibility (Slack 1987), managers should understand that a diversity of flexibilities exist to mitigate different uncertainties.

Following Upton's (1994) framework for defining the nature of flexibility, the dimension, time horizon, and elements must be identified to appropriately classify the flexibility in question (Table 2.0). Identification of the *dimension* of flexibility is the most critical step for establishing the context and application of a specific flexibility. Some dimensions relevant to agriculture might include the marketing window for a commodity, weather or climatic factors that affect production, or the availability of a critical input. *Time horizons* will vary based on the dimension chosen. In some cases, changes or adaptations might occur on a frequent basis, such as adjustments to the day-to-day operations schedule, while others may occur with less frequently, such as the annual crop rotation and planting decisions. While the business might not have much discretion regarding the frequency of changes that occur in the operating environment, proactive efforts to change the conditions affecting the business are under the control of managers. It is important to bear in mind that uncertainties can be imposed on the business very quickly relative to the time required for the business to make the adjustment, and vice-versa. Fires, flooding, or other natural disasters would be an example of this type of change. On the other hand, financing the purchase of an asset with outside capital can impose financial obligations and uncertainty for several years at the least, even though the financing can be obtained in a matter of days. Again, much effort might be spent mitigating the impact of price risk by researching and executing a marketing decision that ultimately takes very little time to implement. The *mobility* element of agricultural flexibility will vary based on the business and dimension of interest. The time, cost, or effort involved with making a change or adjustment may rightly be called “switching costs” as discussed in the literature (Kulatilaka and Trigeorgis 2001; de Neufville, Scholtes, and Wang 2006; Cowan, Kaine, and Wright 2013) even though a direct financial cost may not always be involved. It is relatively easy to switch or re-program the irrigation schedule of a center pivot, but the decision to apply a dry fertilizer instead of a hydrated form may have a higher cost associated with it—either due to a higher price per pound of nutrient or because it requires the purchase or leasing of different application equipment.

Importance of Flexibility

Why is flexibility so important? TenDam (1987) acknowledges that flexibility has no meaning unless its purpose is properly understood. He suggests that “it is about survival and success within changing environments” (TenDam 1987). Similarly, Sethi and Sethi (1990) agree that marketing and volume flexibility are key for business survival. Sharma, Sushil, and Jain (2010) relate that internal flexibility is based on the relationship of the organization and the environment which assumes adaptation is necessary for survival. Kachergis et al. (2014) discuss how flexibility can help ranchers manage uncertainties arising from drought such as production risk and market risk. Aaker and Mascarenhas (1984) suggested flexibility as an effective alternative to traditional management approaches which were apparently inadequate for dealing with the uncertainty of multiple threats and opportunities presented by the operating environment. Beyond the basic provision made for business survival, some authors propose flexibility as a source of firm competitiveness (Carlsson 1989; Gerwin 1993; Upton 1994; Sanchez 1995; Sharma, Sushil, and Jain 2010) or enhanced financial performance (Brozovic 2018). Specifically, Gerwin (1993) noted that a competitive advantage can be realized when the business has potential flexibility in excess of the need for flexibility. Gerwin (1993) further proposed that a business could use flexibility to actively create uncertainty in the operating environment which causes difficulties for competitors. Whether flexibility is used as a means of survival or as a catalyst for growth, the ability to successfully navigate amidst uncertainty seems to be the main reason for such importance being placed on flexibility.

There seems to be an implicit assumption in the discussion of flexibility that a change or uncertainty in the operating environment can affect the business to a large enough degree that it can no longer continue in its former state. Some aspect of the operation—production volume, product quality, profitability, efficiency, etc.—is significantly impacted by exogenous or endogenous influence. Aaker and Mascarenhas (1984) refer to this when describing flexibility as an organization's response to changes that have a "meaningful impact". Clearly then, not just *any* change will be sufficient cause for a business to switch, that is, to have or utilize flexibility. In the case that a business is faced with a *relevant* change or uncertainty, two options exist: the business can choose to respond or not. However, there is a cost associated with either choice, as discussed by Sushil (2001). In the former situation, there may be switching costs associated with changing the business to better fit the circumstances, while the latter case may involve a cost from not optimizing for novel conditions and thereby operating at a loss. Aaker and Mascarenhas (1984) suggest a cost-benefit analysis for evaluating a flexible option. The cost-minimizing business would obviously seek to the lesser of the two costs if possible. Relative costs and benefits differ in each scenario; a smaller cost is preferable if a larger cost may be avoided, just as a larger benefit is preferred to a smaller benefit, *ceteris paribus*. However, an immediate switch is not necessarily always best. Kulatilaka and Trigeorgis (2001) state that consideration of future outcomes and non-symmetric switching costs introduces the possibility of hysteresis, which might make waiting to switch more attractive for the business. In other words, if conditions are fairly volatile, the long-term outcome of repeated optimization (switching) may result in higher costs than choosing not to switch or switching less frequently. A partial budget may be a useful tool in comparing the costs and benefits associated with flexibility alternatives. Flexibility can be valuable for a business if it effectively minimizes the costs arising from risk or uncertainty in the operating environment.

Flexibility, or the ability to switch without great penalty, is useful when changing conditions in the business environment prevent a chosen course of action from attaining the original desired outcome. Flexibility loses all meaning in the absence of uncertainty or when the decision maker has access to complete information. Switching to something "better" is irrational for such cases, since it can be assumed that the decision maker has already chosen the best alternative for that particular set of circumstances. It is critical to understand that flexibility facilitates a beneficial response in the face of change, while the target or goal remains unchanged. In other words, flexibility is less about accepting the burden of circumstances in a spirit of ‘getting by’ and more about choosing and creating alternatives that make ‘getting across the finish line’ a reality. To summarize, flexibility is important for businesses to successfully continue operating or capture value despite the uncertainties faced by the business.

Isolating Flexibility as a Risk Management Tool

Uncertainty creates challenges for any business, whether the uncertainty originates from within the organization or from without. Agricultural businesses frequently deal with five primary types of risk: 1) Production or technical risk, 2) Price and market risk, 3) Financial risk, 4) Legal or institutional risk, and 5) Human or personal risk (Kay, Edwards, and Duffy 2012; Hewlett et al. 2019). A business faces risk in a situation when possible outcomes and their probabilities of occurrence are known, while uncertainty arises from a situation where the potential outcomes and their probabilities are not known (Kay, Edwards, and Duffy 2012). Risk is often understood as the possibility of a negative outcome occurring, but risk also includes the possibility of a positive or neutral outcome as well (Hewlett et al. 2019). Risk management usually seeks to diminish the variability surrounding a desired outcome. Reducing the volatility of an outcome can also be understood as increasing the certainty of a result. For example, a farm or ranch may make efforts to increase the certainty of reaching a desired level of annual revenue by mitigating factors that cause revenue to fluctuate. Usually, risk management does not eliminate variability entirely, it simply diminishes variability to a more reasonable level. Four strategies have been suggested for managing risk, and three ways have been suggested for controlling the impact of risk on an organization (Hewlett et al. 2019):

1. Avoid the risk
2. Transfer the risk
3. Control the risk
    i. Control Probability
    ii. Control Impact
        1. Increase Reserves
        2. Maintain Flexibility
        3. Diversification
4. Accept the risk

Maintaining extra resource reserves, flexibility, and diversification are three distinct tools available to managers for managing the impact of risk on the business as seen in Figure 2.0. While a true separation does exist between these strategies, in reality, they can be complimentary and often witnessed at work together in a business. Diversification among enterprises can provide the opportunity to practice flexibility but is not mandatory for a flexible organization. A diversified business participating in multiple enterprises may operate with absolute rigidity, demonstrating no response to changes in the operating environment. A flexible business may be non-diversified and not utilize any reserve capacity without losing the freedom to switch and thus maintain operations despite uncertainty. Although extra resources exist in an organization, they may be of the type that is inflexible, or have a single purpose (i.e., extra forklifts cannot be used as commuting vehicles and vice-versa). On the other hand, the presence or absence of extra resources can directly affect the flexibility of the firm, provided they are of the correct type. Though these are three distinct strategies, increasing reserves, maintaining flexibility, and diversification may be used individually or collectively to manage the impact of risk for the business. Each of these risk impact mitigation strategies will now be discussed in further detail.

a. Diversification

Diversification of revenue sources is a common risk control measure used by agricultural businesses. This strategy usually involves a business managing income variation through the production of multiple commodities, provided that revenues from the commodity enterprises are non-correlated or negatively correlated (Kay, Edwards, and Duffy 2012). If conditions decline, one of multiple enterprises will generally help keep the organization afloat. On the other hand, improving conditions may not benefit every enterprise but will generally improve the performance of at least one enterprise within the organization. Supplemental income from outside the operation can also lead to revenue stabilization (Mcnamara and Weiss 2001; Kay, Edwards, and Duffy 2012). Mcnamara and Weiss (2001) conducted an empirical analysis of Austrian farms and noted an increase in off-farm employment participation from 1980 to 1990, mostly due to farm income variability. Although the distinction between flexibility and diversification may seem faint, there is a true separation of these two strategies. Diversification usually involves mutually inclusive decisions, such as the purchase of multiple non-correlated stocks, operating two different enterprises out of one business, or offering a variety of product types. Flexibility on the other hand, is characterized by a mutually exclusive decision, such as the sale of one stock to purchase a different stock or retracting resources from one enterprise to employ in a different enterprise. Flexibility operates as ‘either-or’, while diversification fundamentally involves ‘both-and’. Diversification usually only affects the output side of the production equation, but managers may choose to diversify on the input side as well. Examples might include a consistent strategy to purchase from multiple suppliers or using multiple types of an input. A diversified organization typically manages more than one enterprise or creates more than one product/service. Regardless of the level of diversification in place, flexibility in a business implies ability to switch modes of operation. Hence, the company that has a diversified portfolio of outputs without the ability to switch would be correctly called diversified, but lacking flexibility. On the other hand, Aaker and Mascarenhas (1984) listed diversification as a means to increase flexibility. Diversification can mitigate the impact of risk for a business even where flexibility is not present.

b. Flexibility

Flexibility can be used to control the impact of risk for a business since the ability to switch permits optimization in the face of uncertainty. This approach can be understood as the ability to create change or react to change in the operating environment, as described previously (Upton 1994). Gerwin (1993) stated that flexibility “has a proactive function in creating uncertainties that competitors can not deal with.” The key to flexibility is that the business can continue pursuing the same or similar objectives despite needing to use different means than initially planned. It is this quality that also differentiates flexibility from the other strategies to mitigate the impact of risk on a business mentioned above. A business can be flexible even in the absence of resource reserves or diversification, though these are often complimentary strategies. Flexibility has been discussed in the context of project planning (de Neufville, Scholtes, and Wang 2006; Mintah, K., Higgins, D. and Callanan 2018), where weights or probabilities are typically used to estimate risk, i.e., the likelihood of an outcome or set of outcomes. By utilizing a flexible management strategy, a manager may be able to influence the probabilities surrounding a set of outcomes and thus achieve their objectives with greater frequency. Yeo and Qiu (2003) and Trigeorgis (2005) agree that flexibility can result in a re-distribution of expected returns from a project, skewing the results in favor of the project manager (Figure 2.1). Hewlett et al. (2019) describe a similar outcome from utilizing insurance to manage risk, except that insurance only protects against negative outcomes or downside risk, while flexibility permits a manager to achieve better-than-expected outcomes from positive opportunities while avoiding the losses that would occur from continuing to pursue an unprofitable project (Trigeorgis 2005). Furthermore, Trigeorgis (2005) proposes that the NPV equation traditionally used for project valuation should be expanded to account for managerial flexibility as follows:

Expanded (or Strategic) NPV = passive NPV + Option Premium (ROV).

where the option premium is the potential value captured by having flexibility. General-purpose resources were recommended by Aaker and Mascarenhas (1984) to mitigate risk and increase flexibility in the face of uncertainty. Although specialized resources offer better performance and can be obtained at a lower cost, Aaker and Mascarenhas (1984) proposed that commitment to specialized assets was usually associated with greater risks for the business because of heightened exit barriers. Sushil (2017) proposes that a business can mitigate risk if the proper flexibility is pursued, but may incur greater costs and risks if flexibility is unguided. In general, authors agree that the flexibility provides a business with risk protection, especially in an uncertain operating environment.

c. Resource Reserves

Building up extra resource reserves can control the impact of risk and benefit an organization if a shortage occurs due to uncertainty in the operating environment. This situation is commonly referred to as “down-side” risk. Maintaining extra resources can be considered a type of insurance policy. When operating conditions are moderate to good, these resources often sit idle since they are superfluous to the operational needs of the business. However, if a shortage occurs due to factors inside or outside the business, the otherwise unused resources can help the business continue operation without suffering great losses. Although a cost is incurred for years where extra resources are not used, managers might determine that the cost of preserving the organization’s operational status is sufficient justification for investing in extra capacity or resources (Kay, Edwards, and Duffy 2012). Managers may choose to keep additional input or output resources on hand. Input resources may include financial capital, physical assets, or additional laborers. Keeping inventory on hand is an example of resource reserves that may be on the input or output side of the business. Having extra resources on hand does not necessarily provide flexibility, however. The ability to switch resource use in some way to meet a pre-determined objective can only be accomplished when the resources held in reserve are multi-purpose. If the resource reserves are single-purpose or have a very dedicated use, then there is no flexibility to alter resource use; there is only a decision to use or not use the resources. Flexibility might imply a wholesale shift of resources away from one enterprise or activity to another, or it may lead to a less drastic reallocation of resources to optimize for the situation at hand. Maintaining resource reserves is a tool for controlling the impact of risk but is distinct from flexibility when analyzed by itself.

Controlling the Impact of Risk in Practice

The separation of flexibility from diversification and resource reserves is a challenge. As shown in Figure 2.0, these risk management strategies can and do overlap while remaining distinct from each other. Knowledge of this possibility can be helpful for understanding which strategies may be already at work in the business and which might be helpful to incorporate. Each of these three ways to control the impact of risk will be described in practice, both in isolation and in combination with one or both of the other controls.

