ECONOMIC EVALUATION OF SELECTED POLICIES TO ENCOURAGE ADOPTION OF FIELD SHELTERBELTS IN SASKATCHEWAN

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ABSTRACT

Historically, farmers on the Canadian Prairies have planted field shelterbelts on their farms to reduce the damage done by wind erosion due to extreme climatic conditions. However, incidence of such damages has been reduced with improvements in agricultural production methods and cultural practices (such as zero-till, and reduced summer fallowing, among others). Some farmers now regard these field shelterbelts as an economic nuisance. Although many of the barriers to the adoption and retention of shelterbelts by farmers are mostly related to their economic costs, a poor understanding of their environmental benefits may also have played an important role.

In response to the future changing climate, reducing greenhouse gas emissions has become a major objective of various national governments, including the Canadian government. Shelterbelts can play an important role in mitigating greenhouse gases through sequestration of carbon. This requires farmers to plant more shelterbelts. To this effect, an understanding of the factors that influence farmers' decision regarding field shelterbelt adoption, as well as measures to encourage their adoption to increase the environmental benefits of field shelterbelts is relevant. Using a combination of a binary logistic regression model, combined with a spreadsheet-based farm-level net revenue simulation model and other numerical estimation approaches, in this study, the factors that may influence farmers' decisions to adopt field shelterbelts were empirically estimated. In addition, the study estimated the potential impacts of selected policy instruments in encouraging the adoption of field shelterbelts in Saskatchewan. For this purpose, two policy instruments were selected – distribution of free shelterbelt seedlings to farmers, and negative carbon tax for carbon sequestration through shelterbelts. The value of negative carbon tax was determined by the price of carbon. This study considered four different carbon price scenarios – \$ 74.60/tCO_2(eq), \$ 110.49/tCO_2(eq), \$ 574.13/tCO_2(eq) and the carbon price levels of the Canadian carbon tax system (started at \$10/tCO_2(eq) in 2018, with \$10/tCO_2(eq) yearly increment till 2022 and \$15/tCO_2(eq) yearly increment from 2023 to 2030). The two selected policy instruments were evaluated based on four policy evaluation criteria; (1) Farm-level net revenue, (2) Probability of increasing field shelterbelt adoption, (3) Amount of carbon sequestered, and (4) Fiscal cost per tonne of carbon sequestration.

The study results indicated that factors such as farmers' education level, farm income, and their perceptions about the environmental benefits of field shelterbelts had a positive and significant effect on farmers' decisions to adopt field shelterbelts. Moreover, between the two selected policy instruments, results showed that the negative carbon tax policy instrument performed better based on most of the policy evaluation criteria (3 out of 4 – impact on farm-level net revenue, probability of increasing field shelterbelt adoption, and total amount of carbon sequestered) in all the soil zones of Saskatchewan. Among the four different rates of the negative carbon tax (only on the carbon sequestered through shelterbelts), study results indicated that negative carbon tax set at a carbon price of \$ 574.13/tCO_2(eq) was the more effective policy instrument in encouraging the adoption of field shelterbelts in Saskatchewan since it provided the higher rate of adoption than the distribution of free seedlings to farmers. The study's findings suggest that policy designed to increase the adoption of field shelterbelts should clearly define the policymaker's objective of whether to maximize policy benefits or minimize policy costs since the choice of an appropriate policy or set of policies may differ under these policy objectives. Particularly, it is recommended that providing free shelterbelt seedlings should be considered if the objective of the policy design is to minimize policy costs, while the negative carbon tax instrument could be considered if the objective of the policy design is to maximize the potential benefits of the policy. In general, the study's findings suggest that governments' policy intervention to encourage adoption of field shelterbelts by farmers in Saskatchewan through financial rewards can encourage farmers to plant and maintain field shelterbelts on their farms.

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DEDICATION

I would like to dedicate this Thesis to my late parents: Mr. and Mrs. Baffoe, who ensured that I had the right foundation in life, and to my sister, Rose Abena Baffoe.

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Chapter 1

Introduction

1.1 Study Background

Shelterbelts are rows of planted shrubs or trees that provide a variety of positive impacts, goods, and services within agricultural landscapes (Kulshreshtha et al., 2010; Mayrinck et al., 2019). Within these, field shelterbelts are rows of trees or shrubs that grow along field boundaries, and adjacent to roads, while there are also shelterbelts planted around farmyards and livestock facilities (Agriculture and Agri-Food Canada, 2015). Shelterbelts are also known as windbreaks, living hedges, hedgerows or living fences. The various species of trees and shrubs that farmers typically use as shelterbelts in Saskatchewan include caragana (*Caragana arborescens Lam.*), green ash (*Fraxinus pennsylvanica Marsh*), hybrid poplar (*Populus spp.*), Manitoba maple (*Acer negundo L.*), Scot's pine (*Pinus sylvestris L.*), and white spruce (*Picea glauca Monch Voss.*) (Kort & Turnock, 1998).

The history of shelterbelt planting on the Canadian Prairies dates back to the earlier part of the 20th century, during the great depression (Marchildon, 2009), when the Federal tree-planting program was initiated to enhance the landscape, and aid in a thriving agriculture (Marchildon, 2009). The Federal tree-planting program started in 1901 and was operated under the Prairie Shelterbelt Program (PSP), which was administered by the Agriculture and Agri-Food Canada's (AAFC) Agroforestry Development Centre (ADC), based at Indian Head, Saskatchewan (Centre for Northern Agroforestry and Afforestation, 2022). Under the PSP program, farmers, and other eligible clients within the prairie provinces received shelterbelt trees and shrub seedlings at no cost to plant on their lands, with an annual distribution of approximately 5 million tree and shrub seedlings to about 8,000 applicants (Centre for Northern Agroforestry and Afforestation, 2022). Moreover, the PSP provided technical and public information to farmers, and conducted research, development and technology transfer related to shelterbelts (Kulshreshtha et al., 2018). Before the government ended the PSP program in

2013, it was estimated that the PSP had distributed over 600 million shelterbelt trees and shrubs covering over 37 species, to farmers and other eligible clients in the prairie provinces (Kulshreshtha et al., 2018), with a total length of 51,653 km of shelterbelts being planted in the Saskatchewan agricultural region alone (Piwowar et al., 2016). Due to the earlier need for shelterbelts to protect farmyards from harsh and extreme weather conditions, most of the shelterbelts planted in Saskatchewan were farmyard shelterbelts. Piwowar et al. (2016) reported that out of the overall shelterbelts established in the province of Saskatchewan from 1888 to 2014, 57.6% were grown to protect farmyards (farmyard shelterbelts), while the remaining 42.4% being field and livestock shelterbelts.

Shelterbelts provide a wide range of benefits to farmers[1], which is known as private benefits (Kulshreshtha et al., 2010). These are benefits that farmers derive from planting shelterbelts. These benefits depend on the purpose for which the landowner planted the shelterbelt. Thus, whether the landowner planted field shelterbelts, farmyard shelterbelts, or livestock shelterbelts will determine the kind of benefits they will be expecting to receive. The level of private benefits associated with the planting of these shelterbelts primarily determines farmers' willingness to plant shelterbelts (Pannell, 2008). Some of the private benefits of shelterbelts to farmers are discussed in the subsequent paragraphs.

Shelterbelts provide benefits to farmer's crop production, which may include increased profits via improved crop yield (Kulshreshtha et al., 2010), through improving crop yield by protecting them from physical damage from high winds. During such periods, field shelterbelts alter wind speed and helps to protect soil from erosion, which helps to reduce yield losses associated with reduced soil quality and crop damage (Kort, 1988; Brandle et al., 2004). Similarly, by protecting soil from erosion, field shelterbelts help to keep farm site nutrients in place and conserves the soil, which can reduce fertilizer inputs and ultimately increases crop yields (Kort, 1988). Moreover, field shelterbelts are significant barriers to snow movements. Shelterbelts trap snow and reduce the amount and distance of snow movement. This helps to reduce the amount of

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[1] Farmers, producers, and landowners are most often used to refer to the same group of people. This study assumed they were the same concept. Therefore, the study uses farmers to represent all these group of people.

moisture lost to sublimation. By capturing snow, field shelterbelts help to regulate and improve soil moisture to contribute to crop growth (Kort, 1988; Kort et al., 2012). Shelterbelts' ability to trap snow is an essential contributor to improved yields (Kort, 1988), which further provides recharge of surface and groundwater.

Similarly, shelterbelts provide a variety of benefits to farmers in their livestock operations. They can protect livestock from extreme weather conditions, improve energy use efficiency and improve yields of forage and pasture crops (Gregory, 1995; Poppy, 2003). In times of excessive wind, they provide a shield for farm animals and protect them from potential negative health effects that may result from the harsh weather conditions (Gregory, 1995). The provision of shelter for the livestock from shelterbelts helps improve the water use efficiency, feed use efficiency, and releases the animals from stress from extreme weather condition (Gregory, 1995). Similarly, shelterbelts are used in livestock production to mitigate odors generated from residues from farm animals, which affect the farmers as well as neighboring residents. Tyndall & Grala (2009) have reported that livestock farmers mainly plant shelterbelts around the primary sources of swine odor, such as swine buildings, manure storage systems, and crop fields that receive applied manure, to mitigate the resulting odor. By selecting the appropriate shelterbelt design, shelterbelt systems can combat odor from swine production through enhancement of odor dilution or dispersion due to increased ground-level mechanical turbulence and odor filtration through emission interception and retention (Colletti et al., 2006; Tyndall & Colletti, 2007). Shelterbelts also help to mitigate odor through the improvement in site aesthetics, which softens socio-psychological responses to odor (Tyndall & Colletti, 2007).

In addition to providing a variety of private benefits to farmers, shelterbelts offer benefits to society. Significant among these social benefits include enhancing biodiversity. Shelterbelts enhance biodiversity at many different levels including plants, soil organisms, birds, mammals, arthropods, and other fauna (Batáry et al., 2020). Conserving biodiversity affects the performance of the ecosystem and its stability (Cardinale et al. 2012). For instance, by promoting soil supporting services, pollination, or biological control, and serving as habitat for wildlife, biodiversity conservation provides an avenue for food and wildlife security for the changing environmental situations. According to Bainbridge (1994), shelterbelts help to improve habitat diversity and the opportunities for wildlife to feed, live, and nest. Similarly, Myers (1997) posits that biodiversity can benefit society through improving existing crops, developing new foods, use for medicines and pharmaceuticals, industrial products, and biotechnology.

In addition to the above benefits, shelterbelts benefit society through carbon sequestration. Carbon sequestration involves the removal and storage of carbon from the atmosphere in carbon sinks such as oceans, vegetation, or soils through physical or biological means (Jose, 2009). Several studies (Amadi et al., 2016; Amichev et al., 2016; Kort & Turnock, 1998 Udawatta & Jose, 2012) have suggested that, by including trees or shrubs in agroforestry systems, farmers can sequester considerably more carbon as compared to the practice of monoculture for crop production or pastures. By sequestering atmospheric carbon, shelterbelts mitigate greenhouse gases (GHGs) emissions, thereby reducing the impacts of these emissions on global warming (Ricke et al., 2018). This ultimately affects climate change, which in turn provides favorable impacts on agricultural production, global temperatures and other human activities leading to an improvement in the quality of life of members of the society.

Furthermore, society benefits from shelterbelts through the aesthetics and beautification they provide. Due to their visibility, the aesthetic value of a healthy and well-designed shelterbelt around prairie farmland is well recognized by society (Kulshreshtha & Kort, 2009). Shelterbelts aesthetics enhance environmental friendliness for the private farmers as well as people in society. For instance, in the Canadian Prairie regions as well as the USA Midwest and Great Plains regions, shelterbelts have long been noted for their ability to diversify otherwise monotonous agricultural landscapes in ways that are visually and socially pleasing (Grala et al., 2010; Grala et al., 2012). Moreover, society enjoys an improved wellbeing from the aesthetic value of shelterbelts by providing green spaces. Access to a garden or short distance to green areas from the dwelling is associated with less stress and a lower likelihood of obesity (Nielsen & Hansen, 2007). Similarly, Grahn & Stigsdotter (2003) have posited that irrespective of an individual's age, sex, and socio-economic status, their frequent visits to green space area lessen their stress level, as the sweet smell from such green spaces helps to relax their minds and body, resulting in reduced mental illness.

Notwithstanding, planting shelterbelts also imposes costs to the landowner. The large size of farm equipment in modernized agricultural production makes maneuvering around shelterbelts challenging, especially shelterbelts planted in the middle of the field. They result in some areas not covered by this equipment while some other areas overlap. This imposes additional cost to farmers in terms of the amount of time they spend completing field operations due to overlap and (or) missed areas due to shelterbelt coverage (Taylor, 2010; Rempel et al., 2017), and also increases the amount of inputs (seed, fertilizer, and fuel) that is required for a farm with shelterbelts planted in the middle of the field, compared with one without (Islam, 2022; Rempel et al., 2017). Furthermore, shelterbelts occupy arable land available for crop production, which reduces the total amount of area in crop production (Brandle et al., 1992). Therefore, farmers lose crop revenue due to reduced availability of crop area occupied by shelterbelts. According to Rempel et al., (2014), farmers consider the loss of arable land for crop production as a significant cost of planting and maintaining shelterbelts, especially field shelterbelts. Moreover, shelterbelts impose additional cost to farmers relating to cost involved in maintenance activities of shelterbelts, including root and stem pruning, which are labour and time intensive operations. Other costs associated with shelterbelt establishment includes increase in irrigation, tillage, and herbicides cost (Rudd, 2020; Islam, 2022).

1.2 Statement of the Problem

The importance of field shelterbelts within the Saskatchewan agricultural landscape cannot be overlooked. As discussed above, they provide a wide range of benefits to the landowner and society, as well as costs to the landowner. Despite the range of private and social benefits field shelterbelts provide, farmers are not planting new field shelterbelts and increasingly removing existing ones (Rempel, 2014). This is because, improvements in agricultural production methods and cultural practices (zero-till, reduced summer fallowing) have reduced the damage done by wind erosion, which was one of the major reasons private farmers planted field shelterbelts on their land (Rempel, 2014). Moreover, changes in the Federal shelterbelt program with the closure of the shelterbelt centre in Indian Head, Saskatchewan has ended a century of free tree seedlings available to farmers, leaving farmers to purchase tree seedlings from private tree nurseries, which imposes significantly higher cost on shelterbelt establishment (Rempel et al., 2017). With these significantly higher establishment costs, as well the opportunity cost of arable agricultural land used in planting field shelterbelts, farmers may now increasingly regard field shelterbelts as an economic nuisance. Although many of the barriers to the adoption and retention of field shelterbelts by farmers are related to their economic costs, a poor understanding of their social benefits may also have played an important role (Rempel et al., 2017). However, Kulshreshtha & Kort (2009) have posited that the level of the social benefits from shelterbelts investments can be worth as much as the private benefits that are accrued directly to the farmers. Therefore, by considering the value of the social benefits of shelterbelts being relatively large, the role of policy intervention to encourage shelterbelt establishment and (or) maintenance on private land would lead to higher social welfare of the Saskatchewan (if not the entire Canadian society). This study was therefore undertaken to identify and evaluate alternative policy instruments and their role in changing farmers’ decisions towards the adoption of field shelterbelts in Saskatchewan.

1.3 Objectives of the study

The study’s primary objective is to evaluate policy measures that can act as incentives to farmers to renew and plant field shelterbelts (or do not remove them). Furthermore, since location of the farm may influence the effectiveness of these measures, the evaluation was undertaken for various regions (soil zones) of Saskatchewan. The specific objectives of the study were as follows:

1. Determine empirically the factors influencing decisions to plant field shelterbelts by Saskatchewan farmers;
2. Identify policy instruments that can potentially provide an incentive to farmers to renew and plant field shelterbelts in Saskatchewan; and
3. Evaluate selected policy instruments to estimate their effectiveness in adoption (including maintenance and/ or lack of removal) of field shelterbelts in various locations in Saskatchewan.

1.4 Scope of the study

The study's scope refers to the content of the research and the geographical location over which the study is conducted. Generally, there are five soil zones in Saskatchewan's agricultural regions: Black, Brown, Dark Brown, Dark Gray, and Gray soil zones. However, the geographical scope of the study is limited to the Black, Brown and Dark Brown soil zones, which represent the majority of the agricultural production landscapes in Saskatchewan (Kort, 1988).

1.5 Thesis Organization

The thesis is organized into six chapters. Chapter one presents the introduction of the study, where it discusses the need and purpose for the research. Chapter two presents a thematic review of literature regarding policy measures or programs that have been used to encourage the adoption of agroforestry practices. Chapter three provides the theoretical framework for developing shelterbelt policies. Chapter four presents the analytical framework developed for this study and discusses the various methodologies employed to achieve each of the research objectives. In Chapter five, results for the analyses conducted for the study are presented, followed by the interpretations of the study results[2]. Chapter six presents conclusions of the study, including implications of the study, as well as its limitations, and areas for future research.

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[2] Unless otherwise stated, all currency values reported throughout the study are in Canadian dollars. `

Chapter 2

Literature Review

2.1 Introduction

The purpose of the literature review is to provide a critical evaluation of the existing literature relating to this study. The first section (Section 2.2) discusses the adoption of conservation agricultural practices by focusing on Rogers' innovation-diffusion theory of adoption, together with the determinants of conservation agricultural practices adoption (Rogers 2003). Furthermore, factors influencing shelterbelts adoption are explored in this section. The next section (Section 2.3) provides a broad overview of the categories of policy instruments that have been used to encourage the adoption of conservation practices, including command-and-control, economic instruments, and education and information services policy instruments. Following this, Section 2.4 describes the policy instruments and programs used to support the adoption of conservation agricultural practices in the context of Canadian agriculture. The chapter ends with a summary and synthesis of findings from the literature.

2.2 Determinants of Conservation Agricultural Practices Adoption

The use of conservation agricultural practices is a significant part of a farmers' behavior as these practices aid their production as well as protect the environment (Pannell, 2008). Such practices may involve a change in production methods or technology, adoption of innovative crop species, among others. For instance, conservation practice, such as the planting of shelterbelts, could increase crop yield via improved soil moisture content, which may bring about higher economic returns to the farmer (Kort, 1988). However, the decision to adopt a practice or innovation is a complex one as it includes many factors, some of which are external to the farmer (such as policy instruments) with others being directly related to the farmer's world view (Reimer et al., 2012).

The literature on the theory of adoption is a wide one, as several factors are proposed to affect farmers' decision to adopt new technologies or conservation practices

(Bogdan, 2019). According to Upadhyay et al. (2003), three theories that are prevalent in the adoption of conservation agricultural practices and technologies are income, utility, and innovation-diffusion theories. The income and utility theories of adoption have their roots in the neoclassical household production model (Fernandez, 2006). However, the more commonly used theory to explain farmers' adoption behaviors is the innovation-diffusion theory, put forward in the early 1960s by Rogers (2003). Sociologists favor the innovation-diffusion theory more as it explains how specific characteristics of individuals play a role in their decisions to adopt a new technology or practice (Upadhyay et al., 2003). It suggests various factors that are likely to influence individuals' decision to adopt a new practice and are considered determinants of adoption of a new technology.