I. *Resource reserves without flexibility or diversification:*

✓ Resource Reserves O Flexibility O Diversification

A mountain ranch grows and harvests high-quality grass hay for horse owners that live in town. Each summer, the weather patterns in the valley cause ideal harvesting windows to be brief and sporadic. The ranch only produces small square bales, since these are the most liquid and profitable package. However, this also means that baling takes longer than other harvesting alternatives. Since the baling activity seems to be associated with the highest risk, the ranch owner purchased a secondary baler to keep on hand. In the case of a breakdown on the primary baler, the secondary unit can be used to avoid costly downtime and a missed opportunity of good harvesting weather. Since the ranch employs a small crew, there is rarely ever the opportunity to operate both balers at once.

The extra baling equipment on hand mitigates the impact of production risks associated with a breakdown during critical times. In a similar way, a high-value crop farmer may keep extra sprinkler heads on hand to maintain a highly consistent irrigation pattern, and thereby avoid reductions in yield, or a specialized livestock operation may keep extra feed on hand in the case of a bad winter or as a hedge against high prices. A mining operation may keep extra tires for a critical piece of equipment to reduce the downtime (impact) associated with changing a flat. In each of these cases, the reserve of extra equipment or resources cannot be transferred to another alternative use, rather it simply acts as a type of insurance policy against a failure in the production process.

II. *Flexibility without resource reserves or diversification:*

O Resource Reserves ✓ Flexibility O Diversification

A custom backgrounding operation contracts with local ranchers to feed calves from weaning until placement in a feedlot. This is a specialized business structure, proven to be highly profitable, but leaves no opportunities for enterprise diversification. Production risk associated with sickness and death is transferred out of the backgrounding operation because the ownership of cattle is retained by the original owner through the feeding period. The backgrounding operation is constrained on output quantity based on the infrastructure in place. However, it is usually most profitable to operate near maximum capacity. The backgrounder develops a ration for each batch of calves to meet a certain rate of gain desired by the owner. Usually, the backgrounder has the flexibility to choose between two general diet classifications, a high-quality grass/hay-based diet or one with low quality hay and a supplement. In an attempt to minimize cost, the backgrounder chooses the ration based on the prices and availability of feedstuffs immediately prior to receiving the calves. After the feed is obtained, an appropriate fee can be established for the feeding period. The delivery of the cattle is scheduled so that most or all of the feed purchased for a particular batch of calves is fed before they leave the operation.

The strategy implemented by this custom backgrounding yard seeks to mitigate the impact of market risk by the fact that revenues always follow the trends of feed prices, and the backgrounder is allowed to choose the best ration for every set of calves. The backgrounding operation uses flexibility to switch feed inputs to respond to variations in customer requirements, feed availability, and market prices. For example, although pasture might generally be a cheaper source of roughage for the calves, finding cheap pasture outside of the growing season may be infeasible. The owner of an orchard may exhibit flexibility in his choice to apply manure from a local feedlot or anhydrous ammonia from the nearest co-op depending on prevailing prices and availability. Similar flexibility can be observed in a power plant that has the flexibility of burning two different fuels sources to keep costs to a minimum (Kulatilaka 1993). In all of these cases, the ability to switch from using one input to another provides flexibility and protection from risk.

III. *Diversification without resource reserves or flexibility:*

O Resource Reserves O Flexibility ✓ Diversification

A diversified farmer earns revenue by participating in multiple crop markets. After many years of observation and experience, he has decided to always plant 50% of his acres in one crop and 50% of his acres in a different crop, regardless of climate forecast, market conditions, or plant performance. He understands that market prices for both crops grown on the farm fluctuate every year due to the level of domestic supply and foreign trade policy. Market prices for both crops tend to move in opposite directions, but sometimes they follow a similar trend and move up or down together. It seemed that as soon as he began to specialize in growing more of one crop or the other, the markets swing the opposite direction. Instead of trying to “beat the market” he has decided to use a consistent diversification strategy and put equal emphasis on both crops without adjusting the level of production each year.

Diversified farming operations commonly participate in multiple non-correlated or negatively correlated enterprises so that the upturns in one output market can offset the downturns in the other. This strategy is effective for limiting the impact of market risk on the operation. Further, a custom harvesting business might diversify enterprises by offering harvest services for multiple crop types such as winter wheat, alfalfa hay, and corn to increase workload consistency throughout the year. A similar situation can be seen in a large pharmaceutical company that dedicates production efforts towards two or more types of medicine that have non-correlated sales patterns. The strategy of diversification implies a continuity in holding multiple options over time. It follows that a diversified operation is also not specialized. Depending on the enterprises, resources might not be transferrable between them (i.e., a cereal grain thresher may not be used to harvest corn). Despite these and other implications associated with diversification, the use of a consistent strategy can help reduce the impact of risk for the business.

IV. *Flexible resource reserves without diversification:*

✓ Resource Reserves ✓ Flexibility O Diversification

A farm/ranch operating partly on owner equity and partly on borrowed capital keeps a reserve of cash to help maintain business liquidity. If the operation does not perform well in a given year, the extra liquidity offers some flexibility in meeting cash-flow requirements. Cash reserves can be used for a variety of needs such as paying wages to part-time laborers, servicing debt obligations, purchasing supplies, or other moderate-sized purchases. Cash reserves incur an opportunity cost for every dollar that is not earning interest (as in a bank), which can represent a moderate fee depending on prevailing interest rates. The relative size of the cash reserve will create more or less flexibility to meet cash-flow challenges. A cash reserve that is small relative to the cash flow requirement would offer little flexibility, but also incur a low opportunity cost. The opposite case would be where the cash reserve is large relative to the deficiency of cash flow in all periods, and this would create surplus flexibility and come at a higher opportunity cost.

A pizza shop hires additional team members to work the evening shift, which is usually the busiest time of the day. If the shop is understaffed and gets too busy, the manager struggles to balance serving the needs of customers in-house and those requesting delivery, in part because his attention is divided between multiple fronts. Even though the volume of foot traffic or deliveries fluctuates with each day of the week, the extra evening shift workforce is employed all week long. The additional employees are not required for operating the shop all the time, but the manager finds that the cost of hiring extra workers is worthwhile, since it keeps more customers happy and returning when they have shorter wait times. The extra “evening shift” employees are trained to be flexible and fill multiple roles such as delivery, cooking, washing dishes, or waiting tables as needed. The shift manager is able to retain a more wholistic perspective and switch team members to the roles where they are needed most. The higher level of cross-training allows the shop to run smoothly without creating a superfluous workforce in one department. Although small, the extra workforce can readily assist wherever needed, and reduce the average wait time for customers during the busiest time of the day.

The pizza shop can control the impact of human risk and market risk through the employment of additional highly trained workers. If part of the team is absent for some reason, the additional cross-trained labor force is able to fill the gap and maintain operations. Market risk arising from uncertainty in customer demand can also be mitigated by a well-trained flexible workforce since they are able to assist with multiple departments that might fall behind. Maintaining an extra supply of cash can be used to mitigate the impact of financial risk most notably. One advantage of this risk management strategy lies in the flexibility of cash—it is a highly liquid and non-specialized resource, so it has many uses. Another common example would be the use of on-farm storage facilities for grain that provide the flexibility to market when conditions are more favorable (Kay, Edwards, and Duffy 2012). These cases illustrate how superfluous resources may be kept on hand to help mitigate uncertainty for a business.

V. *Flexible diversification without resource reserves:*

O Resource Reserves ✓ Flexibility ✓ Diversification

A lumber mill buys raw timber and produces dimensional lumber for sale at numerous outlets around the nation. The conversion process requires whole logs to be sawn and planed to various widths and thicknesses. Sawdust and wood shavings are biproducts of these processes, which in turn become inputs for further processing to manufacture wood pellets for stoves or marketed as pet and livestock bedding. The diversification strategy used by the lumber mill includes complementary enterprises. Participation in the wood biproduct markets requires a reliable source of wood chips, while the milling process creates voluminous amounts of wood shavings and creates a logistical challenge for management as well. Furthermore, the mill does not confine itself to a singular output in either the lumber business or the biproduct industries. Because of the vertically integrated nature of this business, the manager has the ability to switch between outputs in both the lumber and wood biproduct business units, placing an emphasis on the products with the highest prevailing prices. The lumber mill can easily and quickly respond to both positive and negative movements in all output markets because of the business structure in place.

The diversification strategy, paired with the flexibility to switch outputs, controls the impact of market risk for the lumber mill. A similar situation might be seen in a diversified farm that participates in multiple enterprises such as vegetables, fruit, and poultry with the ability to switch the application of resources among several uses. Likewise, an LCD manufacturing company with the ability to create many sizes of screens for different applications from a similar bank of resources would exhibit flexibility and diversification. If the prices and or demand for TV screens declines, the components can be reassigned for producing computer or smartphone screens, for example. In the face of uncertain output prices and product demand, the flexible and diversified business has the freedom to switch the production emphasis to manage risk and realize revenue stabilization.

VI. *Resource reserves and diversification without flexibility:*

✓ Resource Reserves O Flexibility ✓ Diversification

A small feed store carries a variety of feed, medicine, and ranch supplies. The area is remote, so the customer base is spread across a large geographical area. While the demand for some products is seasonal, others are demanded with high regularity throughout the year. Customers have learned to rely on the store for most of the products it offers since there are no similar stores in the area. However, the store owner has learned that one stockout could result in the loss of a potential repeat customer, who provide most of the business for the store. Therefore, the owner is careful to maintain a reasonable inventory of all the products in the store. The use of extra resource reserves in the form of inventory has proven to be a good management plan to mitigate the impact of market risk for the feed store. Additionally, the store owner has diversified the revenue of his business by offering a wide variety of feed and supplies for the owners of pets and livestock alike. The risk management strategy involves the maintenance of a diversified reserve of inventory to mitigate the risk of lost sales.

It may be uncommon to see diversified resource reserves without flexibility, but these are generally cases where the extra resources are single purpose and cannot be used across multiple enterprises. In the case of the feed store, product inventory serves as a hedge against a shortage of one product only (i.e., inventory of dog food cannot be sold in the place of cattle mineral in the incident of a stockout). Another example might include a diversified operation growing cattle and crops that maintains an extra reserve of hay. Since the hay cannot be used in the cropping enterprise, the cattle enterprise alone benefits from the extra hay inventory. A diversified automotive repair company may employ extra part-time laborers in multiple divisions, but the high level of expertise required for various jobs does not permit the shifting of laborers between divisions. At least in the short-run, technicians who specialize in engine work would not be able help out in the upholstery division without training. Resource reserves and diversification are both valid strategies to manage the impact of risk, and these can operate somewhat independently in a business without the flexibility to switch resource use towards alternative outputs.

VII. *Flexibility with resource reserves and diversification:*

✓ Resource Reserves ✓ Flexibility ✓ Diversification

A diversified farm employs the strategy to plant wheat, corn, and soybeans in a three-year rotation. The farm averages an even split (33% of each crop) over the long term, but actual planted acres will fluctuate each year based on weather and market forecasts. Each crop benefits from at least one application of fertilizer during the growing period. Fertilizer is applied at least once, with other applications following as needed. A field never receives more than three applications per season. At the beginning of the year, the farm always purchases enough for the maximum number of applications (3x/field), even though it rarely gets used. The owner has learned that fertilizer is usually in short supply mid-season when another application is needed, and by the time fertilizer is available, the application is generally too late. Any unused fertilizer is stored and used the following season. The farm strategy mitigates the impact of production risk and market risk through diversification of crops, maintaining the flexibility to optimize profit based on weather and market conditions, and maintaining an extra supply of a critical input to ensure optimal performance of the chosen crop.

A feedlot purchases batches of cattle year-round to fatten for marketing directly to meat packing plants. The ration fed to most of the cattle is comprised of grain and forage to encourage rapid weight gain. The feedlot seeks to maximize profit primarily by purchasing cheap cattle and utilizing a low cost-of-gain ration. The feedlot sources ration components from a variety of suppliers. The owners recognize the value of this practice since the availability and price of a particular feedstuff fluctuates seasonally. Furthermore, it is common practice for the feedlot to keep extra feedstuffs on hand. The management strategy of the feedlot mitigates the impact of market risk on critical inputs (feed) through the use of diversification, flexibility, and extra capacity. First, the network of multiple feed suppliers permits the feedlot to consistently source feedstuffs for the cattle, with the flexibility to switch suppliers based on availability and prevailing price. If one supplier is out of feed, an alternative supplier can usually be found in the area. Second, the feedlot's storage capacity allows excess feed to be kept on-hand in the case of a brief supply shortage or as a short-term buffer while negotiations take place.

It is not unusual to observe the simultaneous utilization of extra resources, flexibility, and diversification to manage the impact of risk on a business. In the case of the diversified farm, the owners have the ability to easily switch the emphasis of production to alternative enterprises that can utilize a resource that is held in excess of need. Labor or management hours in excess of need is an example of a resource that might be flexibly applied to multiple enterprises. A cow-calf operation might become diversified by marketing replacement heifers or yearlings in addition to weaned calves. Flexibility to switch the emphasis placed on these various enterprises can be enabled through the use of pasture or hay, a resource which is commonly held in excess of need by cattle operations. Another example might be an automobile company that manufactures multiple types of cars that require some of the same parts. When an extra reserve of parts is kept on hand for use in all car types, the business is able to easily switch the production emphasis as market conditions dictate. The combined use of all three strategies to manage the impact of risk on the business can be quite beneficial due their complementary nature. This situation is common in practice, sometimes making it difficult to distinguish the benefit of one strategy over another.

Based on the given examples, each of the three ways to control the impact of risk as introduced above can be utilized exclusively or in combination for the business. The scale of Figure 2.0 is slightly misleading—implying that these three strategies occur in greater frequency in isolation than in combination—but this is likely not the case. It is more probable that the regions of overlap will be a larger proportion of the area than those of isolation, but this makes for a less neat diagram. A manager seeking to manage risk may mistakenly believe that the simultaneous use of all three strategies (arrival at the center of Figure 2.0) will provide the maximum risk protection—this concept is incorrect. Kumar and Kumar (1987) discuss how uncertainty can affect the inputs, outputs, the production process, or the operating environment. It is relevant, therefore, to note how diversification, flexibility, or extra reserves may be sought on either the input side, output side, both, or neither. Authors have cautioned against the constant pursuit of more flexibility because it either causes instability (TenDam 1987; Sushil 1997), increases costs (Aaker and Mascarenhas 1984; Sushil 2001), or introduces risk to the business (Sushil 2017). It is also well accepted that flexibilities can interact within a business in a positive or negative way, resulting in antagonistic and/or complementary interactions (Aaker and Mascarenhas 1984; Slack 1987; Carlsson 1989; Weiss 1999; Cowan, Kaine, and Wright 2013). De Treville, Bendahan, and Vanderhaeghe (2007) advise that an effort to increase flexibility should be informed by scanning and interpreting the environment, finding volatility that may be exploited, and emphasizing process consistency. Addressing the impact of a particular uncertainty or risk is important so that efforts to manage *any* risk do not become superfluous and hinder business operations.

Further Considerations for Risk Management

It is also worthwhile to realize that increasing the flexibility of the business may not always be best. Several authors have noted that excessive amounts of demonstrated flexibility can lead to over-responsiveness and have a negative impact on business performance (TenDam 1987; Sushil 1997; Brozovic 2018). Positive and negative interactions among different types of flexibility have also been acknowledged by writers, which adds complexity to the consideration for more flexibility (Aaker and Mascarenhas 1984; Slack 1987; Carlsson 1989; Weiss 1999; Cowan, Kaine, and Wright 2013). Lastly, since flexibility is only one of three ways suggested by Hewlett et al. (2019) to control the impact of risk for a business, it should not be automatically assumed that more flexibility will lead to greater risk protection. Therefore, business managers seeking to mitigate the impact of risk should be informed by the risk(s) which are relevant, the degree of impact that a particular risk has on the business, and the relative suitability of using flexibility over one of the other strategies mentioned to manage the risk effectively.

To illustrate further, consider a farm that maintains flexibility to switch crop types each year in order to maximize revenue but may lack flexibility to deal with the uncertainty of equipment breakdowns. The farm manager may seek to mitigate the impact of unreliable equipment, especially if it poses a greater threat to reaching the targeted level of farm revenue than the choice of crop. Rather than increasing the flexibility of the farm to manage this risk, it might be prudent to invest in extra machinery capacity or to diversify the sources of replacement parts. The cost and efficacy of other strategies should be evaluated to determine if they mitigate the impact of risk more effectively than the use of flexibility.

Measuring Flexibility in Agriculture

Acknowledging that various types of flexibility can exist in an agricultural business helps explain how flexibility, though present, might be ineffective for the risk or uncertainty causing the greatest concern. After the appropriate flexibility and the change or risk it is intended to address are defined, one may wish to know how much flexibility is needed and, perhaps more importantly, how much is already possessed by the business. Gerwin (1993) notes that management should evaluate the potential, actual, and needed amounts of flexibility for each dimension to identify discrepancies between each. Upton (1994) also related that previous authors have discussed flexibility as either a potential or a demonstrated quality of a business. For example, a ranch may possess the potential to mitigate drought impacts through flexibility, but experience indicates little flexibility has been demonstrated in this area since the drought plan has rarely been followed or that risks from drought have not had a significant impact on ranch operations. In this case, the ranch would have high potential flexibility, but low demonstrated and/or needed flexibility. These relationships might be described in equation form as follows:

$$\textit{Potential Flexibility} \geq \textit{Demonstrated Flexibility} \geq \textit{Required Flexibility}$$

The measurement of flexibility can prove challenging for an agricultural business, partially due to the intangible nature of the task and also because of the varied methods suggested for accomplishing this task. Aaker and Mascarenhas (1984) suggested using either a subjective or objective approach to measurement, selecting the most appropriate method for each dimension to be measured. One of the more straightforward ways to measure flexibility simply entails an enumeration or counting of choices available before and after a choice has been made (Kumar and Kumar 1987; Mandelbaum and Buzacott 1990; Shewchuk and Moodie 1998). Essentially, if one action results in fewer choices being available in the future, then that action would provide less flexibility. The general definition for flexibility given the above implies that there must be at least one alternative to permit the *switch* to occur. In other words, no flexibility exists when there are no alternatives from which to choose. Gerwin (1993) notes that precision is not necessary when the number of options is large and difficult to calculate. Mandelbaum and Buzacott (1990) even propose that the value of flexibility diminishes with the additional options; higher value is placed on one option among few than one option among many. Aaker and Mascarenhas (1984) suggest that a regular “flexibility audit” can help monitor the performance of the business on certain measures and remedy concerns as they arise. While flexibility can be estimated by counting alternative actions and the freedom to choose among them, no universal benchmarks are established for determining how much flexibility is “enough”. Using this metric to compare businesses can determine relative levels of flexibility, but the utility of flexibility will be largely determined by each business’ need to accommodate risk and uncertainty.

Flexibility Valuation Methods

It is generally accepted that flexibility will be more valuable in situations where uncertainty or volatility are higher (Kulatilaka 1993; Yeo and Qiu 2003; Simmons 2019). The attempt to value flexibility through the use of real options theory has been the most common and has been well-accepted by authors in this field. Similar to the theory of financial options, the theory of real options describes how an individual may enter a contract acquiring the right to buy or sell a real asset for a specified price by a specified future date, without the obligation to do so. The writer or seller of the option agrees to the terms of the contract and grants this right to the option buyer in exchange for a premium. The option to buy an asset is referred to as a “call” option, while a “put” option gives the owner the right to sell an asset. Two types of options exist: European and American. Whereas the former may be exercised only on the maturity date, the latter may be exercised at any time prior to the maturity date. Most of the real options theory with regards to flexibility is built upon the works of Black and Scholes (1973) and Margrabe (1978). Other authors have recognized von Ungern-Sternberg (1990) for his technique to find the value of flexibility, though his method does not directly correspond to the real options theory.

The work of Black and Scholes (1973) laid a foundation for the pricing of options pertaining to financial assets. The authors referred to corporate liabilities such as common stock, bonds, or warrants as “assets” in their analysis (Black and Scholes 1973). Black and Scholes (1973) noted that an option’s worth could not exceed the value of the underlying stock and cannot be less than zero (it will be non-negative). However, Black and Scholes (1973) do not exclude the possibility that an option's value might fluctuate over time, just as the value of a stock might. Black and Scholes (1973) state that the value of an option can be approximated by subtracting the price of a pure discount bond from the price of a stock with a similar maturity date if the face value is equal to the strike price of the option. Black and Scholes (1973) acknowledged the shortcomings of previous authors in attempting to value options, and proceeded to derive a new formula which, under certain assumptions, describes the value of an option as a function of the price of the stock, time, and known variables. The final valuation formula for a European call option is given by Black and Scholes (1973) as:

$$w(x,t) = xN(d_1) - ce^{r(t-t^*)}N(d_2)$$

$$d_1 = \frac{ln\frac{x}{c} + \left(r + \frac{1}{2}v^2\right)\left(t^* - t\right)}{v\sqrt{t^* - t}}$$

$$d_2 = \frac{ln\frac{x}{c} + \left(r - \frac{1}{2}v^2\right)\left(t^* - t\right)}{v\sqrt{t^* - t}}$$

Where $w(x,t)$ = the value of the option as a function of stock price (x) and time (t),

$N(d)$ = the cumulative normal density function,

c = the exercise price,

t^* = the maturity date,

t = the current date,

v^2 = the variance rate of the return on the stock, and

r = the interest rate

Black and Scholes (1973) note that the expected returns of such an option depend on the expected returns on the stock, but that the value of the option is not equivalent to the expected returns of the option. Further, the option is always more volatile than the stock. Black and Scholes (1973) slightly modified the above formula to find the valuation of European put options given as:

$$u(x,t) = -xN(-d_1) + ce^{-rt^*}N(-d_2)$$

Where $u(x,t)$ = the value of the option as a function of stock price (x) and time (t) and other variables the same as defined above. There is apparently some discrepancy as to whether a European or American option will be more or less valuable or if they are equivalent. Black and Scholes (1973) acknowledged that no formula for the value of an American put option had been identified at that time. Black and Scholes (1973) also showed that their formula could be applied to the valuation of other corporate liabilities such as warrants, bonds, and common stock. Though the Black-Scholes formula was originally used for the pricing and valuation of options on financial assets, it has proved useful for the pricing of other types of options on “real” (non-financial) assets also.

Margrabe (1978) made use of the work done by Black and Scholes (1973) and evaluated an option to exchange one asset for another. Essentially, Margrabe (1978) describes this type of option as compound—simultaneous call and put options with strike prices equal to the price of the opposite asset. The risk and return on such a hedged position is equal to zero according to Margrabe (1978). Furthermore, Margrabe (1978) proves that an equivalent American-type exchange option will be worth the same as its European counterpart with an exercise price equal to the price of an asset since the option will be worth more alive than dead prior to the expiration date, at which time the option values converge. The valuation formula given by Margrabe (1978) is replicated here:

$$w(x_1,x_2,t)=x_1N(d_1) - x_2N(d_2)$$

$$d_1=\frac{ln\,(\frac{x_1}{x_2})+\frac{1}{2}v^2\left(t^*-t\right)}{v\sqrt{t^*-t}}$$

$$d_2= d_1-v\sqrt{t^*-t}$$

$$x_2=ce^{r\left(t-t^*\right)}$$

Where $w(x,t)$ = the value of the option to exchange one asset for another as a function of stock price (x) and time (t),

$N(\cdot)$ = the cumulative normal density function,

x_1 = the price of asset one,

x_2 = the price of asset two,

c = the exercise price,

t^* = the maturity date,

t = the current date,

v^2 = the variance rate of the return on the stock, and

r = the interest rate

Margrabe (1978) theorized that the right (without obligation) to exchange an asset for another asset was a valid application of options theory, and further theorized that this concept could also be applied to other financial arrangements such as the margin account, a standby commitment, or a performance incentive fee. In conclusion, Margrabe (1978) states that the value of an option depends on the current values of the assets to be exchanged, the variance-covariance matrix for rates of return for the assets, and the life of the option.

The flexibility of a business to switch among multiple products was evaluated by von Ungern-Sternberg (1990). The focus of this work diverges from the work of Stigler (1939), who studied the flexibility of single-product firms to adjust output volume, focusing rather on the flexibility of diversified businesses to adjust manufacturing focus from good *X* to good *Y* in response to fluctuations in product demand (von Ungern-Sternberg 1990). It is understood that firms in the market can be of two types: specialized or flexible with regard to output (von Ungern-Sternberg 1990). According to von Ungern-Sternberg (1990), “A flexible firm in the X (or Y) industry can produce Y (or X) at a relatively lower marginal cost, but pays the price of having to incur higher marginal costs in the production of X (or Y).” The ability to easily switch capacity from the production of one good to another requires more sophisticated machinery and more qualified labor, both of which increase the cost of operating with such flexibility compared to without it (von Ungern-Sternberg 1990). The degree of flexibility of a particular firm was defined on a binary 0-1 scale, where zero indicated that the firm was fully specialized in the production of only good X or Y, and one implied that the firm was able to produce either good X or good Y (von Ungern-Sternberg 1990).

Further, von Ungern-Sternberg (1990) makes the following assumptions: (i) fixed costs are non-decreasing in the degree of flexibility, (ii) marginal production costs of X are a convex increasing function of the degree of flexibility, and so (iii) a firm in the X industry will always have to pay more to produce Y instead of X and (iv) the marginal cost of producing Y is a convex decreasing function of the degree of flexibility. von Ungern-Sternberg (1990) also points out that without fluctuating demand, all firms will specialize in the production of one good (obey cost minimization), and fluctuations in the demand for either good will never be large enough to cause firms to completely shift production capacity to the other good (firms will always produce some of both goods). Based on his analysis and a numeric example, von Ungern-Sternberg (1990) concludes that market equilibrium will usually be characterized by some firms choosing to be specialized and non-flexible while at least a few firms will choose to be flexible. Although he disagrees with Mills and Schumann (1985), von Ungern-Sternberg (1990) states that stability will be associated with flexibility and not the opposite.

Dixit and Pindyck (1994) illustrated a real options approach for evaluating investment decisions in an attempt to acquire a more comprehensive understanding of market dynamics not captured in the standard net present value methodology. One notable shortcoming of the NPV approach was that irreversible investments are often considered to be “now or never” decisions (Dixit and Pindyck 1994). Challenging this paradigm, Dixit and Pindyck (1994) propose real options analysis as a method to more completely understand the implications of investment decisions. Dixit and Pindyck (1994) claimed that the value of flexibility could be found by taking the difference between the NPV of a “now or never” investment decision and one which permitted flexibility to invest in the future. They also claimed that the decision to invest now rather than wait had an additional opportunity cost associated with the uncertainty of future market conditions. Depending on the direction of market fluctuations, waiting to invest can be beneficial for choosing between profitable and unprofitable alternatives.