A farmer’s decision to adopt a new agricultural technology represents the weighing of a complex series of options (Kulshreshtha & Brown, 1993). Such choices include several factors regarding economic and social nature, which contributes to the farm-level decisions affecting adoption (Kulshreshtha & Brown, 1993). Moreover, Pannell et al. (2006) posited that landowner's adoption of innovations represents a series of dynamic learning process, which depends on a range of personal, social, cultural, and economic factors, as well as on characteristics of the innovation itself. Therefore, an understanding of this array of factors is essential in better explaining farmers' adoption of conservation practice voluntarily.

Although adoption decision-making processes of farmers is an integrated and complex one (Kulshreshtha & Brown, 1993; Pannell et al., 2006) a wide range of studies on farmers' adoption of conservation agricultural innovations have shown that such factors can be grouped into the following four main categories (Bogdan, 2019): (1) Farmers characteristics and attitudes, (2) Farm characteristics, (3) Characteristics of the conservation practice, and (4) external characteristics. The subsequent subsections provide detailed explanations of each category and how they affect the adoption decision making process.

2.2.1 Farmers’ Characteristics and Attitudes

Farmers' personal characteristics and attitudes are those factors that determines their willingness to adopt conservation practices. This category of factors forms the background in the adoption decision-making process and indirectly influences farmers' decision to adopt or reject conservation practices (Prokopy et al., 2008). It may include farmers' characteristics, such as age, education level, and years of farming experience, among others, that can affect adoption decisions. These are considered demographic factors and are among the commonly used criteria to determine farmers' willingness to adopt conservation practices. Moreover, individuals' perceptions, attitudes, and behavioral intentions, as well as their participation in social clubs or advising networks, form part of their personal characteristics that may determine their willingness to adopt conservation practices. These factors include the primary feature of farmers' adoption decision-making, since an individual's perceptions and characteristics play a significant role in the choices they make (Reimer et al., 2012).

Farmers' age is considered a common factor that influences their adoption of conservation practices. Some studies hypothesize farmers' age to negatively influence their decision to adopt conservation practices (Prokopy et al., 2008). The explanation is that, as farmers grow old, they are less likely to adopt new conservation practices because such practices have longer-term effects, and their shorter planning horizon does not allow them to realize the longer-term benefits from adopting these practices (Ervin & Ervin, 1982). This conclusion is supported by Baumgart-Getz et al. (2012). Thus, the relationship between farmers' age and their decision to adopt a conservation practice is primarily determined by the lag between the time of investment and the period of expected returns on investment (Pannell et al., 2006). Though most studies hypothesize farmers' age to negatively influence their conservation practice adoption, a few studies have suggested that this relationship can be positive. For example, a study by Kim et al. (2005) showed that beef cattle farmers who are much older are more likely to adopt conservation soil and landscape management practices than young farmers. However, in more general terms, farmers age may be hypothesized to negatively influence their decisions to adopt conservation practices.

Farmers' level of education, as well as their years of farming experience, are generally expected to positively influence their innovation adoption decisions (Prokopy et al., 2008). As individuals attain higher levels of education, they become more aware of the wide range of environmental degradation and its effect on the wellbeing of humans and nature (Prokopy et al., 2008). Therefore, they become more willing to adopt practices that aim at enhancing the environmental benefits, which, in turn, improve human wellbeing. Moreover, farmers with high education levels are more likely to adopt conservation practices because they are open to more ideas and have more experience making decisions as well as effectively utilizing information (Prokopy et al., 2008). For instance, a study by Caswell et al. (2001) reported that farmers' level of education had a significant positive effect on their adoption of information-intensive technologies, such as the use of biological pest control or the practice of nitrogen testing. Notwithstanding the expected positive influence of education level on the rate of adoption, several studies have also found insignificant effect of this variable on their willingness to adopt conservation agricultural practices (Baumgart-Getz et al., 2012).

Another factor known to influence farmers' adoption decision-making process is their participation in social networks or organizations. Social networks are primarily a group of people who share common goals and aspirations. They serve as channels or structures to share information. In the process of innovation adoption, farmers make decisions based on the information they receive from their social network members, which could be in the form of advice from members who have already used such innovations (Reimer et al., 2012; Liu et al., 2018). Sometimes, members also receive such information through educational programs organized by their social networks or groups. Some studies have shown that farmers' exposure to information, the quality of the information, and their connectivity to local agricultural associations are essential contributors to conservation practice adoption (Baumgart-Getz et al., 2012; Liu et al., 2018). Moreover, Smithers & Furman (2003) explained that farmers' participation in environmental organizations are more likely to increase their willingness to adopt conservation practices because they are more open to the consequences of environmental conservation programs. Farmers' participation in social networks is more likely to increase their adoption of conservation practices and therefore explains the significance of building social capital in the form of multiple opportunities for farmers to interact with others (Knowler & Bradshaw, 2007; Prokopy et al., 2008).

2.2.2 Farm Characteristics

Farm level characteristics have also been shown to affect farmers' decision to adopt conservation practices. The particular characteristics of the farm, such as size of the farm, type of land ownership, sales from farm activities, and the kind of farm operation (whether it is a crop production farm or livestock production farm or a mixture of both activities) affect farmers' decision to adopt conservation practices (Traore et al., 1998; Prokopy et al., 2008). These farm characteristics are primarily categorized into two groups, namely: (1) farm biophysical characteristics and (2) farm financial and managerial characteristics. The biophysical characteristics of the farm include the soil type and slope, size of the farm, water availability, presence of environmental problems, among others (Knowler & Bradshaw, 2007; Baumgart-Getz et al., 2012). Factors such as farm income sources (on or off-farm), land tenure, land ownership status, and sales from farm operations, among others, include the farm financial and managerial characteristics (Prokopy et al., 2008).

Farm size is considered one of the most common biophysical characteristics of farms explaining farmers' decision to adopt conservation agricultural practices. Generally, researchers have hypothesized that the larger the farm, the more likely farmers are to adopt conservation practices (Prokopy et al., 2008). The reason for this hypothesis is that since agricultural conservation practices require higher initial or establishment costs, farmers with large farm sizes can spread the costs of adopting the conservation practice over the total farm size, which provides a rationale for possible adoption. A synthesis of the existing relevant literature on the determinants of conservation practice adoption by Prokopy et al. (2008) revealed that for all the practices examined, acres of land had a significantly positive influence on the adoption of conservation practices. Even though this is found to be true in most studies, some studies have suggested that the size of farm tends to have a negative influence on the adoption of conservation practices (Baumgart-Getz et al., 2012; Rempel, 2014). In fact, a quantitative summary of 46 adoption studies in the US by Baumgart-Getz et al. (2012) revealed that farm size had mixed effects (positive, negative, or sometimes inconsistent effects) on farmers' decision to adopt conservation practices. A study by Rempel (2014) indicated that farmers with larger farm sizes were removing their already existing shelterbelts and were less likely to plant shelterbelts.

In addition to farm size, soil type can also influence a farmers' decision to adopt conservation practice. For instance, a farmer with a soil type more prone to soil erosion is more likely to adopt a conservation practice that protects the soil against erosion, such as minimum or zero till, or the planting of shelterbelts. Also, the kind of environmental problems a farmer faces will determine his/her willingness to adopt a conservation practice that seeks to address such challenges (Prokopy et al., 2008). For instance, adoption of conservation agricultural practices that make more efficient use of water resources may be appropriate in circumstances where water supplies are depleting, and farmers rely heavily on water resources. Marques et al. (2005) noted that difficulties in accessing reliable water supply could act as a hindrance of adoption to such conservation practices. Moreover, in cases where the activities of farmers impose health risks on neighboring communities, farmers may be encouraged to adopt conservation practices. For example, Tyndall & Colletti (2007) asserted that livestock farmers can plant shelterbelts around the primary sources of swine odor, which include swine buildings, manure storage systems, and crop fields that receive land-applied manure to mitigate the resulting odor. This helps to reduce the negative social impact of odor creation, such as respiratory disorders from inhaling infected air.

Within farm characteristics, land ownership status is considered a factor that can influence farmers' decision to adopt a conservation practice. In general, farmers who own their lands are more likely to adopt practices that can increase the value of their lands by protecting the lands from degrading (Knowler & Bradshaw, 2007). This is because farmers who own their agricultural lands perceive that by adopting conservation practices, they will be able to enjoy the benefits from their lands for a long period (Knowler & Bradshaw, 2007). Conversely, the effect of land ownership type on conservation practices adoption decision has been found to be inconclusive in the literature. For instance, a synthesis of the existing literature on conservation practice adoption by Prokopy et al. (2008) showed that the number of studies that found land ownership type to positively influence adoption decisions was equal to those that found it to have a negative influence on adoption.

2.2.3 Characteristics of the Conservation Practice

The specific characteristics of conservation practice or technology are considered one of the categories of adoption determinants. Even though the farmers' attributes and farm characteristics have been used to explain the adoption decision of farmers, several studies (Adesina & Zinnah, 1993; Reimer et al., 2012) have suggested that the findings of such adoption studies are inconclusive. They posit that the perceptions that farmers' form about new technologies play a significant role in their decision to adopt them.

The technology-specific characteristics are categorized under Roger's original five characteristics of innovation, which he labeled as being: (1) relative advantage, (2) compatibility, (3) complexity, (4) trialability, and (5) observability (Reimer et al., 2012).

The feature of an innovation called relative advantage "is the degree to which an innovation is perceived as being better than the idea it supersedes” (Rogers, 2003). Here, farmers must be convinced that adopting the innovation would provide more positive impacts to their farm operations than their current practice. Several studies have found that farmers are more likely to adopt new practices if they are convinced of receiving high economic gains from the new practice compared to the previous practices (Reimer et al., 2012). Beyond financial profitability, farmers could consider an innovation to have a relative advantage if they perceive gains from adoption, such as an increase in social prestige, time-savings, creating more comfort, and having a lower rate of returns of investment (Rogers, 2003). The type of innovation largely determines what specific kind of relative advantage (such as economic, social, environmental, among others) is of significance to the farmer (Rogers, 2003).

Another innovation-specific feature essential for an adoption decision is the compatibility of the innovation. According to Rogers (2003), compatibility of an innovation “is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters”. Farmers should find the innovation to be more compatible with their sociocultural values and beliefs, previously introduced ideas, as well as their needs for innovations (Rogers, 2003). The degree to which farmers perceive the new technology to be compatible determines their level of the perceived risk of the technology. For instance, if farmers see the innovation to be more consistent with their values, then they may consider it to be less risky or uncertain.

Moreover, the complexity of an innovation “is the degree to which an innovation is perceived as relatively difficult to understand” (Rogers, 2003). Potential adopters are concerned with their ability to use innovation. The difficulty or ease with which an individual can use a practice will largely influence the rate of adoption (Reimer et al., 2012). Generally, farmers’ perception of the complexity of an innovation is expected to decrease their willingness to adopt (Rogers, 2003).

Trialability of an innovation “is the degree to which an innovation may be experimented with on a limited basis” (Rogers, 2003). If an innovation permits a landowner to try it on a small scale without incurring excess cost even if the innovation fails to perform to its full potential, then the farmers will be more willing to adopt. Rogers (2003) posited that farmers are more likely to adopt practices that can be tried in installments than those that are not divisible, and therefore cannot be tested on small scales. Pannell et al. (2006) noted that the trialability feature of an innovation allows adopters to explore its other characteristics, such as relative advantage, complexity, observability, and compatibility, before they adopt it on larger scales. This helps farmers to reduce the level of risk associated with adopting the innovation.

Lastly, observability of an innovation “is the degree to which the results of an innovation are visible to others” (Rogers, 2003). People will want to adopt a practice after they have seen it work for other adopters. If the outcome of an innovation is such that other people can see and feel it, then they will be more likely to adopt.

2.2.4 External Characteristics

Farmers’ decisions to adopt conservation practices are sometimes influenced by factors beyond the farm level, and may be related to the ecological, social, economic, and political systems within which their agricultural systems and operations function (Bogdan, 2019).

Adoption of conservation practices can be affected by overarching agricultural policies, together with programs and schemes aimed at addressing the environmental problems associated with agricultural production systems (Weersink et al., 2001; Bogdan, 2019). These policies may either be in the form of providing incentives (i.e., cost-share programs, subsidies, providing tax rebates) or conversely disincentives (taxes, charges). For instance, cost-share programs that decrease farmer’s cost of adopting conservation practices may increase their adoption of these practices since such programs may reduce the initial cost burden of adopting such practices. Similarly, input charges imposed on production inputs or practices that can cause environmental problems, may deter farmers from using such inputs or practices.

Furthermore, activities of environmental agencies, such as the provision of education, extension, and technical supports, are more likely to increase farmers' adoption of conservation practices (Stonehouse, 1994; Laurent et al., 2006). Through the provision of extension services and education, farmers can acquire knowledge about such challenges, which may affect their decisions to adopt the necessary conservation practices (Laurent et al., 2006). As Rogers (2003) has identified, access to quality information plays a significant role in the innovation diffusion process. Such information can be obtained through the services of extension officers, who are considered experts in providing such knowledge. Similarly, social networks, as well as peer groups, are also known to provide information that aid in farmers' adoption decisions (Prokopy et al., 2008).

Understanding the determinants of conservation practices adoption provides a basis for developing policy mechanisms targeted at encouraging the adoption of such practices. Government policy intervention affects farmers’ decision to adopt conservation practices as they may provide an incentive for adopting conservation practices or hinder adoption of such practices. The subsequent section provides a broad overview of policy instruments used to encourage the adoption of conservation agricultural practices.

2.3 Policy Instruments: An Overview

Policy instruments are mechanisms that governments use to pursue and achieve desired objectives or goals. They are essential in determining and improving the state of our environment (Pannell, 2008). Individuals and sometimes firms can adopt practices that encourage and preserve the environment mainly because of some policy incentives or regulations (Weersink et al., 1998). Through the provision of incentives or restrictions, individuals are encouraged to either accept or refrain from behaviors or practices they would not have undertaken on their own will (Weersink et al., 2002). In the agricultural sector, policymakers can use several types of policy instruments to encourage the adoption of conservation practices by farmers (Pannell, 2008). Weersink et al. (1998) identified three categories of policy tools that may be used to increase the adoption of conservation agricultural practices: (1) command-and-control or regulatory policies (e.g., performance standards, design standards, laws, etc.), (2) economic instruments (e.g., taxes, subsidy payments, tradable permits, etc.), and (3) education and information provision (e.g., technical assistance and extension, research and development, etc.). The following paragraphs present an overview of these categories of policy instruments used to encourage the adoption of conservation practices.

2.3.1 Command-and-Control (CAC) Policies

This category of policy instruments is also known as regulatory requirements. They are enacted to regulate an industry or an activity through legal enforcement of standards. They involve measures imposing requirements on farmers to achieve specific levels of environmental quality, including environmental restrictions, bans, permit requirements, maximum rights, or minimum obligations (OECD, 2004). In most countries, command-and-control policies are considered the most common policy instrument for ensuring that farmers adopt conservation practices (OECD, 2004). Here, policymakers ensure that farmers adhere to restrictions regarding the level of pollution they generate, and the kind of practices they may adopt for their agricultural production (Weersink et al., 1998). These policy instruments outline the acceptable and unacceptable practices. Unlike any other category of policy instruments, such as economic incentives that use taxes and subsidies as motivation for compliance, command-and-control policy instruments use the presentation of quality standards or targets by a government authority that farmers adhere (OECD, 2004). These standards provide the benchmark against which farmers actions are regulated. That is, they include monitoring and enforcement standards with legal measures used to impose fines or other punishment on those who do not comply.

The use of command-and-control policy instruments in agriculture have been applied to different study fields (OECD, 2004), but mostly in issues relating to environmental conservation activities. In many OECD countries, command-and-control policy instruments play an essential role in addressing agriculture's environmental problems. Some of these requirements are specific only to agriculture, while others are a part of broader national environmental legislation affecting many sectors, including agriculture. The command-and-control policy instruments strongly rely on using standards to ensure improvements in an environment's quality (OECD, 2004). These standards may include ambient, emission, and technology standards. Ambient standards require farmers to maintain a certain level of environmental quality (Weersink et al., 1998). Also, emission standards involve putting a limit on the amount of emissions (which may include greenhouse gas emissions, emissions from feed-use, among others) that farmers may emit from their production process, beyond which they would be required to pay emission charges (Weersink et al., 1998). Lastly, technology standards require farmers to adopt certain conservation practices or technologies or prohibits them from using certain practices that are considered environmentally unfriendly (Weersink et al., 1998; Stavins, 2003). Field (1994) asserts that in most pollution control programs, there is a combination of standards being implemented that ensure achieving maximum results. Command-and-control policy instruments tend to be less flexible than economic instruments (Macrory, 2006) since they do not allow farmers the freedom to determine for themselves the most appropriate ways of meeting environmental objectives.

2.3.2 Economic Instruments

Economic instruments are a major category of policy mechanisms used to address issues in environmental conservation practices in general. Economic instruments can be either positive or negative incentives, as well as the creation of new markets (Weersink et al., 1998; Stavins, 2003). They are becoming popular as tools for addressing a wide range of ecological issues, from acid rain to climate change (Weersink et al., 2002). Economic instruments provide continuous monetary inducements to encourage farmers to reduce the releases of harmful pollutants.

Positive incentives involve financial payments in exchange for reducing environmental damage or increasing the provision of environmental benefit (Weersink et al., 1998; Hall, 2006). Examples of such incentives include subsidies and tax releases.

Subsidies can be used to encourage farmers' adoption of conservation agricultural practices via decreasing the cost of adopting the practice or increasing the benefit of adopting such practice (Weersink et al., 1998). These incentives encourage farmers or firms to adopt practices which they may not adopt otherwise. In most cases, the initial cost of adopting conservation practices is considered expensive by farmers, which may hinder their decision to adopt such practices (Rempel, 2014). The subsidy payments are mostly in the form of voluntary cost-sharing programs.

Cost-sharing programs provide incentives for a set of beneficial management practices, thereby making such practices less costly to farmers (Weersink et al., 2001). By participating in such programs, farmers become eligible to receive payments from the government (policymakers), which encourages them to adopt conservation practices. They make conservation practices attractive to farmers by offsetting or reducing the initial investment costs of adopting such practices (Weersink et al., 2001). In Canada for instance, the Federal government has implemented a number of these programs to encourage the adoption of conservation practices. Significant among them is the National Farm Stewardship Program (NFSP), which was established to encourage the adoption of various conservation agricultural practices by farmers (Government of Canada, 2009). The NFSP assists farmers to take action to reduce identified environmental risks and to improve management of agricultural lands to reduce risk to water and air quality, improve soil productivity and enhance wildlife habitat (Agriculture and Agri-Food Canada, 2007), with 60% of the program's funds contributed by the Federal government and the remaining 40% by the provincial government. The program has been in existence in different provinces across Canada including Saskatchewan Farm Stewardship Program (SFSP).

Under the Saskatchewan Farm Stewardship Program (SFSP), participating farmers receive funding to implement conservation practices aimed at improving water quality, climate change and biodiversity (Government of Saskatchewan, 2018). Some conservation practices eligible for payments under the SFSP include permanent tame forage, drainage stewardship, native rangeland grazing management, riparian grazing management, livestock stewardship, invasive plant biocontrol and targeted grazing, and cow-calf water protection. Each conservation practice has its funding limits and eligibility requirement with minimum payment rebate ($250) and claim ($500). (Government of Saskatchewan, 2018). Moreover, the SFSP provides incentives for the establishment of shelterbelts by farmers with the aim of encouraging "the planting of trees and shrubs for livestock facility protection, snow trapping/field enhancement, and vegetative buffers along riparian regions (Government of Saskatchewan, 2018). Farmers who meet the basic qualifying criteria[3] can apply for a cost-share reimbursement of $1,200 per mile of shelterbelt trees up to a maximum of $5,000 (Government of Saskatchewan, 2018).

Another set of economic instruments used to encourage the adoption of conservation practices is negative economic instruments. Though they are not mandatory, negative economic instruments are used to induce changes in agricultural practices rather than force such changes on farmers (Segerson & Walker, 2002). They mostly include taxes or charges on practices or inputs that cause damage to the environment (Hall, 2006). For example, emission charges are imposed on the pollution discharged into the air or water from agricultural production activities thereby increasing the cost of disposing of waste materials (Weersink et al., 1998). Alternatively, input charges are imposed on production inputs thereby increasing the cost of the input, which incentivizes the decreased use of such inputs by farmers so that they no longer pay the input charge, or only pay minimal charge (Weersink et al., 1998; Segerson& Walker 2002). Moreover, input charges be imposed on water used for irrigation resulting in decreased use. By so doing, farmers may choose to shift from the use of such production inputs or practices to a more efficient production input or practices thereby conserving the environment. Examples of input-use taxes include fertilizer and pesticides taxes. Generally, negative economic instruments work by inducing farmers to internalize the negative externalities of their agricultural production decisions on the environment (Weersink et al., 1998). They can reduce the costs of attaining environmental protection objectives by

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[3] Eligibility Criteria for Participating in the SFSP as stated in the Farm Stewardship Program (2016) include: (1) Be a Saskatchewan agricultural Producer (individual, partnership or corporation) and can demonstrate a minimum of $50,000 of gross farm income in the year of application or prior to the year of application, (2) A First Nation in Saskatchewan, (3) Be at least 18 years old and (4) Farmers who own, lease or rent property where livestock and poultry are grown, bred, kept, raised, displayed, or disposed and which require a Saskatchewan premises Identification (PID) number.

encouraging farmers to reduce their input use (fertilizers and pesticides) to the level where the marginal cost of control equals the tax amount (Weersink et al., 1998).

Carbon pricing is a negative economic instrument that has become prevalent in addressing environmental issues, more specifically, carbon emissions into the atmosphere. In Canada for instance, pricing carbon usually takes two forms: (1) Fuel charge and (2) Output-Based Pricing System (OBPS). The fuel charge system of pricing carbon attaches cost to emissions on fossil fuels such as gasoline and natural gas proportionally to the carbon level of the fuels (Government of Canada, 2017). The fuel charge system of pricing carbon is practiced in Ontario, Manitoba, Yukon, Alberta, and Saskatchewan provinces as well as in the Nunavut territory of Canada. Conversely, the Output-Based Pricing System (OBPS) of pricing carbon “retains a price on carbon pollution that creates an incentive for emissions-intensive and trade-exposed facilities to reduce emissions per unit of output, while mitigating the risk of decreased domestic production and of carbon leakage to other jurisdictions” (Environment and Climate Change Canada, 2021). The OBPS is practiced in Manitoba, Yukon, Prince Edward Island, Nunavut, and partially in Saskatchewan. Despite its political flexibility and manipulations, carbon pricing is considered a more effective, transparent, and efficient policy approach to reduce and mitigate greenhouse gas (GHG) emissions (Government of Canada, 2017). In 2017, the Federal government announced a nation-wide carbon price of \$10/tCO_2(eq) to start in 2018, which was expected to increase on a \$10 increment each year up to \$50/tCO_2(eq) by 2022, beyond which it would increase by \$15. Barring any change in federal policy the carbon price should reach \$170/tCO_2(eq) by the year 2030. (Government of Canada, 2017). Carbon pricing works by encouraging farmers and businesses to shift from using inputs and technologies that emit larger amounts of carbon dioxide to lesser carbon emitting technologies or practices.

2.3.3 Education and Information Services

Another set of policy mechanisms that policymakers can use to encourage farmers' decision to adopt conservation practices is education/information providing services. One of the significant barriers to the adoption of conservation practices is the lack of information on the part of the farmer regarding both the profitability and the environmental benefits of adopting such practices (Feather & Amacher, 1994). Moreover, Rogers (2003) has identified that farmers’ perception of innovation’s complexity and trialability are significant in influencing their adoption decisions. Farmers’ who find conservation practices complex may not be willing to adopt such practices (Reimer et al., 2012). Therefore, through the provision of extension and technical assistance to farmers, policymakers may decrease the uncertainty associated with adoption (through ranking them or selecting better practices), which can decrease the cost of adoption and thereby increase the willingness to adopt conservation practices. Organizing workshops can provide these educational services for farmers. Policymakers may also encourage the establishment of social networks, such as Soil Conservation Council (SCCC), to increase the rate of diffusion of knowledge about conservation practices.

Farmers, who participate in social networks that provide extension and technical assistance, have been shown to be more likely to adopt conservation practices (Tamini, 2011). He estimated the impact of Agri-Environmental (A.E.) advisory activities on Best Management Practices (BMPs) adoption in Quebec (Canada) and found the average effect of agri-environmental extension activities to be statistically significant for most BMPs. The study results suggested that farmers' who participate in A.E. advisory activities are more likely to adopt a BMP. The study also revealed a statistically significant formal diffusion effect of producer' membership in an A.E. advisory club. For BMPs that require advanced technical knowledge, the informal diffusion effect for them was found to be statistically significant. Using education/information providing mechanisms such as extension services and technical assistance services, encourages adoption of conservation practices by farmers.

Moreover, the use of information providing services is considered a more cost-effective method of increasing farmers' adoption of conservation practices compared to direct regulations or financial incentives (Feather & Amacher, 1994). For instance, Feather & Amacher (1994) assessed the role of information in the adoption of conservation practices for water quality in the USA. They employed a two-staged adoption model using data from a survey of farmers in the USA and found that producer perceptions play a significant role in the decision to adopt. Their study results suggested that changing the perceptions of farmers by using an educational program may be an appropriate alternative to financial incentives in increasing the adoption of conservation practices. Information-based policy instruments can also be complementary to other policy instruments, such as payment-based (subsidies) or taxed-based policies in that with more information the payment level to encourage the adoption of conservation practice may decrease (Uri, 1998).

2.4 Summary

The theoretical focus of adoption presented in this chapter was based on Rogers' innovation-diffusion theory, which provided an in-depth understanding of the decision-making process regarding the adoption of conservation practices. Moreover, a summary of the determinants of conservation practices' adoption was provided, with a focus on the four main categories of factors affecting farmers' adoption decisions; (1) Farmers characteristics, (2) Farm characteristics, (3) Characteristics of the conservation practice, and (4) External characteristics, thereby providing a basis for designing appropriate policies to encourage farmers' adoption of conservation practices.

As discussed earlier, the appropriateness of any policy instrument depends on the objectives of the policymaker or government. Policymakers may choose a particular policy instrument or a mix of policy instruments to achieve their policy objectives. In this study, one of the objectives was to evaluate various policy instruments that may be appropriate in encouraging the planting of shelterbelts by farmers in Saskatchewan. This chapter, therefore, provided an understanding of the role of government intervention in encouraging farmers adopt conservation practices by reviewing relevant literature in the area of government policies and program.

Chapter 3

Theoretical Framework

3.1 Introduction

Farmers' decision to adopt shelterbelts has effects spanning from gains in farm productivity and income, as well as benefits to the environment. Shelterbelts can provide direct benefits to farmers, through increases in crop and livestock productivity (Kort, 1988), which then raises the farm-level revenue. Also, they can offer services that protect the environment, which improves the wellbeing of society (Kulshreshtha & Kort, 2009). However, a profit-maximizing farmer would make shelterbelt-investment decision mainly by considering the potential level of net private benefits of such investment (Pannell, 2008). That is, it is unlikely for a farmer to adopt shelterbelt if it offers greater cost, whether through the direct cost of establishing and maintaining shelterbelt or the opportunity cost of foregoing arable agricultural land, than the level of private benefits (negative net private benefits). This chapter discusses and illustrates field shelterbelt investment decision making faced by a farmer as supported by economic theory. A simple economic model is developed to demonstrate the optimal choice of field shelterbelts quantity, and the role of government policy intervention in ensuring the provision of social optimal quantity of field shelterbelts by farmers.

3.2 Externalities and Welfare Loss

The concept of externality refers to a situation where the activities or decisions of an economic agent affect a third party outside the scope of the agents' decision-making. Thus, the agent making the decision does not bear the full consequences of his or her action (Tietenberg, 2006). The effects to the third party may be positive (increased in benefits or reduction in costs), the case referred to as a positive externality, or negative (increased in costs or reduction in benefits), the case referred to as a negative externality. For instance, the odor generated from the activities of a hog producer that decreases the well-being of people in the neighboring communities can be considered a negative externality to the members of the community. This is because the hog producer may not consider the decreased welfare associated with the offensive odor borne by the neighbors in their production decision-making, and in fact has no economic signals, such as prices, to represent these external costs to enable an efficient decision. Conversely, a farmer who adopts a practice, such as the planting of buffer strips, which improves water quality, provides positive externality to its neighbors. However, the farmer does not consider the benefits provided to society in its production decision making because there are incomplete prices or economic signals associated with these externalities to enable an efficient decision.

The presence of an externality is considered one of the primary causes of market failure (Tietenberg, 2006) as it does not ensure the efficient allocation of goods and services in the market. In the case of positive externalities, the marginal social benefits of the activity are greater than the marginal private benefits to the decision-maker (Tietenberg, 2006). Moreover, because the third parties do not pay for such external benefits, farmers tend to produce quantities of the commodities that are less than optimal production levels or the underproduction of social goods (Tietenberg, 2006). On the other hand, in the presence of negative externalities, the marginal social costs of the activity are greater than the marginal private costs to the decision-maker or the producer (Tietenberg, 2006). Because producers do not cover the external costs of their production decisions, they produce quantities of the commodities beyond the optimal production levels, resulting in overproduction of goods and services or the overproduction of social bads (Tietenberg, 2006).

Externalities in the market lead to inefficient distribution of resources causing market failure. This market failure occurs when farmers do not internalize all the costs of production (when their actions impose external costs) or internalize all the benefits from their production decisions (when their actions bring external gains in social welfare), which ultimately affects social welfare (Caldari & Masini, 2011). It is important to note that, aside from the presence of externalities that causes the market to fail, there are other sources of market failure. Notable among them include public goods, common property resources, and the presence of monopoly (Randall, 1983). However, for this study’s purpose, market failure resulting from positive externalities is more relevant since the environmental services field shelterbelts provide serve as positive externalities to the society.

3.3 Market Failure in Shelterbelt Provision

Shelterbelt investment is associated with private costs and benefits to the farmer. These costs are referred to as shelterbelt establishment and maintenance costs. They include the cost of tree seedlings, labour, herbicides, as well as irrigation costs (Rudd, 2020). Moreover, farmers face opportunity costs for the arable land they take out of crop production to plant these shelterbelts. On the other hand, the farmer derives some benefits from this shelterbelt investment, which include increased crop yields, improved soil retention, enhanced water quality, and protection of farmsteads from extreme weather conditions (Brandle et al., 2004; Kulshreshtha et al., 2010). In addition to the benefits to farmers, shelterbelts provide ecosystem benefits, which are considered as external benefits to society. These ecosystem benefits include enhanced biodiversity, carbon sequestration, improved air quality and enhanced wildlife habitat (Kulshreshtha et al., 2010). Generally, farmers do not receive financial rewards for the full range of ecosystem benefits the shelterbelts provide. This is due to the lack of markets for the ecosystem benefits supplied by shelterbelts.

The limited financial gains from the ecosystem benefits shelterbelts provide coupled with higher shelterbelt establishment and maintenance costs can lead to farmers supplying lesser quantity of shelterbelts, thereby providing fewer ecosystem benefits than socially optimal level. This is because profit-maximizing farmers may undersupply shelterbelt quantities due to the lack of financial gains for doing so. This underproduction of shelterbelt quantities relative to the socially optimum quantity represents a market failure in shelterbelt management.

The market failure in shelterbelt provision is represented with a market model in Figure 3.1, where the private marginal costs and private marginal benefits of shelterbelts are represented *MCprivate* and *MBprivate* curves, respectively.

The private marginal cost curve slopes upwards as shown in Figure 3.1. This is because, for any additional units of shelterbelts planted, the farmer incurs an additional cost, which increases with increase in shelterbelt planted. For instance, a farmer who plants a single row of field shelterbelts (say caragana shrub) will need to incur the purchase cost of tree seedlings, herbicides cost, cost of irrigation, as well as the opportunity cost of land used for planting the shelterbelts. Higher quantities of shelterbelts provision impose greater management costs. In other words, the cost to the farmer for providing additional quantities of shelterbelts increases as the quantity of shelterbelts increases.

Conversely, the private marginal benefit curve is downward sloping, as shown in Figure 3.1. This is because, increasing the quantity of shelterbelts planted increases the provision of ecosystem services associated with shelterbelts. However, as farmers increase the quantity of shelterbelts planted, the marginal benefits of increasing the ecosystem services decrease.

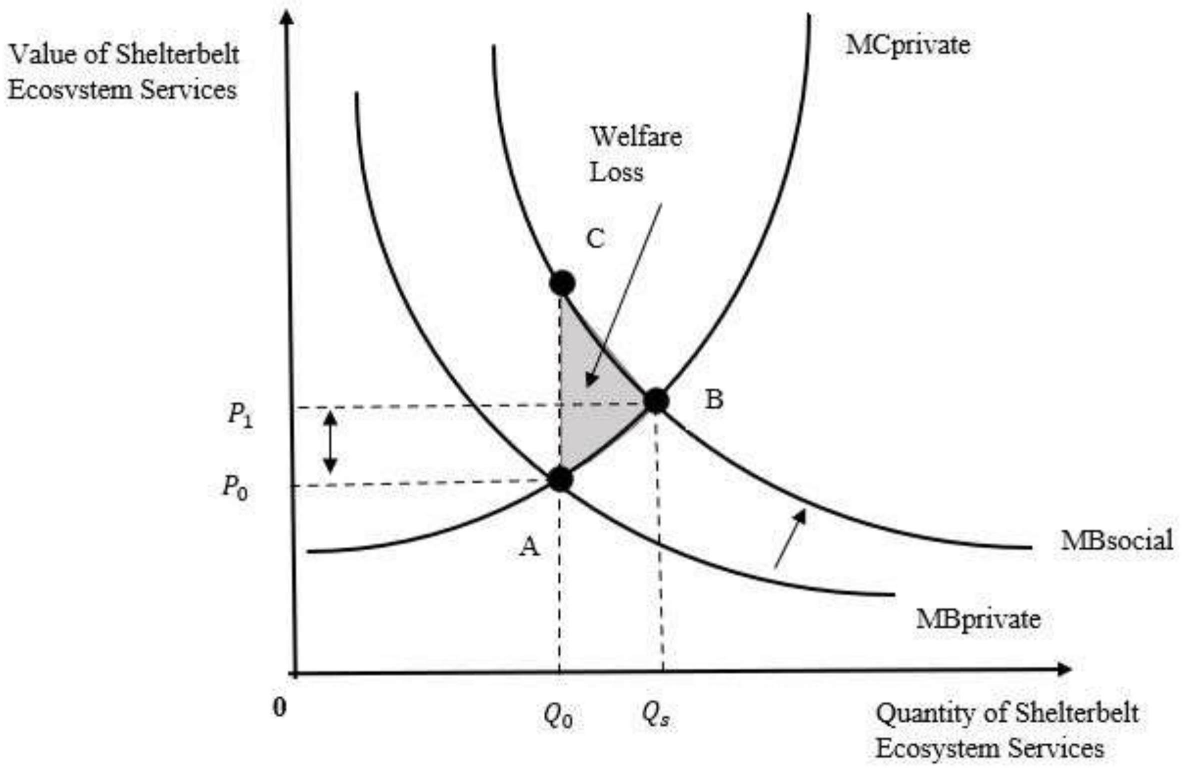

Figure 3.1. Potential of market failure in shelterbelt provision.

Combining the *MCprivate* and *MBprivate* curves or functions in the economic model denotes the private market supply and market demand for shelterbelts. A farmer will supply shelterbelt quantities up to the point where the private marginal cost of establishing the next unit of shelterbelts is equal to the private marginal benefits derived from that unit of shelterbelts. This point is denoted as "A" in Figure 3.1. Point A (the point of intersection between the $MCprivate$ and $MBprivate$) is referred to as the private equilibrium point, from the farmer's point of view. At this point, the farmer supplies Q_0 units of shelterbelts at a marginal cost (price) of P_0. The supply of shelterbelts beyond point A (Figure 3.1) will impose greater costs than benefits to the farmer. Being a profit-maximizing farmer, the farmer will not be willing to make such investment decisions since the private cost associated with such decision exceeds the private benefits.

In addition to the private benefits to farmers, shelterbelts also provide benefits to society. These benefits are the ecosystem services shelterbelts provide, which include carbon sequestration, improved air, and water quality, enhance species biodiversity, and provision of aesthetics. They are referred to as marginal external benefits and are captured by the vertical distance between the $MBprivate$ and $MBsocial$ curves in Figure 3.1. In the presence of the marginal external benefits of shelterbelts, the marginal social benefits ($MBsocial$ = $MBprivate$ + External benefits) exceed the private marginal benefits (Tietenberg, 2006). As noted earlier, increasing the provision of shelterbelts imposes higher private costs to the farmers via increased seedlings and other input costs. Similarly, planting shelterbelts imposes an external cost in the form of potentially less commodity production, which could result in higher food prices. However, for simplification purpose, external costs of shelterbelts are essentially assumed to be zero, in which case, the marginal private cost is equal to the marginal social cost ($MCprivate$ = $MCsocial$).

The socially optimum supply of shelterbelts (the environmental goods and services from shelterbelts), which occurs at point B with corresponding shelterbelt quantity of Q_s (Figure 3.1) maximizes net social welfare. This point is the intersection of the social marginal cost ($MCsocial$) and the social marginal benefit ($MBsocial$) curves (Figure 3.1). Society's demand for shelterbelts as represented in Figure 3.1, is greater than the amount the farmer is willing to supply. This is because, in the presence of positive externalities, the marginal social benefits are greater than the marginal private benefits, society would prefer more shelterbelts than what the farmer would be willing to supply (Tietenberg, 2006). This is shown in (Figure 3.1), where society's demand for shelterbelts , Q_s, is greater than the quantity of shelterbelts the farmer is willing to supply , Q_0. This is the market failure. In other words, the market fails to supply the socially optimal quantity of shelterbelts. The difference between these two quantities represents the loss in social welfare, which occurs due to positive externalities, represented by the triangle ABC in Figure 3.1. It provides clear evidence of a potential market failure in shelterbelt management since private farmers may undersupply shelterbelt quantities less than socially optimum.

As discussed above, the amount of shelterbelts provision associated with the private market supply and demand functions is less than socially optimum. The difference between optimal market supply of shelterbelts by farmers (Q_0) and the socially optimal demand of shelterbelts (Q_s) represents the net welfare loss to society. The welfare loss is the loss in economic efficiency resulting from the undersupply of the quantity of field shelterbelts by the landowner (Tietenberg 2006). This is represented by area ABC in Figure 3.1. The welfare loss to society in shelterbelt management suggests that government policy interventions that could encourage farmers to increase their shelterbelt quantities to the socially optimum level, may further increase social welfare and ensure the efficient distribution of the environmental services of shelterbelts.