In their chapter regarding response to uncertainty, Nicholson and Snyder (2017) discuss flexibility in terms of real options. Using the example of a flex-fuel car, the three characteristics of real options are given as: (1) there is a transaction of interest specified, (2) there is a time horizon specified during which the option can be exercised, and (3) there is at least an implicit price that must be paid to acquire the option. In the case of no flexibility, Nicholson and Snyder (2017) explain that the single best alternative on average should be chosen for an expected utility of: $\max\{E[U(O_1)], \ldots, E[U(O_n)]\}$. However, if flexibility to choose an alternative better suited to a future state of the world is preserved through an option, then the expected payoff is given by: $E\{\max[U(O_1), \ldots, U(O_n)]\}$. While these expected utility functions appear to be very similar, the implications are not. Nicholson and Snyder (2017) point out that while the former represents the expected utility of the best single utility curve, the latter represents the expected utility from the upper envelope of all possible utility curves (Figure 2.2). The latter example thus represents an equation that may be optimized to maximize utility regardless of what state occurs. Although Nicholson and Snyder (2017) evaluated this problem from the perspective of a utility-maximizing consumer, the same logic applies to an agricultural business attempting to maximize revenue.

One of the more straightforward methods used to value flexibility was presented by Kulatilaka and Trigeorgis (2001). Their analysis evaluated the static NPV of two rigid technologies, A and B, in a 2-period scenario, then compared these values with that offered by a third option which provided the flexibility to switch between these two technologies. The source of uncertainty in their case was the price of oil, which favored one technology if the prices were high and favored the other if prices were low. Thus, the flexible project's value was greater than the value of either of the rigid technologies: $V(F) \geq \max(PV(A), PV(B))$ when no switching costs were involved. However, if costs are incurred to switch between technologies, Kulatilaka and Trigeorgis (2001) state that option additivity breaks down and the flexible project represents a compound option (simultaneous put and call). This situation can cause hysteresis, where considerations for the optimum technology in future periods influences the decision to switch technologies in the current period. This explains how some businesses might wait to switch technologies or modes of operation despite the current conditions in the operating environment. Kulatilaka and Trigeorgis (2001) finish by explaining how flexibility to switch between options can be applied to other common options such as deferring an investment, expansion, contraction, abandonment, etc.

Summary

Flexibility as a risk management strategy for agricultural systems is applicable in many scenarios. When the appropriate flexibility is defined and understood, it can be used as a tool to mitigate risk. Flexibility can provide a competitive advantage to businesses, although it often comes at a cost. Risk management strategies such as diversification and maintaining extra resources can complement flexibility, although neither are a requirement for a business to demonstrate flexibility. Measuring flexibility is commonly accomplished by enumerating options, but this effort needs further investigation to provide more practical value to managers. Real options analysis has been applied by several authors to determine the value of flexibility. The real options framework represents one of the most well-accepted methods for this effort. Managers of agricultural system should consider flexibility as a reliable and valuable tool to control the impact of risks imposed by the operating environment.

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Figures

Figure 2.0 Original illustration of the strategies for controlling the impact of risk presented by Hewlett et al. (2019).

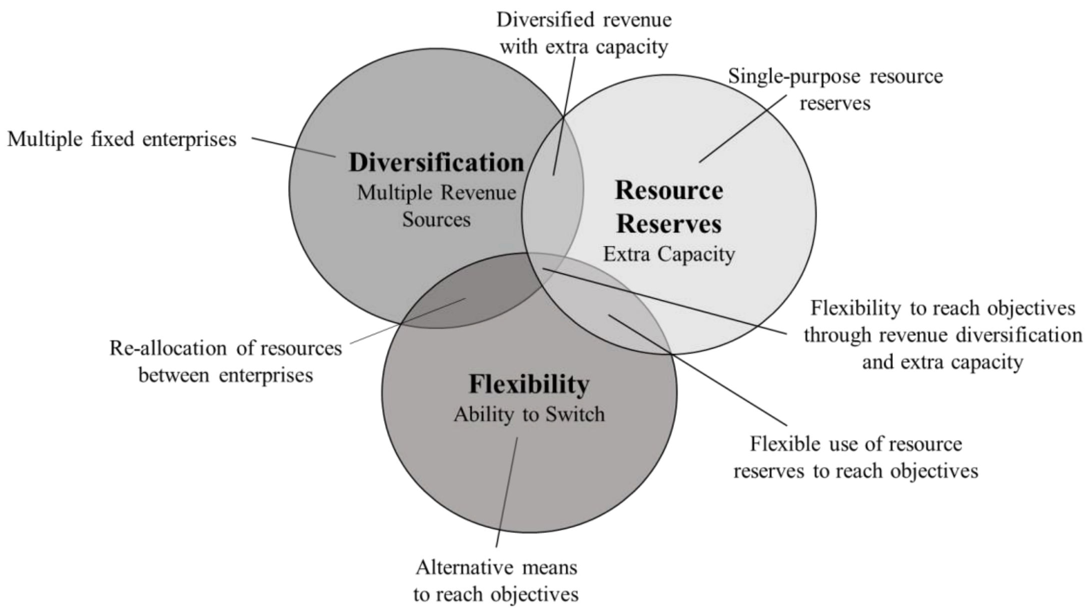


Figure 2.1 The impact of managerial flexibility on expected Net Present Value (NPV) as illustrated by Yeo and Qiu (2003).

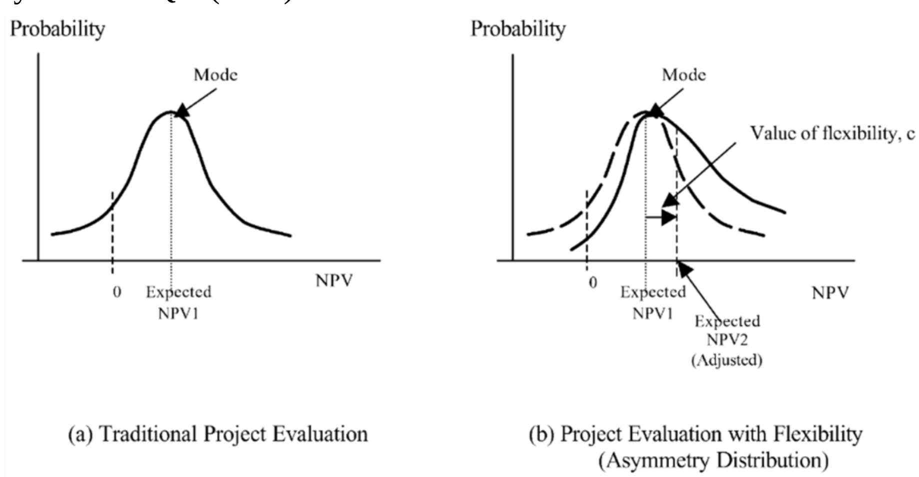
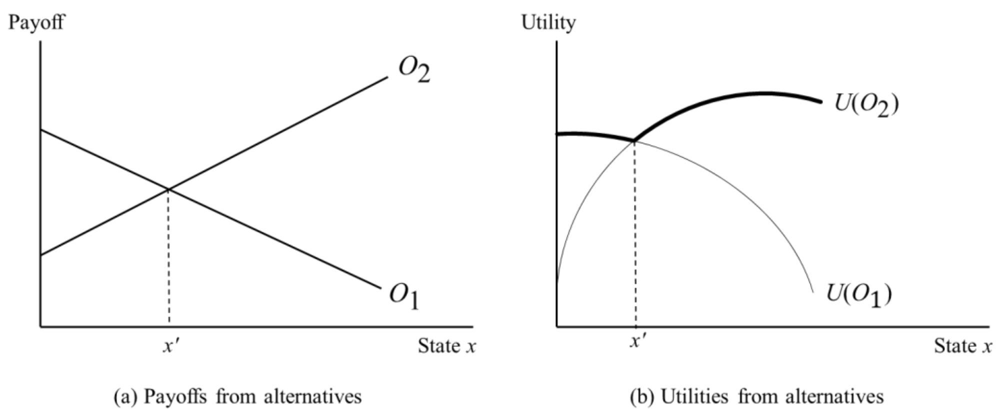


Figure 2.2 Alternative utility curves associated with a non-flexible decision (a) and a flexible alternative (b) as illustrated by Nicholson and Snyder (2017) [pg. 225]. The bold line in (b) denotes the upper envelope of utility curves.



Tables

Table 2.0 Attributes of a flexibility suggested by Upton (1994)

Flexibility Attributes
Dimensions: What exactly is it that flexibility is required over—what needs to change or be adapted to?
Time Horizon: What is the general period over which changes will occur? Minute-by-Minute, days, weeks, or years?
Elements: Which element(s) are most important to us? Which of the following are we trying to manage or improve: range? Uniformity across the range? mobility?

Chapter 3: Flexible Pasture Management Alternatives

Introduction

The history of rangeland fences in the Western United States is lengthy and controversial. Fences generally serve two purposes; they denote land ownership boundaries and provide a barrier to restrict the movement of animals on the property. Usually, fences are considered durable or "fixed" assets since they can last more than 15 years with regular maintenance. Therefore, the decision to install a fence is not trivial. Fences may be sorted into one of two categories, permanent and temporary. In addition to perimeter fences, some landowners choose to use fences to divide their land into smaller parcels for easier management. Production risk due to the annual variation in forage production is a major cause for concern among grazing managers. Due to this variability, the stocking rate established for years with average forage availability will be effectively higher or lower in any year that average conditions are not realized. Drought conditions can promote livestock liquidations or supplemental feeding to avoid rangeland degradation. Fences have been recommended among other methods for increasing animal distribution and thereby increase the forage harvesting efficiency of grazing animals. Cross fencing and the resulting increase in harvest efficiency might allow a relatively stable carrying capacity in the face of reduced forage availability on rangeland pastures. This chapter will evaluate the flexibility of utilizing cross-fencing to mitigate the risk of fluctuating forage production.

Motivation

Flexibility has been mentioned as a desirable attribute of fencing and grazing systems by several authors (Buschermohle 2001; Undersander et al. 2002; Gerrish 2004; Andrae 2008; Barnes and Howell 2013; Gross and Stowell 2018). Flexible stocking rates have been discussed as a management strategy to address low forage availability, as in a drought (Torell, Murugan, and Ramirez 2010; Kachergis et al. 2014). However, despite the apparent interest in having or gaining flexibility, few efforts have been made to define the meaning of flexibility in agricultural systems (Weiss 1999; Cowan, Kaine, and Wright 2013). Applying the general definition introduced earlier, a flexible grazing system or stocking rate should have the ability to be switched without incurring a large penalty of time, cost, effort, or performance. A more specific definition would be helpful for understanding how flexibility might be achieved.

Stocking Rate

Flexible stocking rates are commonly mentioned in discussions regarding drought planning and mitigation. Undersander et al. (2002) and Ogle and Brazee (2009) discuss three primary factors that characterize a grazing system, 1) the size of paddock, 2) the length of the grazing period, and 3) the number of grazing animals. Torell, Murugan, and Ramirez (2010) created a 40-year economic model to evaluate the practice of using yearling cattle to increase and decrease the stocking rate of a cow-calf ranch to accommodate greater- or less-than-average forage production in a given year, respectively. However, the authors acknowledge that this strategy has limitations and introduces extra costs and financial risk with the purchase and sale of yearling animals.

Authors agree that adjusting the length of the grazing season provides the manager flexibility to control the animal impact on forage, especially in drought years (Ogle and Brazee 2009; Barnes and Howell 2013; Kachergis et al. 2014). However, it is commonly held that drought-year grazing should be characterized by shorter grazing periods to avoid overgrazing and allow grazed plants more time to rest (Undersander et al. 2002; Ogle and Brazee 2009; Kachergis et al. 2014). Modifying paddock size may be an alternate way to adjust the grazing system, assuming the manager wishes to avoid livestock liquidations or decreasing the length of the grazing season.

Grazing Distribution

The distribution of grazing animals in a pasture has received considerable attention for at least 30 years. Holechek, Pieper, and Herbel (2011) explain that the goal of proper grazing distribution is to achieve a uniform utilization of rangeland forages. Additionally, Redfearn and Bidwell (2017) note that uniform grazing distribution is assumed to be the case when rangeland stocking rates are established. In critique of historical authors, Norton (1998) points out that researchers often assume that all the forage within a pasture is “available” for grazing, which may not be the case depending on the size of the paddock, stocking density, and animal preferences for certain locations. Reduced harvest efficiency, low animal production per acre, and the possibility of lowered range condition and erosion due to heavy use in some areas are some of the negative impacts of poor grazing distribution mentioned by Volesky, Schacht, and Waller (1996). Smart et al. (2010) reviewed six grazing studies from the North American Great Plains and found that harvest efficiency scaled in a linear fashion with the Grazing

Pressure Index expressed in animal unit days per megagram of forage (AUDs·Mg^{-1}). Redden (2014) proposes that increasing animal distribution can be accomplished through a higher instantaneous grazing pressure—the animal unit demand per unit forage at given instant—even though cumulative grazing pressure—animal unit demand per unit forage over a period of time—might remain unchanged. Both a short-duration and continuous grazing system can have identical cumulative grazing pressures over the same timeframe, but the *instantaneous* grazing pressure will differ according to the number of paddocks or rotations. Thus, the instantaneous grazing pressure for a 2, 4, and 8-paddock grazing system will be two, four, and eight times higher, respectively, than a comparable continuous grazing system with the same number of acres.

Fencing has been listed as one of several factors that affect the distribution of grazing animals on the landscape (Williams and Lacey 1995; Volesky, Schacht, and Waller 1996; Holechek, Pieper, and Herbel 2011). Volesky, Schacht, and Waller (1996) stated that, “generally, livestock distribution can be significantly improved by simply reducing pasture size.” Volesky, Schacht, and Waller (1996) also note that system resilience and range condition may be improved through better grazing distribution. Gerrish (2004) commented that the amount of pasture subdivisions used will depend on the manager’s desired level of control. Holechek, Pieper, and Herbel (2011) noted that minimum fence construction should yield the best economic returns in arid regions, since most of the costs associated with more intensive grazing management are due to fencing. Beside the use of fencing, other methods suggested for increasing animal distribution include the strategic placement of water, salt, and/or mineral within the pasture, changing the class of livestock used for grazing, and mowing or burning old forages in underutilized areas (Volesky, Schacht, and Waller 1996).