3.4 Role of Government Policy Intervention

As noted earlier, the provision of shelterbelt ecosystem services is undersupplied by private farmers because of the positive externalities associated with their establishment. In view of this, government policy interventions may be relevant to encourage private farmers to provide the socially optimum quantity of ecosystem benefits derived from shelterbelts. The goal of the policy intervention may be to increase the private marginal benefits associated with shelterbelt establishment to that point where they are equal to the social marginal benefits. However, policymakers are faced with a wide range of policy options from which they can choose to address the market failure that exists in shelterbelt management. As discussed in Chapter 2, the policy instruments may include regulations, economic incentive instrument, such as subsidy payments and cost-share payment programs, and information-based policies aimed at providing extension, educational and technical assistance to farmers (Weersink et al., 2002). In this study, the role of positive economic incentive policy instruments in resolving the market failure in shelterbelt management is discussed.

Positive economic incentive instruments involve monetary transfers from the policymakers (i.e., tax revenue from government) to the farmer in exchange for reducing practices that creates environmental harm or increasing practices that provide an environment benefit (Stavins 2003; Hall, 2006). Examples of positive economic incentive instruments include subsidies and environmental payments. In most positive economic incentives, such as environmental payments, participation is voluntary and thus farmers only receive monetary transfer when they choose to participate. In shelterbelt management, the role of positive economic incentive instruments may be to reward farmers for giving up arable agricultural lands to plant shelterbelts or subsidize the cost of planting and maintaining shelterbelts.

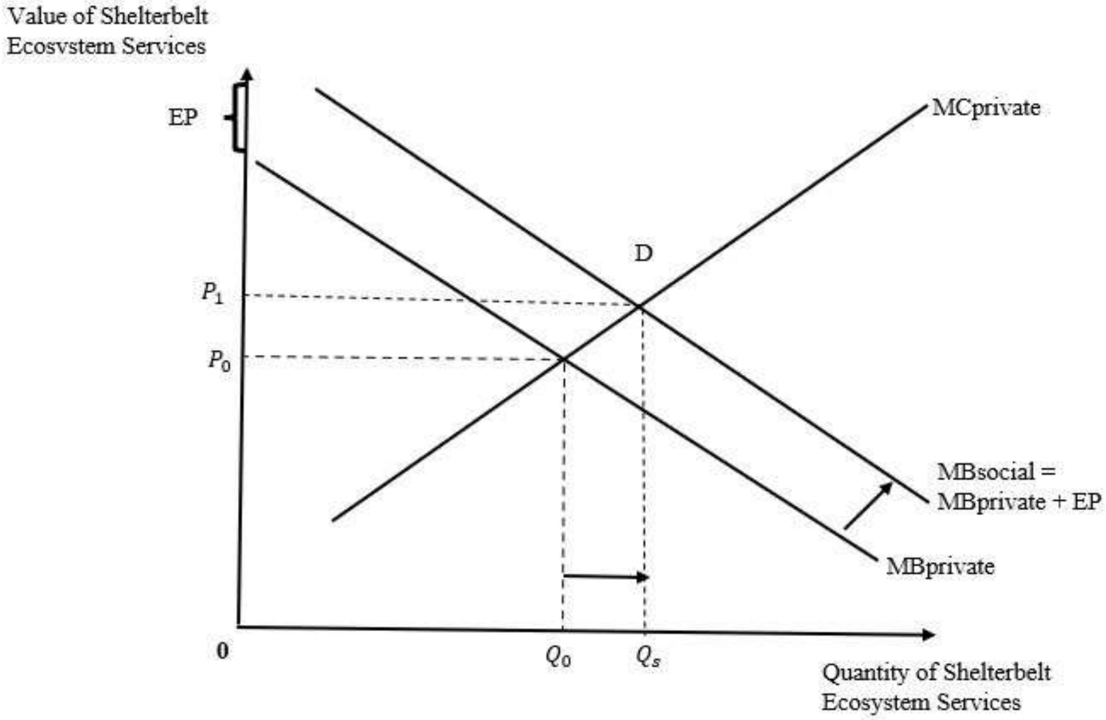

Figure 3.2. Financial incentive and private marginal benefits of field shelterbelts.

Assume that a farmer receives an economic incentive payment (*EP*) for planting a kilometre long field shelterbelt on their farmland (Figure 3.2). In addition to the private benefits of planting the field shelterbelts (*MBprivate*), the economic incentive payment

(*EP*) further increases the farmers' gain from the shelterbelt investment (Total gains = *MBprivate* + *EP*). From Figure 3.2, it can be observed that gains from the economic incentive payment increases the overall benefits that the farmer derive from planting field shelterbelts leading to an upward shift in the private marginal benefit curve. The equilibrium point, where *MCprivate* equals the marginal social benefits (*MBsocial* = *MBprivate* + *EP*) - in this case is established at point D (Figure 3.2), where the farmer makes their shelterbelt investment decision by equating the *MBsocial* curve to the *MCprivate* curve, leading to an increase in the quantity of shelterbelts supply, thereby increasing the provision of the ecosystem services of shelterbelts.

3.5 Summary

In the presence of externalities associated with field shelterbelts (positive externalities), private farmers may undersupply shelterbelt-related ecosystem benefits relative to socially desired quantities, which is a market failure. This market failure may be addressed by the development of economic incentive instruments to encourage the voluntary adoption of shelterbelts by private farmers to increase the provision of shelterbelt-related ecosystem benefits. To encourage the voluntary adoption of field shelterbelts by farmers, economic incentive instruments can be designed such that farmers receive payments necessary to increase private marginal benefits of shelterbelts to the point where they equate the social marginal benefits. This may encourage private farmers to provide shelterbelt-related ecosystem benefits to the level that maximizes social net benefits associated with field shelterbelt.

Chapter 4

Analytical Framework

This chapter presents the methodological approach employed in providing evidence for the study objectives. It is organized in six sections. The first section (section 4.1) provides a complete overview of the research methodology. The second part of this chapter (section 4.2) discusses the geographical locations of the soil zones (Black, Brown, and Dark Brown). The third section (Section 4.3) presents the empirical techniques used for modelling field shelterbelt adoption behavior of farmers in Saskatchewan. Following this, section 4.4 presents the approaches for selecting alternative policy instruments, as well as the selected policy instruments considered in the study. Furthermore, the section discusses various policy evaluation criteria based on which the selected policy instruments are evaluated. The fifth part of this chapter highlights the analytical techniques used for the policy effectiveness analysis in the study (section 4.5). The chapter's last section (Section 4.6) presents a summary of the chapter.

4.1 Overview of Methodology

A flowchart representing an overview of the methodological framework for the study is given in Figure 4.1. The flowchart presents the procedures followed to achieve the objectives of the study. The study's methodological framework consisted of three key components: (1) Policy evaluation criteria, represented by the green ovals in Figure 4.1, (2) Models employed to conduct the policy effectiveness analysis, represented by the blue rectangles in Figure 4.1 and (3) the various external inputs considered in the policy effectiveness analysis, represented by the red parallelograms in Figure 4.1. Policy evaluation criteria are simply the standards against which alternative policy instruments were compared and ranked. Four evaluation criteria were considered in this study: (1) change in farm-level net revenue, (2) probability of shelterbelt adoption, (3) total amount of carbon sequestered (expressed in carbon dioxide equivalent), and (4) fiscal cost per tonne of carbon sequestered (cost-effectiveness). These criteria were used to categorize the policy effectiveness analysis into two levels – farm-level and regional level. The

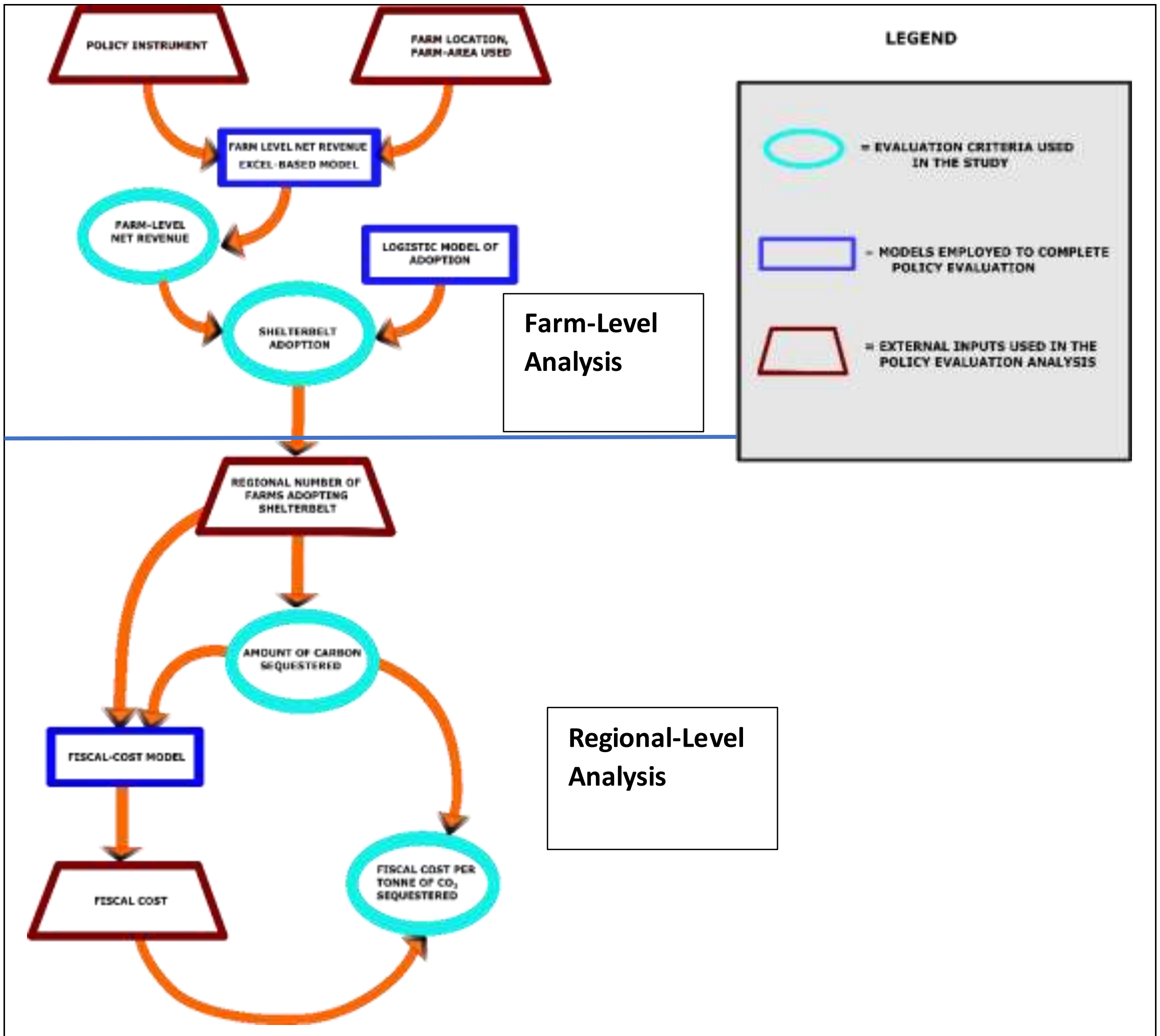

Figure 4.1. Overview of Research Methodology.

farm-level analyses included the impact of selected policy instruments on farm-level net revenue and probability of shelterbelt adoption, while the regional-level analyses included impacts of selected policy instruments on total amount of carbon sequestered and fiscal cost per tonne of carbon sequestered. Moreover, the study model is the model employed to conduct the analyses in the study. Significant among them were a farm-level net revenue spreadsheet-based simulation model, used to estimate the impact of selected policy instruments on farmers' farm-level net revenue; a binary logistic regression model, used to estimate the impact of selected policy instruments on farmers' likelihood to adopt field shelterbelts, and a fiscal cost model, used to estimate the total fiscal cost involved of implementing each selected policy instrument. Finally, the external inputs were simply given factors that aided in the study analyses, such as farm location, the regional number of farms in a soil zone, among others.

As shown in Figure 4.1, the various procedures followed in conducting the policy effectiveness analysis were linked to each other. Firstly, the study analyzed the impacts of alternative policy instruments on farm-level net revenue, using a spreadsheet-based farm-level revenue model developed by Islam (2022). The spreadsheet-based model was developed to estimate the economic returns of shelterbelt investment by considering the farm-level revenue under scenarios where farmers had field shelterbelts and where they did not have shelterbelts on their farms (Islam 2022). The species of shelterbelts considered in this model was caragana. This model was adapted and modified to meet the needs of this study. In the original model, the farm-level revenue with field shelterbelts was estimated using revenue from crop production, cost of production, and the cost of establishing and maintaining shelterbelts. However, in this study, the farm-level revenue under the scenario of field shelterbelts was modified to include payments from the respective policy instruments to determine the impact of the instruments on farm-level revenue. Using the estimates of the policy’s impact on farm-level revenue (expressed as the percentage change in farm-level net revenue for a farm with field shelterbelts under policy), the impact of alternative policy instruments on the likelihood of field shelterbelts adoption was estimated using a binary logistic regression model. The binary logistic regression model was estimated to determine factors that may influence farmers’ decisions to adopt field shelterbelts, as well as to predict the probabilities of adoption under different scenarios. The impact of the policy on the probability of field shelterbelt adoption was estimated as the difference between the probabilities of farmers’ field shelterbelt adoption under scenario policy instrument and the base scenario (no policy instrument). With the estimated probabilities of field shelterbelt adoption, the total number of farms that may adopt field shelterbelts in each soil zone because of the policy instrument was estimated. The estimated number of farms was then used to estimate the total amount of carbon that could be sequestered with the implementation of each policy instrument in each soil zone. Finally, using the estimated number of farms and the total amount of carbon sequestered, the fiscal cost per tonne of carbon sequestered for each policy instrument was estimated.

4.2 Study Location

In Saskatchewan, there are five soil zones (Black, Dark Brown, Brown, Dark Gray and Gray) in Saskatchewan's agricultural region (Rempel et al., 2017). However, this research was focused on three soil zones in Saskatchewan's agricultural area, namely Black, Brown and Dark Brown soil zones[4] (Figure 4.2).

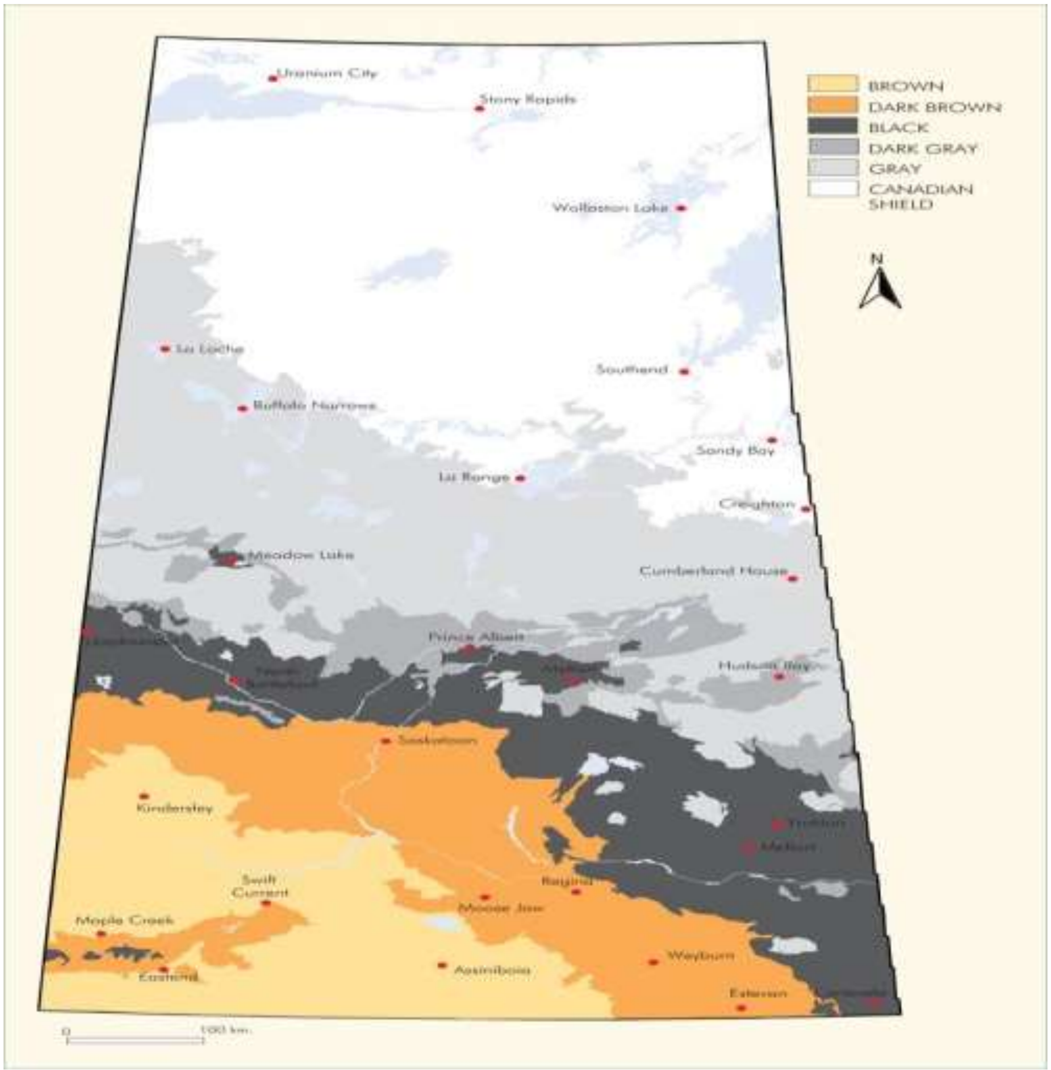

Figure 4.2. Soil Zones of Saskatchewan.

Source: The Encyclopedia of Saskatchewan: https://esask.uregina.ca/entry/soils.jsp (n.d.)

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[4] The component of each soil zone was identified using the Saskatchewan Census of Agriculture Regions (CARs). Islam (2022) noted that the Black soil zone in Saskatchewan comprised regions within CAR 1, 5, and 6. Similarly, the Brown and Dark Brown soil zones comprised of CAR 3 and CAR 4, respectively. Using these CARs, the total number of crop farms in each soil zone was determined using information obtained from Statistics Canada (2021).

The selection of these three soil zones was based on the fact that they represent the agricultural region of Saskatchewan (Kort, 1988). Moreover, each soil zone presents a different soil structure mainly due to differences in their long-term climatic and vegetation patterns, and as such, have varying effects on crop yields (Rempel et al., 2017). As a result, shelterbelt growth rates in the various soil zones would be expected to be different, resulting in a varying impact on crop yields and agricultural production activities in general. For this reason, soil zones could play an important role in the adoption potential of shelterbelts. For instance, Rempel et al. (2017) reported that most farmers in the black soil zone recognize both the market and non-market value of shelterbelts in their farm operations. Therefore, they were more reluctant to remove shelterbelts from their lands. Because farmers in different soil zones may have distinct production practices and economic characteristics, it is essential to understand how differences in such characteristics might influence their shelterbelts-adoption decisions.