Increased harvest efficiency has been proposed as a chief benefit of subdividing pastures and increasing livestock distribution. Smart et al. (2010) define harvest efficiency (HE) as the percentage of peak standing crop (PSC) consumed by grazing animals, and grazing efficiency (GE) as the percentage of total forage disappearance consumed by grazers. If the amount of residual forage at the end of the grazing season is zero, HE will equal GE, but HE will always be less than GE as the amount of residual forage increases. Hart et al. (1989) found that grazing was more uniform in small continuously or rotationally grazed pastures than in larger continuously grazed pastures. Utilization in the large continuously grazed pastures averaged 60 percent utilization near watering points, decreasing to less than 30 percent utilization as the distance from water increased (Hart et al. 1989). Allison, Kothmann, and Rittenhouse (1982) confirmed through experimentation that grazing animals exhibited higher forage harvesting efficiency (expressed as *Intake ÷ Forage Disappearance* x *100*) when grazing pressure was greater (i.e., as daily forage allocation decreased) on Texas rangelands. Higher grazing efficiency (99 percent) was observed when daily forage allocation was approximately equal to daily forage intake, but decreased to nearly 50 percent as the daily forage allocation increased beyond intake requirements and grazing pressure decreased (Allison, Kothmann, and Rittenhouse 1982). In other words, higher demand (AUDs) per unit of forage resulted in higher harvesting efficiency. Volesky, Schacht, and Waller (1996) suggest that a 10 percent increase in grazing capacity and harvest efficiency could be achieved through improved animal distribution as long as the initial stocking rate was appropriate. Harvest efficiency values vary by grazing system, but are generally between 25 and 35 percent (Ogle and Brazee 2009; Redfearn and Bidwell 2017). Harvesting more than 35 percent of available forage is discouraged by Ogle and Brazee (2009), since this can lead to decreased animal performance.

Risk and Variability

Weather is one of the sources of production risk offered by Hewlett et al. (2019) that has a direct impact on grazing operations. Variability in precipitation (Hart and Samuel 1985; Hersom 2005; Redfearn and Bidwell 2017) and growing degree days (GGDs) (Hersom 2005) cause annual variations in the rate and timing of forage growth. Data gathered at the Barta Brothers Ranch near Rose, Nebraska indicates the amount of precipitation has varied widely between and within years between 2001-2017 (Figure 3.1).

Variation in available forage is a major source of recurring production risk for grazing systems. Although forage growth is dependent on favorable conditions, predicting future forage growth using historical records has not been reliable. Hart and Samuel (1985) found that 95 percent of the variation in herbage production on Wyoming rangeland could be explained by a multiple correlation with March-April and May-August precipitation. A study conducted by Irisarri et al. (2019) on Colorado range pasture found that the coefficient of variation for April-July precipitation and annual precipitation was 36 percent and 18 percent, respectively, for 2002-2017. Furthermore, the coefficient of variation for forage production ranged from 26 percent to 32 percent based on data collected from 2003-2017 (Irisarri et al. 2019). Previously, Hart et al. (1988) established a coefficient of variation for total forage production from 1982-1987 to be 21 percent while precipitation varied from 94 to 151 percent of normal over the same period. The volatility of precipitation patterns and corresponding forage production creates risk for cattle ranchers who depend on growing forage for grazing. The occurrence of drought (negative outcome) and rancher's response to it has been the topic of several papers (Bastian et al. 2009; Torell, Murugan, and Ramirez 2010; Kachergis et al. 2014). However, the possibility of abundant forage production (positive outcome) is also a risk, as alluded to by Hewlett et al. (2019), though it creates less cause for concern among land managers. Flexible cross fencing may be a tool that can help land managers mitigate the impact of risk arising from the variation and uncertainty surrounding forage production.

Definition of Grazing Flexibility

Numerous associations could be made between flexibility and grazing. In an attempt to remove ambiguity from this discussion, Upton's (1994) framework for defining the nature of flexibility will be followed. The dimension, time horizon, and elements specified for the flexibility in question are summarized in Table 3.0. The dimension of interest for this analysis relates to the risk of forage production being higher or lower than average, and how the manager will respond. motivating the manager to destock or provide supplemental feed. Flexibility in controlling the harvest efficiency of grazing cattle is the dimension of interest for this analysis, with the goal of maintaining a stable herd size and grazing season length. Pasture cross fencing will be used as the means to facilitate the adjustment of forage harvest efficiency. The time horizon associated with this adjustment will vary. For the purpose of this definition, it will be assumed that if the manager chooses to use cross fencing, it will be used for at least one full year or grazing season. Mobility is the most important element for the pasture cross fence, as it should not be cumbersome to install and remove, effectively switching the harvest efficiency to a new level. To summarize, the flexibility to alter harvest efficiency in any given year with pasture cross fencing and rotational grazing should be recognized by its ability to be changed or switched (installed or removed) without incurring a large penalty of time, cost, effort, or performance.

Measuring Flexibility of Harvest Efficiency

Measuring the flexibility to control harvest efficiency might seem difficult at first glance. The method of measuring flexibility suggested by Kumar and Kumar (1987) involves enumerating the options or alternatives available and the freedom that an individual has to choose an option. Bearing in mind that the control of harvest efficiency is facilitated through the use of technology (i.e., cross fencing), the number of different fence construction options can be counted. A pasture may be divided with either permanent or temporary fencing. Though several options exist in each of these broad categories, this analysis will be restricted to barbed wire and electric poly-wire fences for permanent and temporary implementation, respectively. Essentially, three options exist for the grazing manager who is considering acquiring the option to control harvest efficiency. First, the manager has the option to do nothing. In this case, season-long extensive grazing would be implemented where harvest efficiency does not to exceed 25 percent of available forage. This will be considered the base case. Second, permanent cross fencing can be installed so that harvest efficiency can be 35 percent or less through rotational grazing. In this case, the manager gains the opportunity to harvest more forage in a rigid or fixed set of paddocks. Third, temporary fencing can be used to offer a mix of both options listed above. In years when forage is low, fencing can be installed to achieve a harvest efficiency of 35 percent, while in years with average or better forage production, an extensive grazing strategy can be used so that harvest efficiency is near 25 percent. For simplicity, it is assumed that the manager has full freedom to choose one of these three options. Therefore, the flexibility to control harvest efficiency by the grazing manager can be realized through two alternatives represented by the decision to use permanent or temporary fencing. The implications of these alternatives will be discussed later in more detail.

Risk Management with Grazing Flexibility

The potential to utilize flexibility as a risk management strategy for agricultural operations has been discussed by several authors (Debertin 2012; Kay, Edwards, and Duffy 2012; Hewlett et al. 2019). The discussion regarding the benefits of pasture subdivision and increased forage harvest efficiency prompts several questions worthy of further investigation. Most importantly for this analysis, how do pasture subdivisions mitigate risk for the business through flexibility? What level of pasture subdivision is necessary to achieve flexibility? Lastly, how much risk is mitigated through the use of flexibility? The goal of this chapter is to answer these questions.

Forage Variability

Predicting and planning for an uncertain forage supply is one of the greatest difficulties of effective grazing management. Forage production varies inter-annually and intra-annually. Between years, variation in precipitation and or favorable growing conditions may cause annual forage production to be higher or lower than normal (average). Throughout the year, variation in the rate of forage growth will be determined by environmental conditions and species composition. Typically, cool-season grasses will grow rapidly in the early part of the grazing season and decline mid-season, while warm-season grasses will start growing slowly, reaching a peak later in the season, and declining slowly thereafter (Undersander et al. 2002). If these factors are not considered, then grazing pressure may be unbalanced throughout the season, even with moderate or low stocking rates. At a micro-scale, forage varies by site (affected by slope, topography, aspect, presence of other vegetation, etc.). Across the entire grazing unit, changing pasture size may be needed for optimal utilization of the dynamic forage resource.

Drought Risk

All risk management strategies are intended to mitigate risk and uncertainty in some form or another. As previously stated, flexibility is a strategy proposed to control the impact of risk on a business, not the probability of risk (Hewlett et al. 2019). Cross fencing directly affects the manner in which grazers utilize a given land base, helping to mitigate variation in forage production due to climatic factors mentioned previously. Part of the difficulty in managing a variable forage base arises from the fact that grazing plans must be made before full information about forage availability is revealed. Stephenson et al. (2019) found that over the period of 2001-2017, forage production varied from 39 percent below average in the driest years to 17 percent above average in the wettest years. Furthermore, only about 49 percent of the variation in precipitation received during the growing season explained the variation in total forage production. In short, if the stocking rate of a pasture was based only upon precipitation received during the growing season, the estimate would be correct in only about half the years. If the grazing manager expects a shortage of forage for the season, Butterfield, Bingham, and Savory (2019) suggest destocking animals earlier rather than later so that a larger portion of the original herd can be sustained with minimal supplementation.

Although Undersander et al. (2002) state that a universal rule does not exist for determining the appropriate number of paddocks, they state that any number greater than one (as is the case with continuous grazing) can improve both land and animal performance due to the balancing of grazing and rest, as seen in Figure 3.2. For a management-intensive rotational grazing system, Undersander et al. (2002) recommend the following equation to determine the optimal number of paddocks:

$$\textit{Number of Paddocks} = \frac{\textit{Longest Resting Period (days)}}{\textit{Grazing Period (days)}} + \textit{(Number of animal groups)}$$

According to the calculations presented by Redfearn and Bidwell (2017), a 10 percent increase in forage use efficiency through rotational grazing (35 vs. 25 percent of total standing crop) can result in 28 percent fewer acres required for each animal unit year (AUY) compared to continuous grazing. The specific number of pastures needed in the rotation to achieve a gain of 10 percent harvest efficiency is not stated by Redfearn and Bidwell (2017). For this paper, it will be assumed that rotating cattle through four pastures as discussed by Redden (2014) will be sufficient to increase forage harvest efficiency by 10 percent without changing the stocking rate.

Valuing Flexibility: A Pasture Management Case

The value of flexibility in controlling grazing harvest efficiency will now be evaluated using a real options analysis framework. A fictitious grazing pasture will serve as the basis of this discussion. The grazing unit for this problem will be a 640-acre pasture located in Brown County, Nebraska having perimeter fencing and a centrally located watering point already in place, so that the maximum distance to water is less than one mile, as recommended by Volesky, Schacht, and Waller (1996). Annual forage production in years with average growth conditions will be estimated at 1,875 lbs./acre. This estimate is slightly lower than the average forage production value reported by Stephenson et al. (2019), but higher than some values that Smart et al. (2010) compiled from grazing studies in the Northern Great Plains region. Assuming a moderate initial stocking rate, 25 percent of the peak standing crop can be allocated for grazing (Smart et al. 2010) and the remaining 75 percent being either trampled, grazed by wildlife and insects, or left as soil residue (Redfearn and Bidwell 2017; Meehan et al. 2018). The grazable weight of forage in this instance is 468.75 pounds per acre. To establish the stocking rate for this pasture, the daily intake requirements of grazing animals should be established. A single Animal Unit Day (AUD) will be estimated for a 1,000-pound beef cow assuming intake will be approximately 2.0 percent of live body weight or 20 pounds per day on a dry matter basis. This is similar to the intake values reported by Allison, Kothmann, and Rittenhouse (1982) and Holechek (1988), though lower than estimates made by Ogle and Brazee (2009) and Redfearn and Bidwell (2017). Thus, the stocking rate can be determined to be 23.44 AUDs/acre (Equation 1). If this stocking rate is supported by the entire grazing unit, then the total grazable forage will be roughly equal to 15,001.60 AUDs (Equation 2). The typical 5-month (150-day) grazing season suggested by Jansen and Stokes (2021) establishes the season-long carrying capacity for the pasture to be approximately 100 AUs (Equation 3). Thus, we can assume that in average years, 100 head of cattle can graze for 150 days without detriment to the pasture. If forage production is reduced below average, then the grazing manager might be expected to liquidate all or part of the herd, provide supplemental feed, or lease additional pasture as found by Bastian et al. (2009) and Kachergis et al. (2014). Rather than take any of these actions, it might be the case that gaining extra harvest efficiency through cross fencing will allow a constant herd size to be maintained during a drought.

$$\frac{\frac{468.75 \text{ lbs.}}{\text{ac}}}{\frac{20 \text{ lbs.}}{\text{AU}}} = 23.44 \text{ AUDs/ac} \tag{1}$$

$$\frac{23.44 \text{ AUDs}}{\text{ac}} * 640 \text{ ac.} = 15{,}001.60 \text{ AUDs} \tag{2}$$

$$\frac{15{,}001.60 \text{ AUDs}}{150 \text{ days}} = 100.01 \text{ AUs} \tag{3}$$

First, assuming that no improvement in harvest efficiency (HE) is possible, the land manager will stock the pasture to achieve no more than 25 percent harvest efficiency in all years. In average years, a conservative stocking rate will permit 23 AUDs/acre (Table 3.4). If available forage declines by 25 percent, the stocking rate must be reduced to 18 AUDs/acre. Over 640 acres, this implies a loss of about 3,200 AUDs, or approximately 21 percent of the original stocking capacity. The cattle owner may wish to preserve the number of cattle in the herd for various reasons. Assuming destocking is an undesirable effect of drought, then the season length should be reduced by about 32 days in poor years. For example, the grazing season might need to be delayed, interrupted, or reach its conclusion about a month sooner than usual. Alternatively, about 193 (30 percent) more acres of pasture or supplemental feed would be required to maintain the herd at 100 head and the season length of 150 days. On the other hand, if available forage was higher than average, no livestock liquidation or supplemental feed would be required. Excess forage provides opportunities for alternative pasture management such as stockpiling, burning, or grazing yearling livestock. To summarize, a reduction in available forage would imply that an increase in grazeable acres or a reduction in AUDs (No. head or No. Days) would be required to maintain a moderate (25% HE) stocking rate.

Now it will be assumed that an increase in harvest efficiency is possible through the use of technology (cross-fencing). Thirty-five percent harvest efficiency is assumed to be reasonable for the pasture (i.e., not placing excessive pressure on the pasture). As seen in Table 3.2 and Table 3.3, increasing harvest efficiency is possible without increasing utilization. The common "take half, leave half" rule assumes that no more than 50 percent of the peak standing crop is grazed or destroyed. Returning to the base case, we can assume that average years will permit stocking at 23 AUDs/acre without cross-fencing, or 33 AUDs/acre if cross fencing is used (Table 3.4). Thus, 6,400 AUDs could be gained for the whole pasture—approximately 64 additional grazing days for the base cow herd. As mentioned before, a more efficient use of pasture forage would allow the land manager to set aside unneeded acres for pasture improvements or rest. The values in Table 3.3 indicate that a 28.5 percent reduction in forage production could be sustained with 35 percent harvest efficiency while allowing the herd to be maintained at 100 head (intake level of 469 pounds per acre). Based on these values, a real options problem can be arranged to determine the value of flexibility.

Real Options Analysis

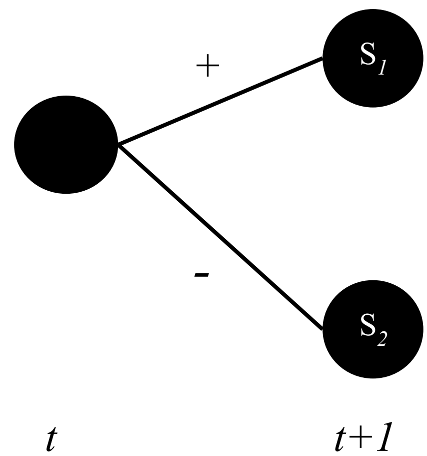
Following the work of Kulatilaka and Trigeorgis (2001), a real options problem can be designed to determine the value of flexibility. Three alternatives are possible as mentioned before. The rigid option (A) of maintaining harvest efficiency at or below 25 percent with a season-long grazing plan will be compared with the rigid option (B) of maintaining harvest efficiency less than or equal to 35 percent with permanent fencing and rotational grazing. The third option (C) of using temporary fence will capture both the value of higher harvest efficiency achieved in option B with the flexibility of reverting the pasture to its original state as with option A. Options A and B can be likened to the rigid technologies compared by Kulatilaka and Trigeorgis (2001). A simple, one-period binomial decision analysis will suffice given the short-run nature of the problem. Since this problem involves predictions about future conditions based on probable conditions, the expected value (EV) will be calculated rather than the Net Present Value (NPV) used by Simmons (2019) to find the value of real options.

The EV of each option can be found by using the following formula:

$$EV_i = \frac{V + \sum_{S_j}[(P*AUMs*B)*(p)]}{1+r} - C_k$$

where the value of an option is a function of:

i = Option choice,
B= Base acres,
V= Value of underlying asset (land),
r= Net rate of return,
p= probability of any state,
P= Rental rate for pasture,
s= State of weather/forage, ($j \in (1,2)$),
C = Cost of fencing for ($k \in (1,2)$),



According to the annual report compiled by Jansen and Stokes (2021), an acre of non-tillable grazing land in the Northern region of Nebraska in 2021 was valued at $695.00/acre, the annual net rate of return for grazing land in this region was reported to be 2.2%, and the average monthly rate for leased pasture was $63.10/AUM. Since returns from the cattle enterprise are difficult to determine accurately, the value of harvested AUMs will be determined by the rental rate for this region. The value of the underlying asset (land) is included in the EV calculation to follow the work done by Simmons (2019). The possible states of forage are almost infinite because of the variation in the natural system. For simplicity, $j \in (1,2)$; 1 indicates that forage production is at or above average (stocking rate = 23.44 AUDs/acre) or 2 if forage production is below the long-term average (stocking rate = 16.74 AUDs/acre). In reality, there is a continuum of values that constitute the negative or “down” state. Only one value has been chosen here to simplify the equations and represent the risk mitigation limit of the fence in this scenario.

Fence costs *C* will only be deducted from the EV when fencing is used, such that *k* will equal 1 for permanent fence and 2 for temporary fence. Exact costs will be delineated later. For the case where no fence is used, *C* will be equal to zero.

Probabilities of each state occurring are somewhat arbitrarily set to be 50 percent for either state. Based on the data collected by Stephenson et al. (2019) at the University of Nebraska-Lincoln Barta Brothers ranch, annual forage production between 2001-2017 was at or above the long-term average in 10 years (58.82%) and at or below 30 percent of average in 4 years (23.53%) (Figure 3.0). The precipitation data reported by Stephenson et al. (2019) for this period is shown in Figure 3.1. The effect of different probabilities on the value of flexibility in this scenario will be discussed later.

Costs

The annualized cost of using permanent fence is estimated to be $1,373.40 per mile and temporary fence is estimated to cost $692.54 per mile including extra labor charges for moving the fence (Table 3.1). The calculations to arrive at these estimates were influenced by the report compiled by Edwards (2012). Most of the costs were taken at face value, with the exception of hourly labor, which was increased to $25.00 per hour for this analysis. It is assumed that each mile of permanent fence will incur the cost of materials and labor for installation, but not so with temporary fencing. Cost estimates for temporary fence are calculated assuming that the materials are purchased but will only be installed if needed (i.e., when drought conditions are expected). Due to this methodology, the annual maintenance and opportunity costs for the temporary fence reflect a percentage of the materials cost alone (Table 3.1). If the pasture is to be divided into four equal parts, two miles of permanent fence would need to be installed (C_1 = \$2,746.80). However, since temporary fence can be easily moved, only one mile of electric fence would be required to fence off a fourth of the pasture at a time. For subsequent pasture rotations, the fence would be disassembled and reinstalled at a new location (Figure 3.3). Although other strategies could be considered, here it will be assumed that temporary fence will only be utilized if forage production is expected to be lower than average. Therefore, the expense created by using the temporary fence will only be incurred about half the years that permanent fence is used. Therefore, $C_2 = (0.5*692.54) = \$346.27$.

$$EV_A = [\$444{,}800 + (\$2.10*23.44*640)*(0.5) + (\$2.10*16.74*640)*(0.5)]/1.022 = \underline{\$461{,}686.01} \tag{4}$$

$$EV_B = [\$444{,}800 + (\$2.10*23.44*640)*(0.5) + (\$2.10*23.44*640)*(0.5)]/1.022 = \$466{,}095.89 - \$2{,}746.80 = \underline{\$463{,}349.09} \tag{5}$$

$$EV_C = [\$444{,}800 + (\$2.10*23.44*640)*(0.5) + (\$2.10*23.44*640)*(0.5)]/1.022 = \$466{,}095.89 - (0.5*\$692.54) = \underline{\$465{,}749.62.08} \tag{6}$$

Kulatilaka and Trigeorgis (2001) state that switching costs cause option additivity to break down, making the calculations slightly more cumbersome and introducing the opportunity for hysteresis. The analysis of switching costs is not straightforward for this scenario. In the case of permanent fence, the full installation cost (including labor) is required to make the switch from a 1-paddock to a 4-paddock grazing scenario. This decision represents a commitment to implement rotational grazing (permanently) for the life of the fence (20 years). Unless the herd size or the length of the grazing season changes, it can be expected that the cattle will continue to harvest 35 percent of the forage each year that the fence is in use. The case for temporary fence is slightly different. Once the materials are purchased, the labor to install, move, and disassemble the fence represent the switching costs for temporary fence. Kulatilaka and Trigeorgis (2001) found that switching costs influenced the decision of whether or not to switch from one operating mode to another based on the future implications of that decision. Although it might be optimal in the short run to make the switch, the manager might decide not to switch since conditions in the environment might soon reverse and it would be costly to switch back to the present operating mode (Kulatilaka and Trigeorgis 2001).

The decision to install permanent fence ought to be heavily influenced by the long-term effects on the grazing system, but the implications of using of temporary fencing are significantly more short-lived. Whereas the cost to switch back from a 4-pasture rotational grazing plan is very high with permanent fence (infinite), the cost to switch back is low for temporary fence. Due to these factors, no explicit switching costs will be considered for this problem. Instead, an annualized cost will be subtracted from the total expected value of the option as the exercise price that must be paid in order to acquire the option of obtaining the right to implement higher forage harvest efficiency. The annualized cost of fencing with permanent fencing reported above assumes no ability to switch back (i.e., once the fence is installed, it will be maintained for its full life). The cost for temporary fencing given above is comprised of the amortized material cost and the labor cost to install, move, and remove the fence for one grazing season. In other words, for the cost incurred, the pasture would be "reset" to a single pasture following the use of temporary fencing. There are a few reasons to take this approach. First, the expense of using either fencing alternative should only be deducted from the value of the forage harvested for one year. Thus, the annual cost of the fence can be compared with the annual benefit derived from using it (i.e., harvesting more AUMs). Second, the decision to use temporary fencing would generally be viewed as effecting only a single season. Furthermore, it would be inappropriate to assume that the temporary fencing would be used for 20 years and thus comparable to the permanent fence, since a large advantage of the temporary fencing is that it can be used if and when the manager chooses. Owing to the fact that temporary fencing is intermittently used, the rate of depreciation is regulated by the amount of use it receives. Lastly, this approach removes the potential for hysteresis in the case of the flexible fencing since the pasture would always begin from the same single-paddock configuration in future grazing seasons.

The calculations to arrive at the expected value of options A, B, and C are found in Equations 4, 5, and 6, respectively. The final EV of options A, B, and C are $461,686.01, $463,349.09, $465,746.62, respectively (Table 3.5). Despite the high cost of gaining 10 percent higher harvest efficiency with permanent fence, the EV_B is still greater than EV_A (no fence). The benefit is even more pronounced when a cheaper fence is used to achieve the same goal. A careful analysis will reveal that the difference between EV_A and EV_B ($1,663.09) represents the value to be gained from using a rigid cross fencing technology to achieve higher harvest efficiency. The difference between EV_A and EV_C ($4,063.61) represents the value of gaining higher harvest efficiency with a flexible technology, so the true value of isolated flexibility is nested with better grazing performance. To isolate the value of flexibility, the difference between EV_B and EV_C must be evaluated. This value ($2,400.53) represents the value of flexibility since it is the difference observed between two technologies that perform the same function but differ in the manner of their application. Dixit and Pindyck (1994) came to a similar conclusion when comparing the NPV of two investment decisions, one being a "now or never" investment and an alternative which permitted flexibility to postpone the decision for one period. In their case, the value of flexibility was defined as the difference between the NPV of these two alternatives.

The value of flexibility determined using this method should be viewed as a "snapshot" rather than an enduring value. The EV of each option changes depending on the probabilities of forage production deviating from average (Figure 3.4). As the probability of forage production being at least average or better increases, EV_A tends toward the expected value of options B and C, where fencing permits stable stocking rate across expected forage conditions. The value of option B remains constant across probabilities because it is assumed that this fencing strategy permits the stocking rate to remain constant across forage conditions. In other words, the value of forage harvested is consistent across good and poor conditions. The expected value of the flexible fencing option increases slightly as the probability of favorable forage production increases. This behavior seems reasonable since the frequency of the temporary fence use and costs associated with it decrease as the probability of average or better forage conditions become more likely. If the rental rate of pasture, the probability of drought, or other parameters used in the above calculations were to fluctuate, the value of flexibility would change as well. This is consistent with the work of Black and Scholes (1973), who found that option values fluctuate over time.

Discussion

Risk Mitigation Strategies Revisited

a. Diversification

Temporary fence provides the opportunity for diversification to manage risk. The increase in forage harvest efficiency from using cross fencing increases the grazing capacity of the operation across all forage/growth conditions, compared to a lower harvest efficiency. Assuming the business uses temporary fencing as a risk management tool to maintain herd size, then years with average or above average production would still represent an opportunity for extra value to be captured from utilizing yearlings or other livestock as an alternative enterprise. Extra forage could also be allocated to wildlife if hunting was an enterprise that the land manager wished to facilitate on the grazing unit. Forage not needed for grazing during the growing season could also be stockpiled for late season grazing or allowed to accumulate as a fuel load for prescribed burning. The exclusion of animals from one part of the grazing unit would permit a diversity of simultaneous land uses that would not be possible if the grazing unit were a single pasture.

b. Flexibility

Temporary fencing offers significantly more flexibility to switch forage harvest efficiency than permanent cross fencing. It must be acknowledged that forage harvest efficiency can be 'switched' from a lower to a higher level when permanent fencing is installed, but the opportunity to switch harvest efficiency in future periods is negligible with a rigid 4-pasture layout. Instead, it will remain permanently "switched" for periods $t > 1$. The advantages of temporary fencing include lower investment costs and higher portability/mobility, verified by the low number of hours required for the switch (Table 3.1). The temporary fence creates additional value because the effect it has on harvest efficiency can be reversed in future periods. The expected value of flexibility is fairly stable over the range of possible forage outcomes (Figure 3.5). On the other hand, the expected value of the permanent cross fencing strategy declines as the expectations of forage conditions improve. As the likelihood of favorable forage production increases above 70 percent, the value of the rigid system becomes zero, implying that the benefit of harvesting additional AUMs (compared to not using fence) is not sufficient to offset the high cost of the fence. This can also be seen in Figure 3.4, where the EV of option A surpasses the EV of option B when average or better forage conditions become more probable $(p \geq 0.70)$. Thus, a manager would not invest in the rigid technology option if the severity of drought conditions as described were unlikely $(p \leq 0.30)$. Viewed another way, the value of permanent cross fencing increases with the probability of poor conditions.

c. Extra capacity

Utilizing temporary fencing and increasing the forage harvest efficiency creates a "cushion" of extra forage for the base herd above what is possible at a lower harvest efficiency level. As with many efficiency equations, output can increase under normal circumstances or it can remain steady even in declining conditions. The former outcome is desired by growing businesses, while the latter is more valuable to established businesses. In the case of a grazing operation, increasing harvest efficiency from 25 percent to 35 percent through the use of fencing allows the amount of forage harvested to increase across poor, average, and good growing conditions (Figure 3.6). However, if pastures are stocked and managed to take full advantage of the benefit of increased harvest efficiency across all conditions, then there is no extra capacity created by cross fencing (Figure 3.6, Line 3). In fact, stocking the pasture to match 35 percent harvest efficiency introduces more risk to the operation, rather than mitigating it. If forage conditions decline, the requirements of grazing animals must be met either through destocking, supplemental feeding, leasing additional acres, etc. More animals would need to be sold or fed than if the grazing unit was stocked to match 25 percent harvest efficiency and the same decline in forage occurred (Figure 3.6, Line 2).