4.3 Modelling Farmers' Field Shelterbelt Adoption Decisions

One of the study's objectives was to determine factors that may influence farmers' decisions to maintain field shelterbelts across various soil zones in Saskatchewan. Understanding these factors could provide a basis for policymakers to design and implement appropriate policy instruments that may encourage farmers to include field shelterbelts in their management plans. A policy instrument's effectiveness can be described by its ability to increase the likelihood of adopting a particular practice, making it possible to compare alternative policy instruments (Bogdan, 2019). This section discusses the econometric technique used to estimate field shelterbelt adoption decisions by farmers in Saskatchewan.

4.3.1 Binary Choice Models

Generally, a farmer's decision to adopt a particular conservation practice can be described as a binary choice problem, where the landowner can either adopt or not adopt the practice. This decision process could be affected by several characteristics, including characteristics of the farmer (decision-maker), those of the conservation practice, farm characteristics and other external factors that may affect the decision-maker (Roger, 2003; Reimer et al., 2012). The binary choice nature of farmers' decision to adopt a practice requires the application of a model that provides a mutually exclusive binary dependent variable.

Binary choice or response models are statistical models used to explain changes in a random variable, Y, taking on the values one and zero, representing the presence or absence of an event, respectively (Wooldridge, 2010). For these models, one generally describes the observations in the data such that occurrence of the selected event is represented by one, and the remaining choice or non-adoption, denoted with a zero. These choices are treated as mutually exclusive so that each observation falls in any one of the two choice categories. The mutually exclusive outcomes of the response variable, Y, in a binary choice model are represented as:

$$Y = \begin{cases} 1 & denote\ the\ presence\ of\ the\ event\ of\ interest\ (success) \\ 0 & denote\ the\ absence\ of\ the\ event\ of\ interest\ (failure) \end{cases} \tag{4.1}$$

Binary choice models are primarily used to estimate or predict the choice probability in the response variable (Y=1) given a set of explanatory variables, $X_i(i = 1, 2, 3, \ldots, X_k)$ as well as the relationship between the response variable and the set of explanatory variables (Wooldridge, 2010). The response probability is denoted as

$$P(Y = 1) = P(Y = 1|X_1, X_2, X_3, X_4, \ldots, X_k), \tag{4.2}$$

for various values of X. The statistical techniques commonly used to model discrete or binary choice outcomes are the binary logistic (logit) model, the probit model, and the linear probability model (LPM) which are described below.

Linear Probability Model (LPM): A linear probability model (LPM) is a binary choice model in which the choice probability for the dependent variable $P(Y = 1|X)$ is expressed as a linear function of the explanatory variables (Wooldridge, 2010). The equation for the response variable, Y, in the LPM is represented in equation (4.3) below:

$$p(Y_i = 1|X) = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_k X_{ik} + \varepsilon_i \tag{4.3}$$

Where Y_i is the response variable, which takes the value of 0 or 1, for observations i = 1, 2, …, n, β_i $(i = 0,1,2 \ldots, k)$ is the regression coefficients, representing the quantified relationship between the response variable and the set of predictors. X_i is the set of predictors for each i^{th} observation, and ε_i denotes the stochastic error term for $i =$

$1, 2, 3, \ldots, n$; which have the property of being independent and normally distributed with zero mean and variance $S^2\varepsilon$.

The LPM can be estimated using ordinary least squares (OLS) estimation approach and would result in estimated probability of the binary response variable given the level of explanatory variables. Even though the coefficients of the explanatory variables in the LPM are straight forward to interpret, there are many discussions on its appropriateness in estimating a model with a binary or dichotomous response variable, Y (Wooldridge, 2010). One main disadvantage of the LPM[5] is that its regression coefficients are likely to provide misguiding or meaningless results since the predicted probabilities associated with the coefficients may go beyond the 0 and 1 probability intervals (Wooldridge, 2010). Moreover, the statistical tests for linear analyses in LPM become problematic as there is the presence of heteroskedasticity and non-constant variance of the error term (Wooldridge, 2010).

Binary Logistic (Logit) Regression Model: A binary logistic regression model is a class of generalized linear models[6] (GLMs) used to estimate the choice probability (P(Y=1) of a binary response variable. The choice probability (P(Y=1)) in the logit model is expressed as

$$\mathrm{P}_i = \frac{\exp(\theta_i)}{1+\exp(\theta_i)} \tag{4.4}$$

$$\theta_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_k X_{ik} \tag{4.5}$$

One advantage of the logit model over the LPM is that the predicted probabilities stay within the 0 and 1 probability interval. Because, from Equation (4.4) above, one can observe that the value in the numerator ($\exp(\theta_i)$ is always positive, and it is less than the value in the denominator $(1 + \exp(\theta_i))$, indicating that $0 < \mathrm{P}_i < 1$.[7]

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[5] Detailed explanation on the LPM is provided in Wooldridge (2010, pp. 592-596).

[6] Generalized linear models (GLMs) are procedures used to transform the dependent variable in a model so that the "right hand side" of the model equation can be interpreted as a 'linear combination' of the explanatory variables. In the case where the dependent variable is a binary response variable, the logistic or probit model may be used to model such linear combination between the binary response and the explanatory variables (See Dobson, 2001 pp. 51-58; and Tranmer & Elliot, 2008 for further explanation).

[7] See (Bilder & Loughin, 2014) for more explanation.

The logistic model employs the maximum likelihood estimation (MLE) technique to estimate the coefficients of the explanatory variables $\beta_0, \beta_1, \beta_2, \dots, \beta_k$. The MLE technique ensures that the estimated values for the parameters are those values that maximize the log-likelihood function (Wooldridge, 2010). The logistic regression model is represented in equation (4.6) below:

$$ln\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_k X_{ik} + \varepsilon_i = logit(P_i) = \ln(odds) \qquad (4.6)$$

Where P_i represents the likelihood that the i^{th} observation has an outcome Y_i of value 1, and $1 - \mathrm{P}_i$ is the probability that Y_i is 0. The ratio, $\left(\frac{P_i}{1-P_i}\right)$ is referred to as the odds, and by taking the natural logarithm of the odds ratio, $ln\left(\frac{P_i}{1-P_i}\right)$, one obtains the linear prediction equation of the logit model. The logistic regression model has a logistic cumulative distribution function (Bilder & Loughin, 2014).

<u>Probit Model</u>: Just like the logit model, the probit model is also a class of the generalized linear models that uses the maximum likelihood estimation (MLE) technique to estimate the choice probability (P(*Y*=1)) of a binary response variable. The choice probability (P(*Y*=1)) in the probit model is expressed as

$$P_i = \int_{-\infty}^{\theta_i} \Phi(v)dv \qquad (4.7)$$

Where $\Phi(\theta_i)$ is the standard normal density

$$\Phi(\theta_i) = (2\pi)^{-1/2\exp(-\theta_i{}^2/2)} \qquad (4.8)$$

The predicted probabilities from the probit model are bounded between the 0 and 1 interval. The probit model has a cumulative standard normal distribution function and a nonlinear S-shaped curve explaining the relationship between a predictor and choice probability (Wooldridge, 2010). It is essential to note that, on practical grounds, the probit and logistic models are similar (Chen & Tsurumi, 2010).

4.3.2 Model Selection

As discussed in the previous sections, the three frequently used binary choice models to estimate farmers' adoption decisions are the LPM, the binary logistic regression model and the probit model. Selecting the best binary choice model to use is essential as each model possesses its advantages and limitations. For instance, the regression coefficients from the linear probability model are easy to interpret. However, the regression coefficients are likely to provide unreliable results since the predicted probabilities are not bounded between the 0 and 1 probability interval, with a heteroscedastic error term and non-constant variance (Wooldridge, 2010). Even though LPM's violation of the homoskedastic assumption has little practical implications (Hellevik, 2009), its use is limited in the adoption literature.

In contrast, the logistic and probit models have been used in several studies (Neupane et al., 2002; Akudugu et al., 2012; Bogdan, 2019) to predict farmers' management or policy adoption decisions since they produce reliable probabilities in the binary response variable, Y_i. That is, for the logistic and probit models, the probability that Y_i is 1 is bounded within the 0 and 1 probability interval ($0 < \mathrm{P}(\mathrm{Y}_i = 1) < 1$). They both employ the maximum likelihood estimation (MLE) technique to estimate the regression parameters. However, the differences between these two models lie in their probability distribution functions. The logistic model has a logistic cumulative distribution function, while the probit model follows a standard normal cumulative distribution function (Bilder & Loughin, 2014). Moreover, Chambers & Cox (1967) noted that conditions for which the logistic model may differ from the probit model include cases of large sample size and extreme independent variable levels. For instance, they revealed that a sample size of approximately 1000 observations is required to produce significant difference between the logistic and probit models. This implies that in cases of limited sample size, there is no significant difference between the logistic or probit models and using either of them could produce similar results.

In this study, farmers' shelterbelts adoption decision was modeled using the binary logistic regression model. Though both the probit and logistic model provide practically similar results, the binary logistic model was employed in this study because it provides less computational difficulty and interpretation of its estimated coefficients (Hellevik, 2009). This choice was supported by its wide use in the adoption literature.

4.3.3 Source of Data

Data used to estimate the logistic model were obtained from a survey of farmers across Saskatchewan's agricultural region. The survey collected data on farmer's thoughts, opinions, and values related to shelterbelts as part of agricultural production (Rempel, 2014). The selection of potential survey participants was done by using participants who were randomly selected and had agreed to participate in the Agricultural Greenhouse Gas Program (AGGP) shelterbelt research. These participants were selected using tree order records from 1925 to 2009 from the Indian Head shelterbelt centre (Rempel, 2014). The survey combined multiple choice, yes/no, Likert-Scale ranking questions, and open-ended questions, focusing on three main sections (1) the farm operations, (2) shelterbelt management information and opinions, and (3) farm operator information. The surveys were conducted in the Black, Brown, and Dark Brown soil zones during the summers of 2013, 2018, and 2019 through on-farm visits (in conjunction with AGGP research), phone calls, and meeting farmers at agricultural events. A total of 164 farmers completed the survey, including 61 from the Black soil zone, 60 from the Brown and 43 from the Dark Brown soil zone[8]. The data were cleaned to remove incomplete responses. In all, a total of 96 respondents, made up of 40 from the Black soil zone, 32 from the Brown and 24 from the Dark Brown soil zone, were used to estimate the binary logistic model. A copy each of the survey questionnaires used are shown in Appendix A.

4.3.4 Selection of Model Variables

Farmers' adoption decision-making processes involve a complex set of activities influenced by several characteristics, which can be grouped into four main categories (Rogers, 2003; Prokopy et al., 2008). These categories include farmers' personal attributes, farm characteristics, features of the conservation practice, and context-specific characteristics. Knowledge of these attributes helps to understand how farmers are likely to make decisions regarding their adoption of conservation agricultural practices. Similarly, several empirical studies on adoption (Adesina & Zinnah, 1993; Prokopy et al., 2008; Akudugu et al., 2012; Baumgart-Getz et al., 2012; Reimer et al., 2012) have

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[8] See Rempel (2014) (pp. 40-43) for detailed explanation of the survey design and evaluation as the author developed the "mother" survey administered in 2013, and from which the survey used in the 2018 and 2019 data collection were obtained.

suggested the specific farm and farmer characteristics likely affecting farmers' adoption decisions.

Variables included in the logistic model in this study were selected to reflect farmer and farm characteristics, as well as shelterbelt-related characteristics. Variables, such as years of farming experience and level of education were selected to reflect farmers' personal characteristics. Similarly, soil zone location of farm and gross sales from farm operations (farm income) were included to reflect farm characteristics. Lastly, farmers' perceptions about the environmental benefits of shelterbelts captured by an estimated environmental quality index were included to represent shelterbelt-related characteristics. However, variables such as farm size, and farmers' age, among others, that have been used to explain farmers' decision (Reimer et al., 2012) were not included in this study because they provided statistically insignificant results.

4.3.5 Description of Model Variables

This section provides a detailed explanation of dependent and explanatory variables included in the adoption analysis. The meaning of each variable and the way they were coded and included in the model are also provided. Moreover, the hypothesized relationship between each explanatory variable and the dependent variable (*a priori* expectation about the coefficient of each explanatory variable) is also explained. Table 4.1 provides a list of the variables, together with their measurement types and the expected relationship of each explanatory variable with the dependent variable.

Adopt: This variable is the dependent variable, as it represents farmers' response to the question, "Have you planted field shelterbelts" answered as yes or no. This question's responses were coded as 1=Yes and 0 =No. This question was used as a proxy to measure farmers' willingness to continue planting (adopt) field shelterbelts, since the survey did not include a specific question that required farmers to express their willingness to continuously maintain field shelterbelts. Thus, caution is needed when explaining the results from the binary logistic regression model as results may not reflect the true willingness of farmers to adopt and/or maintain field shelterbelts.

Education: This variable represents level of education attained by the head of the farm household. It was treated as a categorical explanatory variable in the logistic model. Those with elementary or some high school education were categorized as having a low level of education. Similarly, those with high school or technical diploma were categorized as having middle (mid) level of education. Finally, farmers with university bachelors and master's degrees were categorized as having high education level. Farmers' education level was hypothesized to positively influence their decision to adopt shelterbelts (Prokopy et al., 2008).

Soil Zone: This variable represents the location of the farm in Saskatchewan. As noted above, all farms were located within one of three soil zones – Black, Brown, and Dark Brown soil zones. Soil Zone was treated as a categorical predictor variable with the help of two dummy variables (one each for Black and Brown soil zones).

Farming Experience: This variable represents farmers' years of experience related to farming operations. It was treated as a continuous explanatory variable and was hypothesized to positively influence decisions to adopt shelterbelts (Prokopy et al., 2008).

Farm Income: This variable represents the gross farm income from sales of various products (measured in Canadian dollars). It measured the impact of income from farm operations on the decisions to adopt field shelterbelts. Farm income was hypothesized to positively influence their decision to adopt shelterbelts (Prokopy et al., 2008).

EQI: This Environmental Quality Index (EQI) variable summarized the perception of farmers about environmental attributes of field shelterbelts. In the survey, farmers were asked about the extent to which they agree or disagree with the impacts of field shelterbelts on the environment. The following attributes were used to develop this as an index of perception : (1) Carbon sequestration (CS), (2) Improvement in air quality (IAQ), (3) Protect wildlife habitation (PWH), (4) Reduce wind erosion (RW), (5) Enhance species biodiversity (ESB), and (6) Enhance natural insects (pollination) (EI). The weights for this index were estimated using principal component analysis[9].

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[9] See Appendix B for detailed explanation of the principal component analysis.

Table 1. Table 4.1. Variables considered for estimating the Binary Logistic Regression Model

Variables	**Abbreviations**	**Measurement Type**	**Frequency (Percentage) N=96**	**Expected Sign**	**Averages (Base Scenario Values for Predictor Variables)**
Response Variable					
		Categorical			
ADOPT	ADOPT	1 = Yes	N = 36 (38%)		
		0 = No	N = 60 (62%)		
Predictor Variables					
Soil Zone:	SZ	Categorical			
Black	BLK_SZ		N = 40 (42%)		
Dark Brown	DBRW_SZ		N = 32 (33%)		
Brown	BRW_SZ		N = 24 (25%)		
Farming Experience		Continuous (years)	N = 96 (100%)	+	40 (years)
Education Level	EDU	Categorical			
High level	EDU_High		N = 22 (23%)		
Mid-level	EDU_Mid		N = 60 (62%)	+	Mid-education level
Low level	EDU_low		N = 14 (15%)		
Farm Income	FI	Continuous	N = 96 (100%)	+	$300,000
Environmental Quality Index	EQI	Continuous	N = 96 (100%)	+	12 (Neutral)

This variable was hypothesized to positively influence a farmer's decision to adopt field shelterbelts (Rempel, 2014) such that a larger value of EQI corresponds to a perception that environmental attributes of field shelterbelts are more important to the landowner, which was hypothesized to increase their likelihood of field shelterbelt adoption.

4.3.6 Model Specification and Estimation

The binary logistic regression model was specified as:

$$ADOPT = \beta_0 + \beta_1 BLK_{SZ} + \beta_2 BRW_{SZ} + \beta_3 EDU_{High} + \beta_4 EDU_{mid} + \beta_5 FI + \beta_6 EXP + \beta_7 EQI + \varepsilon_i \qquad (4.9)$$

Descriptions of the variables in equation (4.9) are provided in Table 4.1.

As discussed earlier, the binary logistic regression model was estimated to empirically identify factors that are significant in explaining farmers' shelterbelts adoption decisions in Saskatchewan. The logistic regression model was estimated using Stata, version 15 (UCLA, 2016). Stata operates using written commands and syntax to produce the required output or results.

4.4 Selection of Policy Instruments and Policy Evaluation Criteria

4.4.1 Selection of Policy Instruments

The decision on what particular policy instrument or mix of policy instruments to use may not be straightforward and would depend on several factors. For instance, Weersink et al. (1998) has suggested that the choice of a particular policy instrument or a mix of policy instruments may depend on the policymaker's objective such that a particular policy instrument that may be appropriate in achieving one objective may not be necessarily appropriate in achieving a different objective.

In terms of policy development to encourage the use of conservation practices among farmers, several authors have suggested that much more emphasis needs to be placed on the levels of net private and net public returns associated with the conservation practice (Uri 1998; Pannell 2008). For instance, Uri (1998) posited that the development of policy instruments to encourage the adoption of conservation practices should begin with the identification of whether the adoption of such practice generally provides a positive or negative net returns to potential adopters. Depending on the potential impact of the practice on the adopters' net returns, Uri (1998) made the following recommendations: (1) if the practice provides positive net returns (profitable) but the farmer is not aware of the practice or its profitability, then education or information supporting the policy instrument (extension or technical assistance) may be appropriate to encourage adoption of such practice; (2) if adoption of the practice imposes a negative net return (loss) to the farmer but provides a significant amount of public benefits, then positive economic instruments or financial assistance (subsidies, cost-sharing incentives) may be appropriate to encourage the adoption of such practice, and; (3) in cases where the conservation practice is required by all farmers, then command-and-control policy instruments (regulations) may be appropriate to enforce adoption of such practices. These recommendations served as the basis for selecting the appropriate policy instruments that were considered for further evaluation in this study.

The trend of field shelterbelts removal by farmers, especially in Saskatchewan may suggest that farmers consider these shelterbelts as economic nuisance (Rempel et al., 2017). Similarly, a study by Islam (2022) revealed that field shelterbelts investments are not economical (net present value of farm revenue) to private farmers in different soil zones in Saskatchewan. She reported that farmers were better off under the scenario of having no field shelterbelts than having field shelterbelts (Table 4.2).

Table 4.2. Total NPV Values ($/ha) of farm-level net revenue under scenarios of field shelterbelt establishment and no field shelterbelt by soil zones (Source: Islam, 2022).

Soil Zone Location	NPV/$/ha/year No field shelterbelt	NPV/$/ha/year Shelterbelt Maintained	**$ change in NPV/$/ha/year**
1. Black SZ	$32.50	$30.07	**-$2.43**
2. Brown SZ	$32.41	$30.89	**-$1.52**
3. Dark Brown SZ	$31.84	$30.69	**-$1.16**

This work clearly showed that adopting field shelterbelts could impose negative net private returns to farmers. However, as discussed in Chapter 3, field shelterbelts offer public benefits, including carbon sequestration, enhance biodiversity, and promote air quality.

Therefore, in accordance with the policy selection recommendations suggested by Uri (1998), the range of policy instruments that may be appropriate in encouraging the adoption of field shelterbelts in Saskatchewan are positive economic instruments or financial incentives (subsidies, cost-sharing incentives). Specifically, two such policy instruments were selected for further evaluation in this study, including: (1) provision of free tree seedlings to farmers, and (2) negative carbon tax for carbon sequestration through shelterbelts, referred to as negative carbon tax and for simplicity (NCT). The subsequent section describes the hypothesized relationship between the selected policy instruments and field shelterbelt adoption in Saskatchewan.

4.4.2 Relationship between Selected Policy Instruments and Field Shelterbelt Adoption

Free Tree Seedlings Policy Instrument and Field Shelterbelt Adoption: The high private cost of planting field shelterbelts is considered a significant disincentive to farmers' adoption of field shelterbelts, especially in Saskatchewan (Rempel et al., 2017). Tree seedlings cost is incurred in the first year of shelterbelt establishment and is significant (75 percent of the total shelterbelt establishment cost) (Rudd 2020, Islam, 2022). Therefore, providing farmers with free tree seedlings will reduce the cost of shelterbelt establishment. Typically, farmers would be expected to pick up the tree seedlings from the nursery sites, which will imply some transportation cost to be borne by farmers, which is mostly influenced by the distance between the farm and the nursery site. That is, differences in farm sites from the nursery site may imply different costs of transportation. However, to simplify the analysis, an assumption was made that tree seedlings are provided at the farm gate (translating into zero transportation cost for the farmers). The potential effect of providing farmers with free tree seedlings is a reduction in shelterbelt establishment cost and thereby a potential increase in their farm-level net revenue. Since the increase in farm-level net revenue is solely due to farmers receiving tree seedlings at zero cost, the overall impact will be an incentive for farmers' adoption of field shelterbelts.

Negative Carbon Tax (NCT) Policy Instrument and Field Shelterbelt Adoption:

Unlike a carbon tax that attaches a cost to the emission of carbon dioxide into the atmosphere, a program of negative carbon tax (NCT) would pay farmers for sequestering carbon through the establishment and maintenance of shelterbelts. The financial payment received by farmers under the NCT policy instrument would depend on the estimated price of carbon. In this study, four prices for carbon were selected: (1) The world trading carbon price of CAD\$74.60/tCO_2(eq) is the current price of carbon as traded under the European Union Emissions Trading Scheme (EU-ETS, 2021). This price was treated as the minimum price of carbon in the study; (2) A carbon price of CAD\$110.49/tCO_2(eq) was selected to be consistent with the World Bank Group's estimation of carbon price required to achieve the emissions level committed under the 2016 Paris Agreement (World Bank Group, 2019); (3) A carbon price of CAD\$574.13/ tCO_2(eq) was the highest carbon price in this study based on the global social cost of carbon dioxide emissions (Ricke et al., 2018); (4) Finally, a carbon price pegged at the Canadian carbon tax rate (CCTR) was selected for the study to be consistent within the 2017 Canadian policy context. In 2017, the Federal government imposed a minimum benchmark for carbon emission pricing of \$10 per tonne of CO_2 (eq) starting in 2018, to be increased by \$10 per tonne of CO_2 (eq) until it gets to \$50 per tonne of CO_2 (eq) in 2022, after which it will increase by \$15 per tonne of CO_2 (eq) annually from 2023 to 2030 (Government of Canada, 2017), resulting in a carbon price of \$170 per tonne of CO_2 (eq) in 2030. The study assumed that the \$170 per tonne of CO_2 (eq) would be constant even after 2030 for the remaining years in this study (Figure 4.3). Since the current Canadian carbon tax policy does not reveal the nature of increase in the tax rate after 2030, it should be noted that this is merely an assumption of this study.

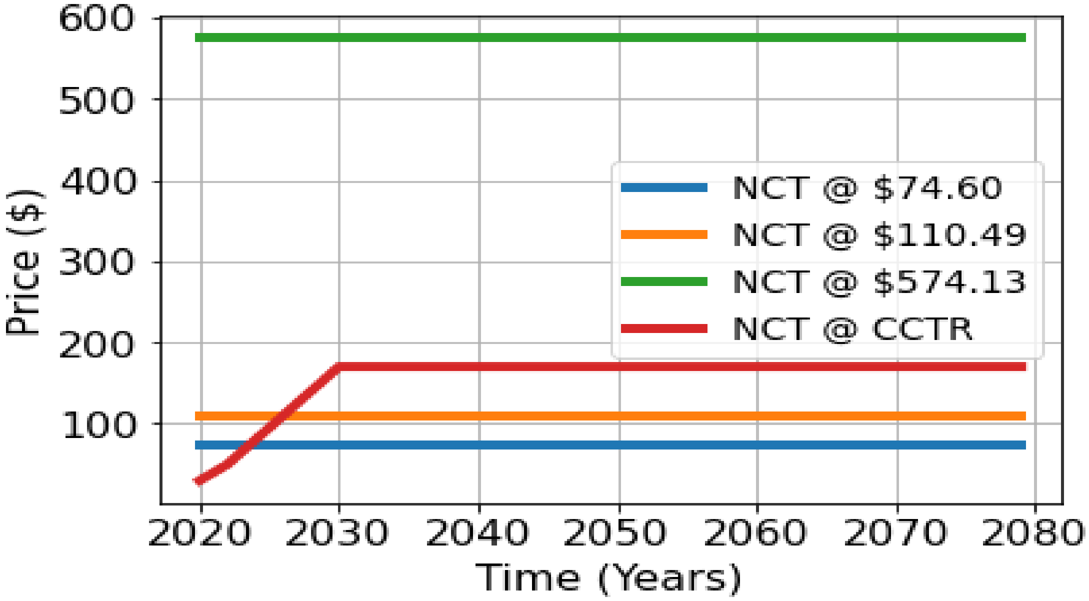

Figure 4.3. Carbon prices over the 60-year planning horizon.

As shown in Figure 4.3, the blue line represents the negative carbon tax valued at a carbon price of $74.60, which was assumed to be fixed throughout the 60 years planning horizon. Similarly, the orange horizontal line represents the negative carbon tax valued at a carbon price of $110.49, assumed to be constant throughout the 60 years planning horizon. Moreover, the red line represents negative carbon tax valued at the existing Canadian carbon tax rate, which starts at $30 in 2020, rising by $10 on yearly basis to $50 in 2022, and then rising again by $15 annually until it reaches $170 in 2030, after which the value of $170 is assumed to be constant for the remaining years in the planning horizon.

Finally, the green horizontal line represents the negative carbon tax valued at $574.13, which is the global social cost of carbon. The carbon price valued at the social cost of carbon is significantly larger than the other included carbon prices (Figure 4.3) because it captures the full cost of carbon to the society. Thus, the global social cost of carbon estimates the marginal damage cost of carbon emissions, which represents the net present value of the incremental damage due to a unit increase in carbon dioxide emissions (Ricke et al., 2018). Hence this estimate may better represent the full global social cost of carbon of carbon emissions since its estimation considers the contributions of different countries to global climate change (Ricke at al., 2018).

The potential effects of an NCT policy instrument would be an increase in farm-level revenue. Paying farmers for carbon sequestered by these trees would increase their farm-level revenue over and above their usual crop revenue. Since the receipt of carbon payments depends solely on farmers having field shelterbelts on their crop lands, holding all other things being equal, the larger the field shelterbelts, the higher the farm-level net revenue. This was assumed to increase farmers' willingness to adopt field shelterbelts. Moreover, it is important to note that payments under this policy instrument is for new shelterbelts based on incremental (additional) carbon sequestered due to the establishment of new field shelterbelts. Thus, it does not capture the costs of paying for all carbon sinks in existing shelterbelts.

4.4.3 Selection of Policy Evaluation Criteria

Policy evaluation criteria are the standards against which alternative policy instruments can be compared to determine which one is more likely to be effective in achieving the policy objective. Policy evaluation criteria provide the basis for assessing the effectiveness, as well as used for ranking alternative sets of policy instruments (Goulder & Parry, 2020), thereby guiding the selection of appropriate policy instruments among alternative instruments (Weersink & Livernois, 1996). Thus, the effectiveness of a policy instrument in achieving the specific goal depends on the set of criteria on which the evaluation was conducted (Weersink et al., 1998). For example, a study by OECD (1989) revealed that in most cases of pollution control policy, economic instruments, such as pollution taxes and tradable permits, have been considered more effective than command-and-control policies. Therefore, it is essential that the set of evaluation criteria developed to assess the effectiveness of policy instruments are clear and consistent to ensure appropriate policy instruments are selected. That is, although some criteria may be appropriate under a given policy objective (for example, reducing the use of fertilizer in farm production), these same criteria may not be appropriate in another policy objective. It is therefore important that policymakers' select evaluation criteria that are more appropriate for the specific policy objective.

Several evaluation criteria have been used to assess policy instruments aimed at encouraging the adoption of conservation practices directed at reducing environmental damage resulting from agricultural production activities (Weersink et al., 1998). These may include, among others, ecological effectiveness, cost-effectiveness, incentives created for innovation, administrative costs, monitoring and enforcement costs, and the ability of the suggested policy instrument to be consistent with other existing government policies (Weersink et al., 1998). Other policy analysts have used criteria such as legal feasibility, political feasibility, technical feasibility, and socio-cultural feasibility to assess and compare alternative policy instruments (Barbados, 2007).

In this study, selected policy instruments were evaluated using four criteria: (1) change in farm-level net revenue; (2) probability of shelterbelt adoption; (3) total amount of carbon sequestered (expressed in carbon dioxide equivalent), and ;(4) fiscal cost per tonne of carbon sequestered (cost-effectiveness). These criteria were considered appropriate as they provide a basis for comparing and ranking the alternative policy instruments considered in the study.

The first policy evaluation criterion selected was the impact on farm-level net revenue. Generally, private farmers’ aim to maximize their farm-level net revenue and thus are more likely to adopt conservation practices that have the potential to increase their farm-level net revenue (Pannell 2008). Therefore, this criterion compared the two alternative policy instruments in terms of their potential for making field shelterbelts more economically feasible to farmers. A policy instrument that had a higher potential of increasing farmers’ farm-level net revenue was preferred over those that had less impact on it.

Furthermore, the probability of shelterbelt adoption criterion assessed two selected policy instruments in terms of their potential for increasing field shelterbelt adoption. The evaluation under this criterion was undertaken by calculating the changes in field shelterbelt adoption due to the selected policy instruments using a binary logistic model. The policy instrument with the greatest response to field shelterbelt adoption was preferred.

The total amount of carbon sequestered policy evaluation criterion assessed the total amount of carbon that could be sequestered in an entire soil zone with the implementation of the policy. The policy instrument that provided the greatest sequestration potential was preferred.

The last policy evaluation criteria considered in the study was the fiscal cost per tonne of carbon sequestered, which served as a cost-effectiveness measure, a criterion important for governments when developing policies (Weersink et al., 1998). In this situation, policy instruments with lower average cost of sequestering are preferred to those with higher average cost.

4.5 Policy Effectiveness Analysis

Once the appropriate policy instruments and policy evaluation criteria were selected, the next step was to compare these alternative policy instruments using the selected evaluation criteria. The policy effectiveness analysis was conducted at two levels: farm level and regional (sub-regional) level. Change in the farm-level net revenue was undertaken since it was assumed to be associated with the likelihood of increasing field shelterbelt adoption. The regional level analysis was undertaken to estimate the impact of the policy instrument on the total amount of carbon sequestered and fiscal cost per tonne of carbon sequestered.

4.5.1 Impact of Selected Policy Instruments on Farm-Level Net Revenue

Free Shelterbelt Seedlings: As noted above, a spreadsheet-based simulation model of net revenue for shelterbelt management developed by Islam (2022) was used to assess the impact of providing free tree seedlings on farm-level net revenue. The simulation model considered crop production costs, shelterbelt establishment and maintenance cost, and crop revenue over a 60-year period for a representative farm located in each of the three soil zones[10]. Annual farm-level net revenue was estimated using equation (4.10).

$$NR_t = R_t - CP_t - SC_t \qquad (4.10)$$

Where NR_t is the farm-level net revenue in year t, R_t is the farm-level gross revenue (from crop production) in year t, CP_t is the crop production cost in year t, and SC_t is the shelterbelt cost in year t.

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[10] See Appendix D (D.1 – D.5) for detailed explanation of the spreadsheet-based model for estimating NPV farm-level net revenue under field shelterbelt.

After the free tree seedlings were provided, the farmers will also incur establishment costs, such as, irrigation, tillage, and fertilizer and herbicides costs (Table 4.3). Since these costs are relatively small, free seedlings reduced total cost of shelterbelt establishment cost significantly. This resulted in higher net revenue for the landowner over the 60-year period. These values were converted into present value (Net present value or NPV) using a discount rate of 8.68% as suggested by Islam (2022). For comparison purposes, the estimated NPV was converted to a per hectare basis.

Table 4.3. Total Cost of Shelterbelt Establishment for a Farm Field for a 160-acre land (Source: Islam, 2022).

Input	Amount (CDN$)
Caragana Seedlings	$7,014.33
Herbicide	$627.39
Fertilizer	$17.02
Irrigation	$1,661.19
Tillage	$3.70

Source: Islam (2022)

The NPV per ha under the free seedlings was compared with a situation where the landowner did not plant field shelterbelts. The difference between the two NPV was attributed to be the net impact of the policy measure. This analysis was repeated for a sample farm in each of the three soil zones in the study.

Negative Carbon Tax: Estimation of impact of negative carbon tax on farm-level net revenue required an estimate of annual total revenue that farmers could receive under a negative carbon tax program. This revenue was obtained by multiplying the tonnes of carbon the trees could sequester by the per tonne price of carbon[11]. Carbon estimates expressed as total ecosystem carbon (TEC), in tonnes of carbon dioxide equivalents (tCO_2 (eq)), were obtained from Amichev et al. (2016) (Table 4.4), while the estimated value for price of carbon was noted above.

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[11] See Appendix C for detailed explanation on the procedures followed in estimating the farm-level revenue from negative carbon tax.

Table 4.4. Cumulative TEC CO2 km in Tonnes by Caragana Species in the Soil Zones, Five-Year Increment (Source: Amichev et al., 2016).

Age	Black Soil Zone	Brown Soil Zone	Dark Brown Soil Zone
5	-2.13	-0.26	-1.30
10	6.03	10.47	8.30
15	21.15	28.81	25.14
20	42.53	53.91	48.63
25	70.05	85.45	78.61
30	102.26	122.53	113.69
35	137.62	162.12	151.48
40	182.08	210.67	198.61
45	234.13	267.02	253.61
50	286.07	322.76	308.48
55	345.49	384.69	370.11
60	410.71	454.88	436.92

Source: Amichev et al. (2016)

Having estimated the payments farmers would receive from the negative carbon tax, the spreadsheet-based simulation model for farm-level net revenue was re-estimated to generate farm-level net revenue with the negative carbon tax. These values were converted into NPV of net returns. The marginal contribution of negative carbon tax on farm-level net revenue was the difference between the farm-level net revenue in the presence of no negative carbon tax and that with negative carbon tax. The analysis was repeated for a sample farm in each soil zones.

4.5.2 Impact of Selected Policy Instruments on the Probability of Field Shelterbelt Adoption

As discussed in section 4.4.2, the selected policy instruments in this study are designed to have a direct relationship with farmers' field shelterbelt adoption decisions. For instance, the free shelterbelt seedlings policy instrument directly affects farmer's decisions to adopt field shelterbelt by reducing the cost of establishing and maintaining field shelterbelts. Similarly, the negative carbon tax policy instrument, which pays farmers for carbon their shelterbelts sequester, is expected to directly affect their decisions to adopt field shelterbelts. These policy instruments can be considered as conditional policy instruments where payments are based on farmers adopting the field shelterbelts. For example, farmers will only receive payments under the negative carbon tax policy instruments if they plant field shelterbelts, since the payments is based on the quantity of carbon their shelterbelts sequester. The expected impact of these conditional payments on farmers willingness to adopt field shelterbelts may differ from unconditional payment or income transfer to farmers, which seeks to increase farmers income with the objective of encouraging the adoption of a conservation practice. In fact, we may expect that conditional policy payments, such as the distribution of free shelterbelt seedlings and the negative carbon tax, may provide greater incentives for adopting field shelterbelts than an unconditional income transfer that seeks to increase farmers income without any requirement for shelterbelt establishment.

Although the conditional policy instruments addressed in this study were designed to directly affect farmers decisions to adopt field shelterbelts in Saskatchewan, an analysis of these specific instruments was not possible with the available data. In the study, it was assumed that the impact of the selected conditional policy instruments on increasing the adoption of field shelterbelt could be predicted through the indirect effect on farmers income. In the analysis, the impact of the selected policy instrument on farm income was first estimated, and based on that, a corresponding impact on field shelterbelt adoption was estimated. The reason why this approach was necessary was that the adoption model – the logistic regression model estimated in the study did not include an explicit variable (a subsidy variable) to measure the direct relationship between the conditional policy instruments and farmers' willingness to adopt. Therefore, the coefficient of farm income was used as a proxy to measure the impact of the conditional policy instruments on the adoption of field shelterbelt. The inability of the model to include variables to represent a subsidy payment for shelterbelt establishment was due to the lack of data. As a result, the estimates for the selected conditional policy instruments' impacts on field shelterbelt adoption may be low estimates, as this approach of measurement only provides an indirect relationship between the selected conditional policy instruments and the adoption of field shelterbelts. A more detailed explanation on estimating the impacts of field shelterbelt policy instruments is provided below.

Free Shelterbelt Seedlings: To estimate the impact of providing free seedlings (a conditional policy instrument), the logistic regression model was adjusted to reflect the percentage change in annual farm-level income (an unconditional change) that resulted from this policy. The adjustment involved developing a commensurate value of the income variable in the logistic regression and farm-level simulation model. Given the percentage change in farm income in the simulation model resulting from the free seedlings policy instrument, the average farm income variable in the logistic regression model. The new value for average farm-level income (in the logistic model), together with the initial values for the other explanatory variables, were used to estimate the new level of probabilities of field shelterbelt adoption for all soil zones. The marginal impact of the free seedling policy instrument on farmers' likelihood to adopt field shelterbelts was obtained as a difference between field shelterbelt adoption under policy measure and that without such a policy instrument. This procedure was repeated for a sample farm in each of the three soil zones.

Negative Carbon Tax: Farm income in the logistic model was adjusted to reflect payments for carbon sequestered by established shelterbelts. As above, this analysis assumed that with greater farm income due to shelterbelt sequestered carbon, the farmers will be more likely to establish field shelterbelts. The marginal effect of this tax was the difference between the probability of field shelterbelt adoption with and without the negative carbon tax. This analysis was repeated for a sample farm in each soil zone for all levels of carbon prices.