Some ranches choose to stock conservatively (Kachergis et al. 2014) to avoid the possibility of livestock liquidations in drought years (Figure 3.6, Line 1). “Stocking light” creates a reserve of forage resources in most years, since the demand of the grazing herd are less than the supply of forage. Although this is an effective risk management strategy, it comes at the cost of less-than-full utilization of forage in years when forage production is average or higher. Due to the relatively low frequency of severe droughts in this area (Stephenson et al. 2019), the grazing operation would be operating below the level of technical efficiency for a majority of years following this strategy. The flexibility provided by the temporary fence permits the grazing unit to be fully stocked at a moderate level for the majority of the time, which simultaneously increases revenue and reduces the risk of livestock liquidations.

The extra capacity of forage created by increasing harvest efficiency can mitigate the risk of declining forage availability, to a certain point. As shown in Figure 3.6, if the manager is not willing to exceed 35 percent harvesting efficiency, then the base herd can only be maintained if the reduction in forage is less than or equal to 28.5 percent. Just as in the case of no fencing, the requirements of animals would need to be matched with another management technique if forage production was 71.5 percent of average or less. Hence, the flexibility to switch harvest efficiency with temporary fencing performs properly as a tool to reduce the impact of risk up to a certain threshold. This strategy can be likened to an insurance policy that effectively limits losses for the one who purchases protection, even though all losses are not fully rescinded.

Flexibility and Reversibility

Flexibility involves the ability to respond to changing conditions. The ability to switch some aspect of operation or management is key to realizing flexibility. However, the ability to switch *back* to a former mode of operation is of particular interest in this discussion of flexibility. Options on other options have been described as "compound options", and can be difficult to value because of the variety of possibilities (Margrabe 1978; Kulatilaka 1993; Kulatilaka and Trigeorgis 2001). Intuitively, one might easily understand that fluctuating conditions provide the incentive, if not the requirement, to change business operations in some way. Over time, trends in the operating environment might also reverse, leading to a situation identical to one experienced before. If this were the case, a former mode of operation, optimized for those conditions, would again be desirable. In the case of grazing, rotational grazing might be desired in years when forage production is low, but not in years when forage production is average or better.

Dixit and Pindyck (1994) discussed how investments are often irreversible because they are firm or industry specific. This holds true in the case of either fencing alternative, but the magnitude of the sunk costs differs greatly between permanent and temporary fencing (Table 3.1). Despite the irreversibility of the initial investment, future costs associated with the temporary fence can be avoided simply by not using it, whereas this is not the case for the permanent fence. Practically speaking, permanent fencing permits a single pasture to be “switched” only in one direction. After the initial switch in $t = 0$, many smaller paddocks exist instead of one larger one. Due to the highly mobile nature of temporary fencing, cross fencing can be installed and removed at low cost, permitting a two-way switch (Figure 3.3). Thus, the ability to switch back to a single pasture following rotational grazing (and vice versa) represents a compound option on forage harvesting efficiency; the land manager is able to easily exchange one configuration for another. The cost structure and reversible application of the temporary fencing option leave more options available in future periods—demonstrating that it provides more flexibility to adjust forage harvest efficiency than permanent fence.

Conclusion

Fluctuations in forage production represent a common risk that managers of grazing livestock must accommodate. Since the success of a grazing business depends largely on the availability of forage, managing the risk surrounding this key input should prove valuable. Improving the harvest efficiency of grazing livestock can be accomplished through the use of rotational grazing (Redfearn and Bidwell 2017). Permanent and temporary fencing are two alternatives which represent an effective means for implementing rotational grazing and increasing the forage harvesting efficiency of grazing animals in a pasture. Temporary fencing proves to be a more flexible technology than a permanent alternative. Based on the real options framework, the value of being able to switch forage harvest efficiency with temporary fencing was found to be $2,400.53. The value of flexibility and related options cannot not be taken as static, as values will fluctuate when different assumptions are used in the equations. Perhaps most important, the assumptions made about the probability of utilizing flexibility will have a direct impact on the value of flexibility for a business. Flexibility is a unique risk management tool that can be defined, measured, and valued for pasture management.

Supplemental Cases

Flexibility has value in many situations in agriculture, due to the cyclic nature of the operating environment and market conditions. In a paper exploring farmer's willingness to pay for crop land leases, Du and Hennessy (2012) used real options valuation to determine the value of flexibility in crop input decisions. The authors stated that cash rental rates were determined in a large part by expectations about planting decisions in the following year (i.e., which crop would be most profitable). Due to the uncertainty of commodity markets, farmers may change their choice of crop between the time when the lease contract is finalized and planting season. Du and Hennessy (2012) acknowledged that farmers have flexibility to switch which crop is planted each year (corn and soybeans in their case) and also have flexibility in choosing how much of an input to apply (i.e., nitrogen fertilizer). Based on the results from their empirical analysis, Du and Hennessy (2012) found that the real options approach resulted in a higher cash rent value than was determined through the traditional NPV approach, effectively proving that the conventional approach underestimated the level of rent that farmers should pay for cropland. The results of the model also showed that the option to switch crops increased in value as the profits of corn and soybeans converged toward each other but was worth little if the profit from one crop was expected to dominate the other.

Further research could be conducted to explore the value of flexibility in similar “switching” decisions in the agricultural industry. For example, what is the value of switching the sale date for a group of cattle to take advantage of annual market cycles? Is it worthwhile to take on the risk of maintaining storage capacity to target a different marketing window for a harvested crop? Can flexibility be used to manage a fleet of machinery? How does flexibility mitigate the risk of sudden and severe supply-chain shocks? Although it may be tempting to try using flexibility as the proverbial silver bullet, it is only one of three risk mitigation strategies that has proven valuable in certain circumstances. Realistically, flexibility should be considered in cases where switching can be expected to occur somewhat regularly and where risk cannot be mitigated through other strategies such as diversification or maintaining extra resource reserves.

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Figures

Figure 3.0 Original depiction of annual forage production for 2001-2017 at the Barta Brothers Ranch near Rose, Nebraska. Data collected by Stephenson et al. (2019). Values reported as percentage of average for the period.

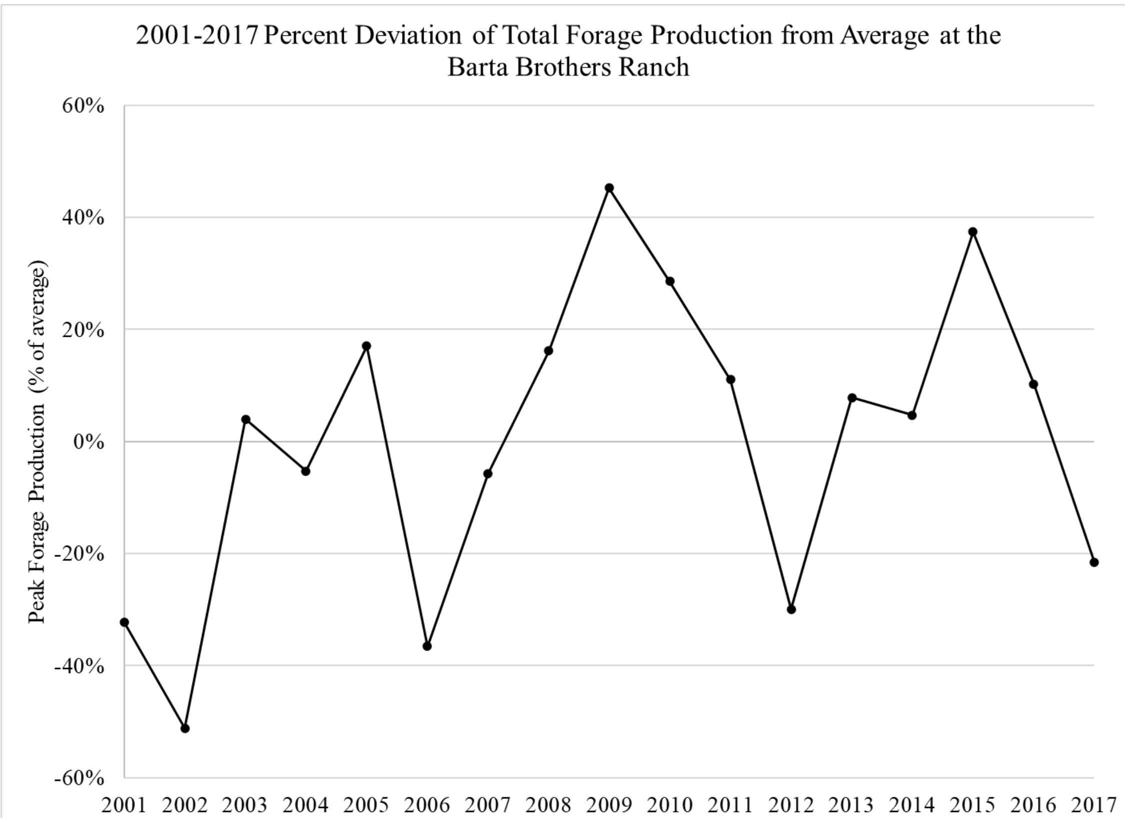


Figure 3.1 2001-2017 Annual precipitation for the Barta Brothers Ranch near Rose, Nebraska reported by Stephenson et al. (2019).

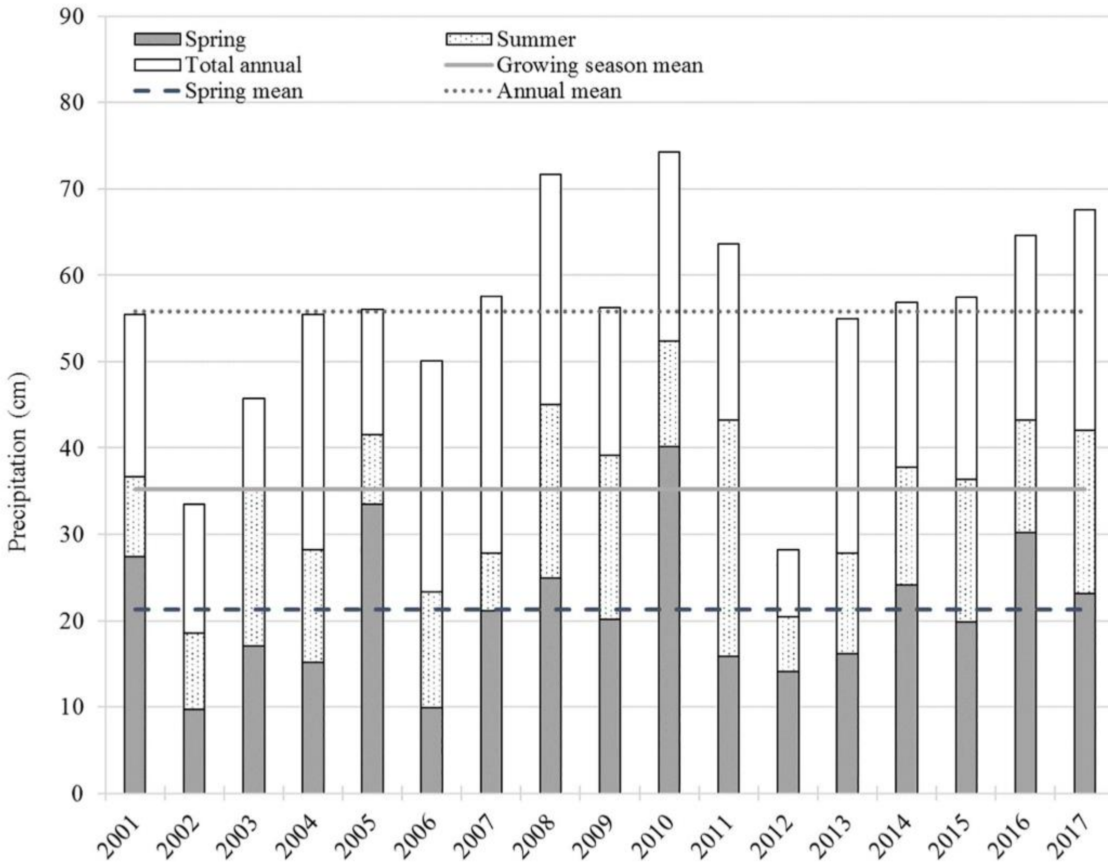


Figure 3.2 Balance of grazing and rest achievable with pasture subdivision fences as presented by Undersander et al. (2002).

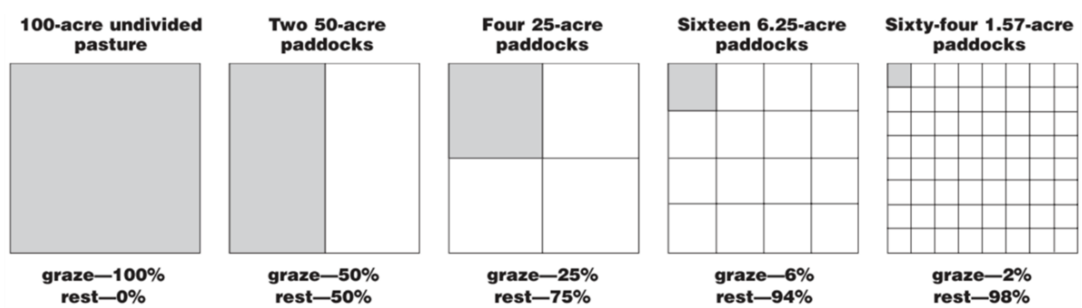


Figure 3.3 Permanent and temporary pasture cross fencing alternatives, denoted by solid and dashed lines, respectively.