4.5.3 Impact of Selected Policy Instruments on the Amount of Carbon Sequestered

Free Shelterbelt Seedlings: The total amount of carbon that could be sequestered in each region from a certain policy instrument depends on the number of farms that would adopt field shelterbelts in response to the policy measure. To estimate the total amount of carbon sequestered due to this policy, the first step was to identify the total number of farms in each soil zone. The estimated number of farms were: 15,248, 6,970, and 5,514 farms, in the Black, Brown and Dark Brown soil zone, respectively (Islam, 2022). The next step involved estimation of the number of farms that have already adopted field shelterbelts under the base scenario (no policy intervention) and those under the free tree seedlings policy intervention. These were obtained by multiplying the probability of field shelterbelt adoption (obtained from the logistic model) under both scenarios by the total number of farms in each soil zone. Finally, the total number of farms adopting field shelterbelts due to the free seedlings policy instrument was estimated as the difference between the number of farms adopting field shelterbelts under the free seedlings policy and the base scenario.

Once the total number of farms adopting field shelterbelts was estimated the analysis then estimated the total length of field shelterbelts, reported in kilometres, that could be planted due to the free tree seedlings policy in each soil zone. For this, estimation, the number of farms adopting field shelterbelts were multiplied by the average kilometre length of field shelterbelt on a farm in each of the three soil zones. The average length of field shelterbelts in the three soil zones were: 13.8 km, 16.0 km, and 17.8 km for the Black, Brown, and Dark Brown soil zones, respectively (Islam, 2022).[12] The above estimates were then multiplied by carbon sequestration estimates provided by Amichev et al. (2016) to obtain the total amount of carbon sequestered. This procedure was repeated for a sample farm in each of the soil zones.

Negative Carbon Tax: As noted earlier, the financial payment received by farmers under the negative carbon tax policy instrument was dependent on the price of the carbon. At each level of carbon price, the number of farms that would adopt field shelterbelts due to this policy instrument were estimated. This was followed by

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[12] Islam (2022) estimated the kilometre length of field shelterbelt on a quarter section field (64.8ha) following field shelterbelt planting spacing recommendation provided by AAFC (2010). This recommendation suggested that for field shelterbelts to protect significantly larger area of a field, they should be established 200-250 metres apart, with the first shelterbelt planted on the extreme west side of the field (AAFC, 2010). Using this spacing recommendation, Islam (2022) estimated the kilometre length of a single row field shelterbelt established on a quarter section field as 747.1metre. However, the Islam study used three rows of field shelterbelts in the quarter section field implying a total kilometre length of field shelterbelt as 2.3 km on this field. The estimates for the total kilometre length of field shelterbelt in the Black (384 ha), Brown (462 ha) and Dark Brown (515 ha) were therefore estimated as 13.8 km, 16.0 km, and 17.8 km, respectively.

estimation of the total length of field shelterbelts that would be planted by these farmers, as discussed earlier, using shelterbelt length multiplied by the per kilometre carbon sequestration estimates provided by Amichev et al. (2016) to determine total amount of carbon sequestered in a given soil zone. This procedure was repeated for a sample farm in each of the soil zones.

4.5.4 Impact of Policy Instrument on Fiscal Cost per Tonne of Carbon Sequestered

Free Shelterbelt Seedlings: The first step in estimating the average cost of carbon sequestration was to estimate the fiscal cost of the policy. The fiscal cost is simply the total cost to the government to implement the free seedlings policy instrument. This cost included only the cost of the seedlings. That is, costs such as administrative, monitoring and opportunity cost of the government implementing this policy instrument were ignored for simplification's sake, as well as due to lack of data. Thus, total fiscal cost of implementing the free seedlings policy was obtained by multiplying the cost of purchasing tree seedlings[13] (Islam, 2022) by the total number of farms that would adopt field shelterbelts under this policy instrument. The average cost was simply a ratio of total fiscal cost of implementing the free seedlings policy instrument and the total amount of carbon sequestered. The procedure was repeated for a sample farm in each soil zone.

Negative Carbon Tax: The average cost of carbon sequestration under negative carbon tax policy instrument is simply the price per tonne of carbon, which is paid to the participating landowner by the government.

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[13] The cost of purchasing free seedlings was estimated as follows: Islam (2022) estimated the average price per seedling of caragana shrub to be $3.13. As mentioned earlier, the kilometre length of a single row field shelterbelt planted on a quarter section of land is 747.1 metres, which requires a total of 747 tree seedlings to plant based on the 1-metre spacing requirement for planting caragana (AAFC, 2010). Thus, a total of 2,241 seedlings of caragana is required to plant the tree rows of caragana on the quarter section of land. Therefore, given the $3.13 price per seedling of caragana, the total seedlings cost for planting three rows of caragana-field shelterbelt on the quarter section of land was estimated as $7,014.33 (Islam, 2022). Using the seedlings cost for a quarter section of land, the total seedlings cost for the sample farm in the Black (384 ha), Brown (462 ha), and Dark Brown (515 ha) soil zones was approximately $41,600, $50,000, and $ 55,800, respectively.

4.6 Summary

This chapter highlights various methods of analysis used to achieve the objectives of this study. It began by providing an overview of the study location (Black, Brown, and Dark Brown Soil Zones in Saskatchewan) and the reasons for the selection. The main reason for selecting these locations was that they form the primary agricultural regions in the province. Following this, the process of selecting and estimating the binary logistic regression model was discussed. The logistic regression was estimated for two main reasons: (1) To determine factors that may influence farmers' decisions to adopt field shelterbelts and ;(2) To predict the probability of field shelterbelt adoption. Though other binary choice models (Probit model and LPM) could be used to achieve these same purposes, the logistic regression model was selected for this study as it provides better coefficient estimates even with relatively small sample size data. Furthermore, the available literature also supports this choice. This was followed by selecting alternative policy instruments for further evaluation. This choice was guided by Uri (1998) and Pannell (2008), that suggested that selecting policy instruments to encourage the adoption of conservation practice should take into consideration the level of net private and net public benefits associated with those practices. Based on this, two major policy instruments were considered for further evaluation in this study: (1) Provision of free tree seedlings to farmers; and (2) Negative carbon tax payments to farmers. The final section of this chapter discussed the methods employed in conducting a policy effectiveness analysis to identify policy instruments that may encourage the adoption of field shelterbelts in Saskatchewan. The selected policy instruments were evaluated using four evaluation criteria: (1) impacts on farm-level net revenue; (2) probability of field shelterbelts adoption; (3) impacts on the amount of carbon sequestered; and (4) cost per tonne of carbon sequestered.

Chapter 5

Results and Discussions

This chapter presents the results of economic evaluation of two policy instruments – provision of free shelterbelt seedlings to the farmers, and a negative tax on sequestration of carbon through shelterbelts. The chapter is divided into three main sections. Section 5.1 discusses the results obtained from the binary logistic regression model of field shelterbelt adoption while Section 5.2 presents the results from the effectiveness analysis of the selected policy instruments. Finally, Section 5.3 concludes the chapter by highlighting and summarizing some of the key insights from this chapter.

5.1 Results of the Estimated Logistic Regression Model

As noted earlier, the purpose of the logistic regression model was to use data from the farmer survey to empirically identify the factors that influence decisions to adopt field shelterbelts in the Black, Brown, and Dark Brown soil zones in Saskatchewan. However, due to the nature of the survey question used as the dependent variable, "Have you planted field shelterbelts", the result from the logistic regression represents the factors that explain farmers' past adoption of field shelterbelts. Results from the model is further used to predict farmers' willingness to adopt field shelterbelts, assuming that the impacts of the predictor variables in explaining past adoption would be same for explaining future adoption. The estimated coefficients for the logistic regression model are summarized in Table 5.1, which includes the parameter log odds for the logistic regression model.

The estimated coefficients of the logistic model suggested that farmers in the Brown soil zone have been more likely to adopt field shelterbelts compared to farmers in the other two soil zones while farmers in the Black soil zone were more likely to adopt field shelterbelts compared to those in the Dark Brown soil zone. The probability of field shelterbelt adoption in each soil zone was computed under the assumption that the trend in past adoption of field shelterbelts as revealed by the logistic regression model would be consistent with future adoption. The probability of field shelterbelt adoption can be interpreted as estimates of proportion of all farmers in the respective soil zone willing to adopt field shelterbelts even without any policy instrument. This probability was obtained by considering a no policy scenario and assuming a landowner with 40 years of farming experience, has attained some mid-level of education (technical diploma), earns an annual farm income of $300,000 and has a neutral perception about the environmental benefits of field shelterbelts, and was estimated as 24.4%, 29.2%, and 14.5% in the Black, Brown, and Dark Brown soil zones, respectively. The probability of field shelterbelt adoption was highest in the Brown soil zone, followed by the Black soil zone, and least in the Dark Brown soil zone.

Farmers characteristics in the model that influenced field shelterbelt adoption included, presented in a decreasing order of influence, education level, EQI, and farming experience (Table 5.1). For example, farmers' perceptions of the environmental benefits of field shelterbelts, measured by EQI, contributed to field shelterbelt adoption in a positive way. Particularly, for any unit increase in farmers' perception about the environmental benefits of field shelterbelts, their willingness to adopt field shelterbelts could increase by 4.6%, at 10% significance level, holding all other factors constant (Column 3 – Table 5.1). Similarly, farmers' years of experience also influenced the probability of field shelterbelt adoption in a positive way. More specifically, the probability of field shelterbelt adoption increased by 1.1% when years of farming experience increase by one year, at 1% significance level, holding all other factors constant. Moreover, farm income had a positive effect on field shelterbelts adoption decision. Though this effect was positive, the marginal effect was significantly smaller compared to the other variables. Particularly, a $10,000 increase in farm income resulted in 0.4% increase in the probability to adopt field shelterbelts, holding all other factors constant. The most important variable, based on this analysis, was the education level, such that farmers with an education achievement of technical training or diploma (mid-level education) were the most likely to adopt field shelterbelts compared to those with different educational qualification. It was found that with a significance level of 5%, a one-level increase in a farmer's level of education could increase the probability of field shelterbelt adoption by 46%, holding all other variables constant.

Table 5.1. Parameter log odds estimates for the logistic regression model for factors influencing farmers' past adoption decisions of field shelterbelts in Saskatchewan.

ADOPT	Coefficient (Log odds)	Delta Method (Dy/dx)	S.E.	Z	P > | z |	Odds Ratios	95% C.I.for Odds Ratios	
							Lower	Upper
BLK_SZ	0.64	0.12	0.67	0.96	0.34	1.90	0.51	7.12
BRW_SZ	0.89	0.17	0.69	1.30	0.20	2.44	0.63	9.39
EDU_High	2.30	0.43**	1.14	2.01	0.04**	9.93	1.06	93.24
EDU_Mid	2.47	0.46***	1.02	2.43	0.02**	11.78	1.61	86.10
Farm Income	0.02	0.01*	0.01	1.67	0.09*	1.02	1.00	1.05
Experience	0.06	0.01***	0.02	2.94	0.01***	1.06	1.02	1.10
EQI	0.24	0.05*	0.14	1.76	0.08*	1.28	0.97	1.67
Constant	-10.02		3.03	-3.31	0.00***	0.00	0.00	0.02

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Log Odds – Also referred to as logit is the natural log of the odds ratio of an outcome. **Dy/dx** – measures the marginal change in the dependent variable (ADOPT) resulting from a unit change in each independent variable. **S.E** – coefficient's standard error, used for testing whether the parameter is significantly different from 0, by dividing the parameter estimate by the standard error to obtain the value of the test statistic. **Z** – Normal distribution used to determine whether the parameter is different from zero (shows value of the normal distribution (z-score)). **Odds Ratio** – exponential of the log-odds. **C.I** – Confidence interval for estimated odd ratio. **95% CI lower** – lower bound for the 95% confidence interval expressed as odds ratio. **95% CI upper** – upper bound for the 95% confidence interval expressed as odds ratio.

The results from the logistic regression analysis provide insight into the factors that affect farmers' decisions to adopt field shelterbelts in Saskatchewan. The difference in the probability estimations in the three different soil zones considered in the study suggests that different incentives through policy instruments are required to encourage the adoption of field shelterbelts by farmers in the different soil zones. For instance, farmers in the Dark Brown soil zone may need greater levels of policy instruments in order to adopt field shelterbelts since they had the lowest willingness to adopt field shelterbelts voluntarily based on the probability of field shelterbelt estimates in the study.

In the subsequent subsections, the results from the policy effectiveness analysis are discussed. The results from this analysis provide a basis for ranking alternative policy instruments in terms of their potential for increasing the adoption of field shelterbelts by farmers in Saskatchewan.

5.2 Estimated Results from the Policy Effectiveness Analysis

The purpose of the policy effectiveness analysis was to estimate the impacts of the two selected policy instruments (distribution of free shelterbelt seedlings and negative carbon tax) on the adoption of field shelterbelts by farmers in Saskatchewan. As noted in Chapter 4, this analysis was conducted at both the farm-level and the regional-level. Estimated results from the policy effectiveness analysis conducted at the farm level are discussed in subsections (5.2.1 and 5.2.2) while subsections (5.2.3 and 5.2.4) discuss the results at the regional level.

5.2.1 Impact of Policy Instruments on Farmers' Farm-Level Net Revenue

As profit maximizing individuals, farmers may be willing to adopt conservation practices that offer the potential of increasing farm-level net revenue. This policy evaluation ranked the selected policy instruments based on how the adoption of field shelterbelts would increase their farm-level net revenue. The estimated results under the two policy scenarios and no-policy scenario were compared to determine the impact of the policy instrument on farm-level net revenue. It is important to note that estimates for farm-level net revenue under the base scenario (no policy scenario) were obtained from Islam (2022). The results from this evaluation are presented in the subsequent sub-sections.

Free Shelterbelts Seedlings: Under the free shelterbelt seedlings policy, farm-level net revenue estimates were based on a zero cost of purchasing shelterbelt seedlings. For comparison purposes, results are presented on a per ha basis.

The results suggest that providing free shelterbelt seedlings results in an increase in farm-level net revenue of 5.4 to 5.6%, across the three soil zones (Table 5.2). For instance, in the Black soil zone, providing free seedlings increased present value farm-level net revenue from crop production activities from $1,804 per ha to $1,904 per ha, for the 60-year planning period. This is mainly due to the reduced field shelterbelt establishment cost with zero cost of purchasing shelterbelt seedlings. Similarly, the present value of farm-level net revenue in the Dark Brown soil zone increased from $1,840 per ha to $1,940 per ha for the entire 60-year period and in the Brown soil zone from $1,850 per ha to 1,950 per ha.

Table 5.2. Total NPV of farm-level net revenue under free shelterbelt seedlings policy instrument over a 60-year period, by soil zones.

SZ Location	NPV/$/ha No Policy	NPV/$/ha With Policy	$ change in NPV/$/ha	% Change in NPV/$/ha
1. Black SZ	$1,804	$1,904	**$100**	5.6%
2. Brown SZ	$1,850	$1,950	**$100**	5.4%
3. Dark Brown SZ	$1,840	$1,940	**$100**	5.5%

The impact of this policy instrument on farm level net revenue was estimated to be same (in terms of $/ha change) across the different soil zones. This is because, although the cost of purchasing shelterbelts seedlings, in terms of dollar amount, varied across the different soil zones, the cost constituted approximately the same proportion of the total cost of shelterbelt establishment in the three soil zones. For instance, the cost of purchasing shelterbelt seedlings was approximately $41,600, $50,000, and $55,800 in the Black, Brown, and Dark Brown soil zones, respectively, yet constituted approximately 75% of the overall shelterbelt establishment cost in all soil zones. The difference in the cost of purchasing shelterbelt seedlings across the three soils was mainly due to the size of the representative farm in the soil zones, which was 384 ha, 462 ha, and 515 ha in the Black, Brown, and Dark Brown soil zones, respectively. Moreover, because the seedling cost is incurred only in the first year of establishing shelterbelts, its impacts over the 60-year planning horizon were reduced significantly and could explain the similar impact across all the soil zones.

Negative Carbon Tax: The NPV of farm-level net revenue in all the soil zones increased with the implementation of the negative carbon tax instrument (Table 5.3). Particularly, the different carbon prices considered under this policy resulted in an increase in present value of farm-level net revenue of 4.2 to 31.7%, 4.8 to 36.7%, and 4.4 to 33.7% in the Black, Brown, and Dark-Brown soil zones, respectively. The higher the level of the payment for carbon sequestration, the greater was the change in farm-level net revenue. In the Black soil zone, NPV per ha of present value farm-level net revenue for the 60-year period increased by \$75, \$110, \$571, and \$172 respectively, for the carbon price levels of \$74.60/tCO$_2$(eq), \$110.49/tCO$_2$(eq), \$574.13/tCO$_2$(eq), and the Canadian carbon tax rate. Similarly, present value farm-level net revenue in the Brown soil zone increased by \$89, \$131, \$679, and \$193 under the implementation of this policy instrument at the four price levels, respectively. In the Dark Brown soil zone, on a per ha basis, NPV value of farm-level net revenue for the 60-year period, increased by \$81, \$120, \$620, and \$180, respectively under the four levels of carbon prices.

The difference in the policy impact across soil zones was due to differences in the amount of carbon sequestration in the soil zones (Table 4.5). As discussed earlier, farmers’ total revenue from this policy was dependent on the amount of carbon sequestered by their shelterbelts. Though the same species of field shelterbelt – caragana was considered in all soil zones, differences in the tree growth rate in the soil zones due to different climatic conditions resulted in different rates of carbon sequestration (Amichev et al., 2016). Therefore, the differences in the amount of carbon sequestered in the soil zones, which influenced the carbon payments they would receive under the policy, ultimately affected the impact on the farm-level net revenue.

Table 5.3. Total NPV Values ($/ha) of farm-level net revenue under negative carbon tax policy instrument over a 60-year period, by soil zones.

	Black Soil Zone				Brown Soil Zone				Dark Brown Soil Zone			
Carbon price ($CAD)	NPV/$/ha No Policy	NPV/$/ha With Policy	**$ change in NPV/$/ha**	% Change in NPV/$/ha	NPV/$/ha No Policy	NPV/$/ha With Policy	**$ change in NPV/$/ha**	% Change in NPV/$/ha	NPV/$/ha No Policy	NPV/$/ha With Policy	**$ change in NPV/$/ha**	% Change in NPV/$/ha
74.60	$1,804	$1,879	**$75**	4.2%	$1,850	$1,939	**$89**	4.8%	$1,840	$1,921	**$81**	4.4%
110.49	$1,804	$1,914	**$110**	6.1%	$1,850	$1,981	**$131**	7.1%	$1,840	$1,960	**$120**	6.5%
574.13	$1,804	$,2375	**$571**	31.7%	$1,850	$2,529	**$679**	36.7%	$1,840	$2,460	**$620**	33.7%
CCTR	$1,804	$1,976	**$172**	9.5%	$1,850	$2,043	**$193**	10.4%	$1,840	$2,020	**$180**	9.8%

5.2.2 Impact of the Selected Policy Instruments on the Probability of Field Shelterbelt Adoption

In order to meet the objective of developing policy instruments that may encourage the adoption of field shelterbelts, an estimate the potential increase in field shelterbelt adoption that may occur with the implementation of the two selected policy instruments is needed. This would provide a criterion for ranking alternative policy instruments based on their associated likelihood of increasing field shelterbelt adoption. The subsequent paragraphs present the estimated results from the evaluation of the selected policy instruments based on this policy evaluation criteria.

Free Shelterbelts Seedlings: The impact of the providing free shelterbelt seedlings policy instrument on field shelterbelt adoption was estimated as the difference in probability of field shelterbelt adoption under the policy instrument scenario and the base scenario (no policy instrument) (Table 5.4).