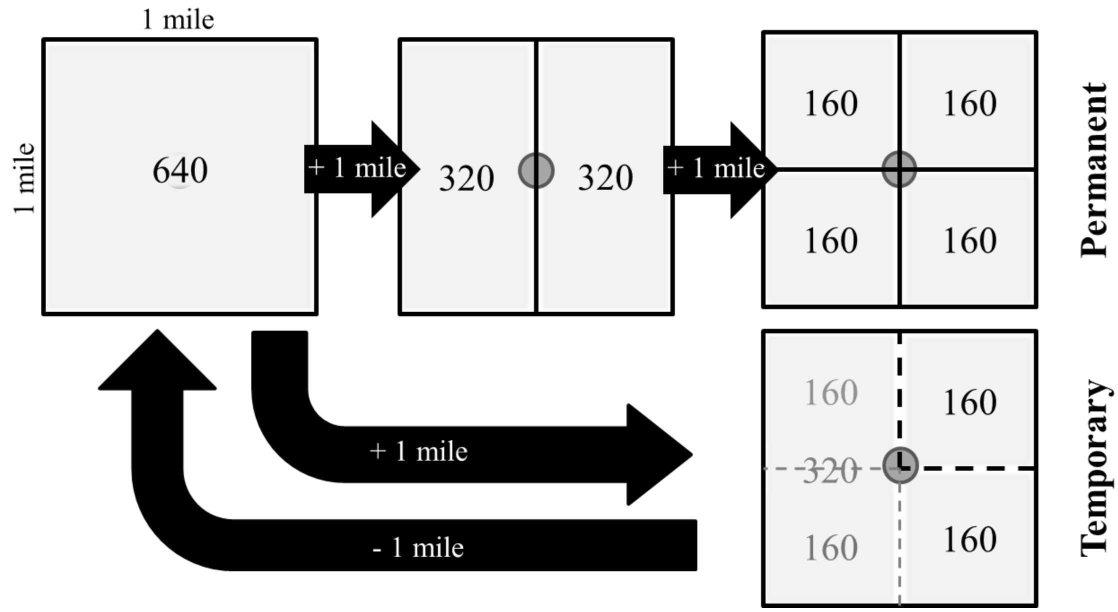


Figure 3.4 Option value over a range of probabilities that forage production will be average or better. See Table 3.5 for further information.

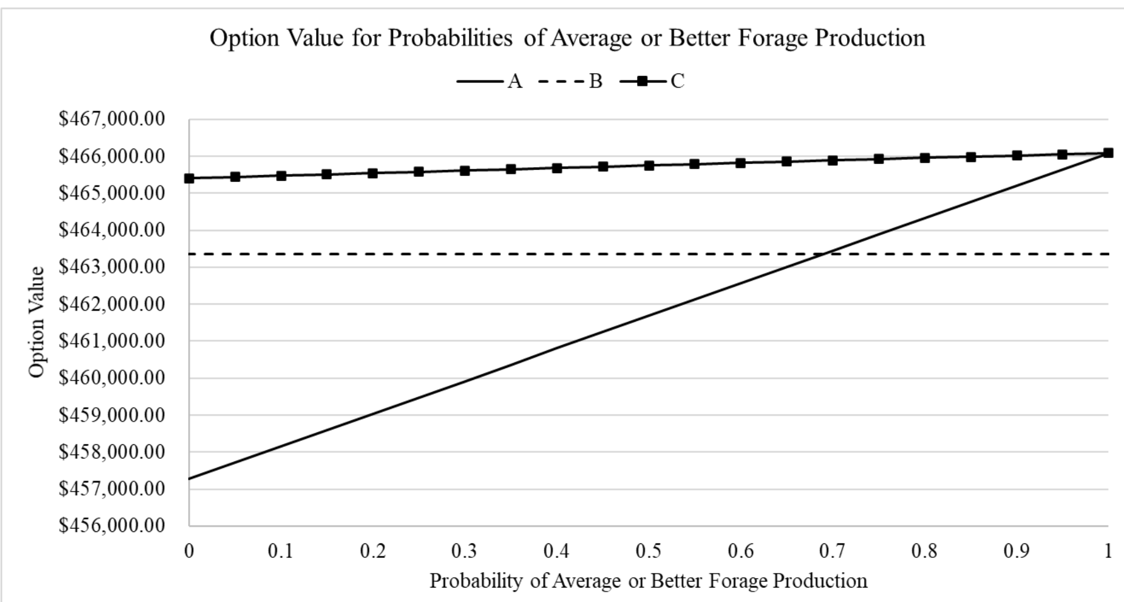


Figure 3.5 Value of fencing alternatives over a range of probabilities that forage production will be average or better. See Table 3.5 for further information.

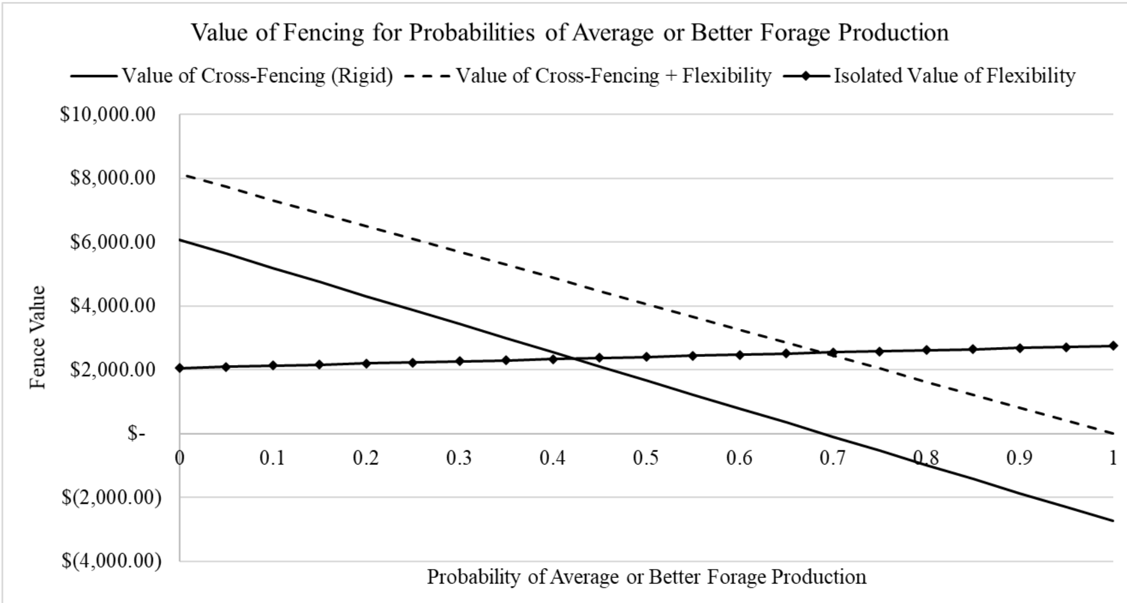
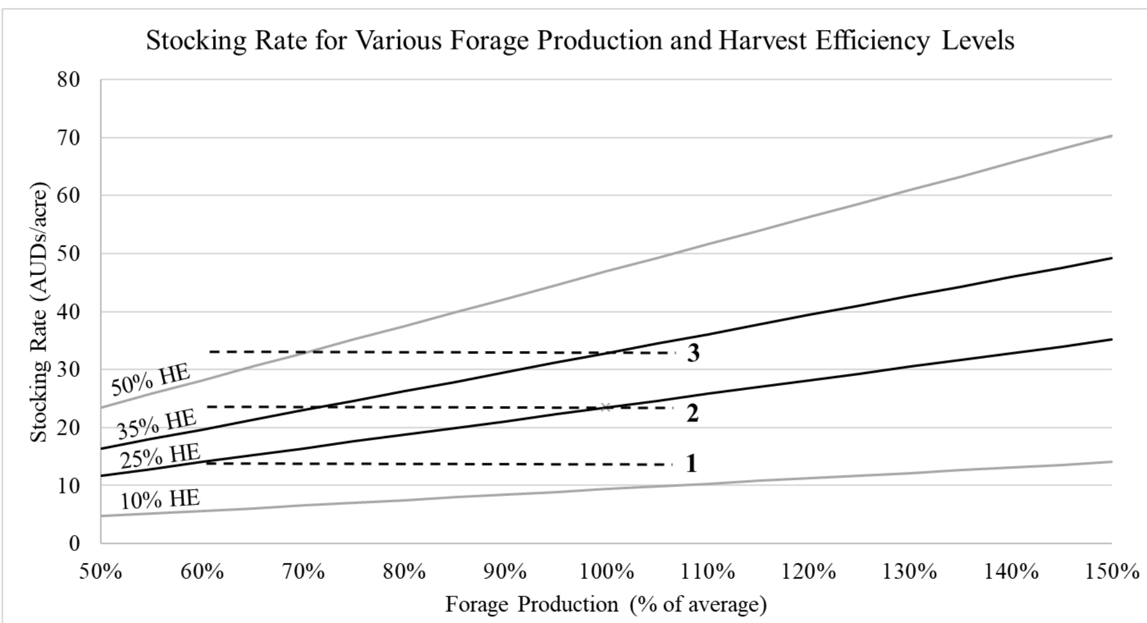


Figure 3.6 Stocking rates in Animal Unit Days per acre based on various forage production and forage harvest efficiency levels. See also Table 3.4 for a numerical representation.



Tables

Table 3.0 Attributes to define flexibility for grazing suggested by Upton (1994).

Attributes of Flexibility to Modify Harvest Efficiency
Dimensions: What exactly is it that flexibility is required over—what needs to change or be adapted to? ▪ Variation in forage production creates risk: deficit (excess) of forage in poor (good) years. Pasture stocking rate and harvest efficiency.
Time Horizon: What is the general period over which changes will occur? Minute-by-Minute, days, weeks, or years? ▪ Once per year
Elements: Which element(s) are most important to us? Which of the following are we trying to manage or improve: range? Uniformity across the range? mobility? ▪ Mobility: Easily movable fence

Table 3.1 Schedule of fence costs (per mile). Estimates influenced by data reported by Edwards (2012).

	Barbed Wire			Electrified Poly-Wire		
Item	**Qty**	**Cost per unit**	**Total cost**	**Qty**	**Cost per unit**	**Total cost**
Materials	1 mile	$5,256.00	$5,256.00	1 mile	$914.20	$914.20
Labor to Install (hrs.)	156	$25.00	$3,900.00	8	$25.00	$200.00
INSTALL TOTAL			$9,156.00			$1,114.20
Labor to Move (hrs.)	N/A			8	$25.00	$200.00
Useful Life	20 years			4 years		
Expected Salvage Value			$0.00			$0.00
Amortized Install Cost			$457.80			$228.55
Maintenance Cost	8% of Install cost		$732.48	5% of Install cost		$45.71
Opportunity Cost	4% of Average value*		$183.12	4% of Average value**		$18.28
Annual Cost			**$1,373.40**			**$692.54**
Reversible Investment	No			No		
Reversible Placement	No			Yes		

Source: Edwards (2012) "Estimating Costs for Livestock Fencing."
**Average Value = (Total Install Cost + Salvage Value) ÷ 2*
***Average Value = (Materials Cost + Salvage Value) ÷ 2*

Table 3.2 Increasing harvest efficiency with constant peak standing crop

Increase Intake with Consistent Forage Supply

Peak Standing Crop (lbs./acre)	Intake (lbs./acre)	Harvest Efficiency	Residue	Insects, Wildlife, etc.
1875	469	25%	50%	25%
1875	563	30%	50%	20%
1875	656	35%	50%	15%
1875	750	40%	50%	10%
1875	844	45%	50%	5%
1875	938	50%	50%	0%

Table 3.3 Increasing harvest efficiency with a declining peak standing crop

Maintain Intake at 469 lbs./acre with Declining Forage Supply

Peak Standing Crop (lbs./acre)	Intake (lbs./acre)	Harvest Efficiency	Residue	Insects, Wildlife, etc.
1875	469	25%	50%	25%
1563	469	30%	50%	20%
1339	469	35%	50%	15%
1172	469	40%	50%	10%
1042	469	45%	50%	5%
938	469	50%	50%	0%

Table 3.4 Stocking rates for various forage production levels above and below average and harvest efficiency levels.

Intake (lbs./day) 20	Stocking Rate (AUDs/acre)				
Forage (% of Average)	Forage Production (lbs./ac)	Harvest Efficiency Rates			
		10%	25%	35%	50%
50%	938	5	12	16	23
55%	1031	5	13	18	26
60%	1125	6	14	20	28
65%	1219	6	15	21	30
70%	1313	7	16	23	33
75%	1406	7	18	25	35
80%	1500	8	19	26	38
85%	1594	8	20	28	40
90%	1688	8	21	30	42
95%	1781	9	22	31	45
100%	1875	9	23	33	47
105%	1969	10	25	34	49
110%	2063	10	26	36	52
115%	2156	11	27	38	54
120%	2250	11	28	39	56
125%	2344	12	29	41	59
130%	2438	12	30	43	61
135%	2531	13	32	44	63
140%	2625	13	33	46	66
145%	2719	14	34	48	68
150%	2813	14	35	49	70

Table 3.5 Expected value for considered pasture management options and evaluation of differences.

Option	Strategy	Expected Value
A	No fence used	$ 461,686.01
B	Use 2 miles of permanent fence	$ 463,349.09
C	Use 1 mile of temporary fence	$ 465,749.62
B-A	Value of Cross-Fencing (Rigid)	$ 1,663.09
C-A	Value of Cross-Fencing + Flexibility	$ 4,063.61
C-B	Isolated Value of Flexibility	$ 2,400.53