Table 5.4. Probability of field shelterbelt adoption under free shelterbelt seedlings policy instrument.

Soil Zone Location	Prob. Shelterbelt Adoption: No Policy Instrument	Prob. Shelterbelt Adoption: With Policy Instrument	Changes in Prob. of Adoption due to Policy Instrument
1. Black	24.4%	25.1%	**0.7%**
2. Brown	29.2%	30.0%	**0.8%**
3. Dark Brown	14.5%	15.0%	**0.5%**

Overall, the estimated results in Table 5.4 suggest that providing farmers with free tree seedlings can increase their likelihood to adopt field shelterbelts, but the magnitude of change is small. For instance, the highest increase was noted for Brown soil zone (at 0.8%), followed by Black soil zone (at 0.7%) and lowest in the Dark Brown soil zone (at 0.5%).

One way to interpret this result is to estimate the additional kilometre length of field shelterbelt associated with these adoption rates. The adoption rates due to the free seedlings policy instrument translated into 1,479 km, 847 km, and 464 km length of field shelterbelt in the Black, Brown, and Dark Brown soil zones, respectively. It can be observed that although the changes in field shelterbelt adoption rates due to this policy was highest in the Brown soil zone, the corresponding length of field shelterbelt was highest in the Black soil zone, showing inconsistencies in the rate of field shelterbelt adoption and the corresponding kilometres of field shelterbelt. This is because, in addition to the rate of field shelterbelt adoption, the length of field shelterbelt that could be planted due to this policy instrument also depended on the total number of farms in each soil zone and the average length of field shelterbelt on the sample farm in the soil zones. Since the number of farms in the Black soil zone (15,248 farms) was significantly higher than that of the Brown soil zone (6,970 farms), the change in the rate of field shelterbelt adoption in the Brown soil (0.8%) translated into a smaller additional number of farms (56 farms) adopting field shelterbelt than the Black soil zone (0.7%, translating into 107 farms), and ultimately a smaller total kilometre length of field shelterbelt added. Therefore, to allow for comparison across the soil zones, an equal number of farms (1,000 farms) and average length of field shelterbelt (15.8 km) in all soil zones was assumed and the corresponding length of field shelterbelts, in kilometres, that could be planted due to the free seedlings policy instrument was estimated. The adoption rates due to the free seedlings policy instrument translated into field shelterbelt length of 111 km, 127 km, and 79 km in the Black, Brown, and Dark Brown soil zones, respectively.

Negative Carbon Tax: The results indicate that at all levels of carbon pricing the impact on the probability of field shelterbelt adoption varied across the three soil zones, although their magnitudes stayed consistent for the four price levels (Table 5.5). For instance, at a carbon price of $74.60, the probability of field shelterbelt adoption, relative to the no-policy scenario, increased by 0.5%, 0.7%, and 0.4% in the Black, Brown, and Dark Brown soil zones, respectively. Similarly, at the carbon price of $110.49, the probability of field shelterbelt increased by 0.8%, 1.1%, and 0.6% in the Black, Brown, and Dark Brown soil zones, respectively. Moreover, at the highest level of carbon price of $574.13, the probability of field shelterbelt adoption increased by 4.2%, 5.4%, and 3.1% in the Black, Brown, and Dark Brown soil zones, respectively.

Table 5.5. Probability of field shelterbelt adoption under negative carbon tax policy instrument.

	Black Soil Zone			**Brown Soil Zone**			**Dark Brown Soil Zone**		
Carbon Price ($CAD)	Prob (%) No Policy Instrument	Prob (%) With Policy Instrument	**% Change in Prob**	Prob (%) No Policy Instrument	Prob (%) With Policy Instrument	**% Change in Prob**	Prob (%) No Policy Instrument	Prob (%) With Policy Instrument	**% Change in Prob**
74.60	24.4%	24.9%	**0.5%**	29.2%	29.9%	**0.7%**	14.5%	14.9%	**0.4%**
110.49	24.4%	25.2%	**0.8%**	29.2%	30.3%	**1.1%**	14.5%	15.1%	**0.6%**
574.13	24.4%	28.6%	**4.2%**	29.2%	34.6%	**5.4%**	14.5%	17.6%	**3.1%**
CCTR	24.4%	25.6%	**1.2%**	29.2%	30.7%	**1.5%**	14.5%	15.3%	**0.8%**

Lastly, pricing carbon according to the Canadian carbon tax rate led to an increase in the probability of field shelterbelt adoption by 1.2%, 1.5%, and 0.8% in the Black, Brown, and Dark Brown soil zones, respectively. The impact of negative carbon tax policy on the probability of field shelterbelt adoption was highest in the Brown soil zone and lowest in the Dark Brown soil zone for all levels of carbon price considered for this policy instrument in the study.

The differences in field shelterbelt adoption rate across the soil zones is mainly attributed to the percentage change in farm-level net revenue due to this policy. As discussed earlier, the probability of field shelterbelt adoption under the policy instruments is positively influenced by the percentage change in the farm-level net revenue due to the policy, and hence the greater the percentage change in farm-level net revenue due to the policy with greater increases in revenue resulting larger increases in the probability of field shelterbelt adoption. Therefore, since the impact of the negative carbon tax policy on farm-level net revenue was highest in the Brown soil zone and lowest in the Dark Brown soil zone, the probability of field shelterbelt adoption was in the same order.

As discussed earlier, one way to interpret the change in the rate of field shelterbelt adoption due to the negative carbon tax policy instrument is to estimate the additional length of shelterbelt corresponding to these rates. The change in field shelterbelt adoption due to a negative carbon tax at a carbon price of $74.60 translated into additional shelterbelt length of 1,092 km, 752 km, and 375 km in the Black, Brown, and Dark Brown soil zones, respectively. Similarly, at a carbon price of $110.49, field shelterbelt adoption rates translated into additional shelterbelt length of 1,617 km, 1,119 km, and 553 km in the Black, Brown, and Dark Brown soil zones, respectively. Moreover, at a carbon price of $574.13, field shelterbelt adoption rates translated into additional shelterbelt length of 8,762 km, 5,993 km, and 2,993 km in the Black, Brown, and Dark Brown soil zones, respectively. Lastly, the change in the rate of field shelterbelt adoption at carbon price at the Canadian carbon tax rate translated into additional shelterbelt length of 5,653 km, 3,596 km, and 1,835 km in the Black, Brown, and Dark Brown soil zones, respectively. Again, it can be observed that although changes in the rate of field shelterbelt adoption was highest in the Brown soil zone at the four different levels of carbon price, the corresponding length of field shelterbelt that could be planted was highest in the Black soil zone instead of the Brown soil zone at the four different levels of carbon price. As noted earlier, the inconsistencies between the change in field shelterbelt adoption rate and the corresponding length of field shelterbelt planted was due to differences in the total number of farms in each soil zone and the average length of shelterbelt, in kilometres, on the sample farm in the soil zones. Similarly, to allow for comparison across the soil zones, an equal number of farms (1,000 farms) and average length of field shelterbelt (15.8 km) in all soil zones and estimated the corresponding length of field shelterbelts, in kilometres, that could be planted due to the negative carbon tax policy instrument at all the four different levels of carbon price were assumed. This led to an additional shelterbelt length of 79 km, 111 km, and 63 km in the Black, Brown, and Dark Brown soil zones, respectively at a carbon price of \$74.60; 125 km, 174 km, and 95 km in the Black, Brown, and Dark Brown soil zones, respectively at a carbon price of \$110.49; 664 km, 853 km, and 490 km in the Black, Brown, and Dark Brown soil zones, respectively at a carbon price of \$574.13; and 427 km, 522 km, and 300 km in the Black, Brown, and Dark Brown soil zones, respectively at the Canadian Carbon tax rate.

5.2.3 Impact of Policy Instruments on Total Amount of Carbon Sequestered

In the context of developing greenhouse gas (GHG) mitigation measures, the total amount of carbon sequestered is important. Therefore, this evaluation criterion provides a ranking of selected policy instruments based on their potential for sequestering more carbon in agricultural landscapes through shelterbelt establishment. Estimates for the total amount of carbon that could be sequestered annually in each soil zone due to selected policy instruments are directly related to the number of farms adopting field shelterbelts. In other words, the greater the number of farms adopting field shelterbelts under a given policy instrument, the greater would be the amount of carbon that could be sequestered in the region.

Free Shelterbelts Seedlings: The total amount of carbon that could be sequestered annually due to providing free shelterbelt seedlings to farmers, expressed as CO_2 (eq) was estimated at 10,124tCO_2 (eq), 6,422tCO_2 (eq), and 3,379tCO_2 (eq) in the Black, Brown, and Dark Brown soil zones, respectively. This result is mainly influenced by the number of farms adopting field shelterbelts due to the free shelterbelt seedlings policy instrument and the rate of carbon sequestration by the shelterbelt species – caragana, in the different soil zones. Though the same shelterbelt species was considered for the different soil zones in the study, the rate of growth of shelterbelt trees and therefore its rate of sequestering carbon (Table 4.3), is different in these soil zones mainly because of differences in soil type, and climatic conditions, with the Black soil zone having the greatest annual tree growth rate and Brown soil zone having the lowest annual tree growth rate (Amichev et al., 2016). Therefore, one will expect the amount of carbon sequestered due to the free seedlings policy instrument to be higher in the Dark Brown soil zone than the Brown soil zone. However, though the rate of tree growth was smallest in the Brown soil zone, the number of farms adopting field shelterbelt due to the free seedlings policy instrument was significantly greater here (0.8% of all farms) than in the Dark Brown soil zone (0.5% of all farms). In general, the amount of carbon sequestered due to the free seedlings policy was found to be greatest in the Black soil zone and least in the Dark Brown soil zone.

The estimates for total amount of carbon sequestered in soil zones were compared with the agricultural GHG emissions for the province of Saskatchewan to assess how this policy could mitigate agricultural GHG emissions in the province. It was estimated that providing farmers with free shelterbelt seedling could reduce agricultural GHG emissions in the province by 0.11%. This estimate was obtained by dividing the estimated total amount of carbon sequestered due to this policy by the total annual amount of agricultural GHG emissions in the province (see Appendix D for detailed explanation). Therefore, a free tree seedling policy may not make a significant contribution to agricultural GHG mitigation in the province.

Negative Carbon Tax: The total amount of carbon annually sequestered due to the implementation of a $74.60 per tonne negative carbon tax policy instrument, expressed as CO_2 (eq) was 7,475 tCO_2(eq), 5,702 tCO_2(eq), and 2,731 tCO_2(eq) in the Black, Brown, and Dark Brown soil zones, respectively, (Table 5.6). For comparison, at a carbon price of $110.49 per tonne, the total amount of carbon annually sequestered, expressed as

CO_2 (eq) was 11,069 tCO_2(eq), 8,484 tCO_2(eq), and 4,027 tCO_2(eq), in the Black, Brown, and Dark Brown soil zones, respectively. Moreover, at a carbon price of $574.13 per tonne, the total amount of carbon annually sequestered under this policy was 59,978 tCO_2(eq), 45,434 tCO_2(eq), and 21,796 tCO_2 (eq), in the Black, Brown, and Dark Brown soil zones, respectively. Finally, at the Canadian carbon tax rate, the total amount of carbon annually sequestered was 17,880 tCO_2 (eq), 12,600 tCO_2(eq), 5,971 tCO_2(eq), in the Black, Brown and Dark Brown soil zones, respectively. As discussed above, the difference in this result across the different soil zones is mainly influenced by the rate of shelterbelt adoption due to the policy instrument and the rate of carbon sequestration by the trees. The total annual amount of carbon sequestered at all levels of carbon prices was highest in the Black soil zone and lowest in the Dark Brown soil zones.

The total amount of carbon sequestered for all soil zones under this policy instrument was compared with the agricultural GHG emissions in the province to determine how negative carbon taxes could mitigate agricultural GHG emissions in the province. It was estimated that provincial agricultural GHG emissions could be reduced by 0.09%, 0.13%, 0.70%, and 0.21% at carbon price of $74.60, $110.49, $574.13, and the Canadian carbon tax rate, respectively (see Appendix D for detailed explanation). The results suggest that, although paying farmers for carbon their shelterbelts sequester could encourage the adoption of field shelterbelts, this policy may not significantly reduce the provincial agricultural GHG emissions.

Table 5.6. Estimates of annual total amount of carbon sequestered under negative carbon tax policy instrument across all three soil zones.

	Black Soil Zone	**Brown Soil Zone**	**Dark Brown Soil Zone**
Carbon price ($CAD)	Carbon Seq. (tCO_2(eq)/yr)	Carbon Seq. (tCO_2(eq)/yr)	Carbon Seq. (tCO_2(eq)/yr)
74.60	7,475	5,702	2,731
110.49	11,069	8,484	4,027
574.13	59,978	45,434	21,796
CCTR	17,880	12,600	5,971

5.2.4 Impact of Policy Instruments on Fiscal Cost per Tonne of Carbon Sequestered.

Free Shelterbelts Seedlings: Average cost of carbon sequestration due to free seedlings over the 60-year planning horizon was estimated as $7.32/tonne, $6.88/tonne, and $7.15/tonne in the Black, Brown, and Dark Brown soil zones, respectively. The difference in the values was due to total cost involved in implementing this policy, as well as the total amount of carbon sequestered because of this policy across the different soil zones. The annual total fiscal cost of implementing this policy was estimated as $4.32 million, $2.60 million, and $1.39 million, in the Black, Brown, and Dark Brown soil zones, respectively. It can be observed that though the annual fiscal cost of implementing this policy was lowest in the Dark Brown soil zone, it had a larger cost per tonne of carbon sequestered compared to the Brown soil zone with a total fiscal of $ 2.60 million. The reason is the total amount of carbon sequestered in the Brown soil zone was significantly greater than that of the Dark Brown soil zone, thereby making the ratio of fiscal cost of carbon sequestration to the total amount of carbon sequestered lesser in the Brown soil zone than in the Dark Brown soil zone. This result suggests that judging a policy's effectiveness by considering only its total fiscal cost or total benefits may not always lead to efficient judgement about the policy's effectiveness. In general, carbon sequestration due to the free seedlings policy instrument was found to be more cost-effective in the Brown soil zone.

Negative Carbon Tax: As noted earlier, the average cost of carbon sequestration under the negative carbon tax was simply the price per tonne of carbon. Therefore, this value was the same for all the soil zones since the price per tonne of carbon was same for all the soil zones. Particularly, for all the levels of carbon price considered, the average cost of sequestering carbon under the negative carbon tax instrument was $74.60, $110.49, $574.13, and $157, respectively.

5.3 Summary

A binary logistic regression model was estimated to determine the factors that influence farmers' field shelterbelt adoption decision. Study results showed that a landowner with a mid-level of education, forty years of farming experience, who also earns annual farm income of $300,000, and has a neutral perception about the environmental benefits of field shelterbelts is most likely to adopt field shelterbelts in the Brown soil zone, followed by the Black soil zone, and finally the Dark Brown soil zone. Particularly, the probability of field shelterbelt for a landowner with the above characteristics was estimated as 29.2%, 24.4%, and 14.5% in the Brown, Black, and Dark Brown soil zones, respectively. When evaluated individually for factors, farmers' education level had the most influence in explaining farmers' ability to adopt field shelterbelts, with farm income having the least influence.

A key finding from the policy effectiveness analysis was that across the different soil zones, any policy instrument that had the potential to significantly increase farm-level net revenue would most likely increase the probability of field shelterbelt adoption, as well as increase the amount of carbon sequestered, since these policy evaluation criteria are directly interrelated. That is, farmers' willingness to adopt field shelterbelts due to a policy instrument is directly influenced by the impact of such policy instrument on their farm-level net revenue, which largely influences the amount of carbon that could be sequestered due to that policy. This result is consistent with economic theory since profit-maximizing farmers are most likely to adopt conservation practices that have greater impacts on their net revenue. However, it may not always be the case that the policy instrument with the greatest impact on farm-level net revenue will be more cost-effective.

Findings from the policy effectiveness analysis suggest that ranking of alternative policy instruments should be made with the policy objective in mind since a policy that works best for one objective may not be the best for another objective. Based on the study results, shelterbelt policy developed with the objective of minimizing policy cost should consider the policy of providing free shelterbelt seedlings since that policy is found to be more cost-effective. On the other hand, developing shelterbelt policy with the objective of maximizing the benefits of shelterbelts to both farmers and society should consider implementing a negative carbon tax valued at a carbon price of $574.13 since this policy had the greatest impact on farmers' farm-level net revenue, the probability of field shelterbelt adoption, and the total amount of carbon sequestered.

Chapter 6

Summary and Conclusions

6.1 Summary

Although shelterbelts may represent a significant feature on the prairie landscape and an important source of ecosystem services, their adoption and presence has declined in recent years. This decline is seen in the increased rate of shelterbelt removal on the Prairies by farmers' and their decreased willingness to plant or maintain existing shelterbelts (Rempel, 2014). The decline, especially field shelterbelts, is mainly due to improvements in agricultural production methods and practices, such as zero-tillage, reduced summer fallowing, which has decreased the risk of soil erosion thereby decreasing the private benefits of shelterbelts and the increasing size farming equipment, which has increased the private cost of shelterbelts (Rempel, 2014). Moreover, the change in Federal policy, with the closing of the shelterbelt centre in Indian Head around 2013, may have also reduced farmers' access to free shelterbelt seedlings, and thereby, contributed to the decline in the use of shelterbelts in the province.

Despite the wide range of private benefits (increased crop yield via improved soil moisture, reduce soil erosion, enhance livestock feed efficiency, etc.) and public benefits (carbon sequestration, enhance biodiversity, improve water quality, etc.) that shelterbelts provide, farmers may still regard these field shelterbelts as an economic nuisance. This is because, in the opinion of these farmers, since they receive little to no financial gains from the public benefits that these shelterbelts provide but must sustain cost of shelterbelts on the farm, their private marginal cost of shelterbelt investment might outweigh their private marginal benefits. This could lead to underproduction of shelterbelts from a societal welfare perspective. Although many of the barriers to the adoption and retention of shelterbelts by farmers are mostly related to their economic costs, a poor understanding of their environmental benefits may also play an important role.

Understanding the factors that influence farmers' decisions regarding field shelterbelt adoption, as well as measures to encourage their adoption to increase the environmental benefits of field shelterbelts is very relevant. Building on existing literature on adoption of conservation practices, this study aimed to understand the current context within which Saskatchewan farmers make field shelterbelts investment decisions. That is, the study explored the factors that may affect Saskatchewan farmers' decisions to plant field shelterbelts on their agricultural lands. Having understood the current context within which farmers may adopt field shelterbelts, the study further explored policy instruments that may encourage the adoption of field shelterbelts, as well as estimated the potential impacts of these selected policy instruments on the adoption of field shelterbelts in Saskatchewan. The study's objectives were reflected in the three research objectives:

1. To determine empirically the factors influencing decisions to plant field shelterbelts by Saskatchewan farmers;
2. To identify policy instruments that can potentially provide an incentive to farmers to renew and plant field shelterbelts in Saskatchewan; and
3. Lastly, to evaluate selected policy instruments to estimate their effectiveness in adoption (including maintenance and/ or lack of removal) of field shelterbelts in various locations in Saskatchewan.

Factors affecting farmers' decisions to adopt field shelterbelts were modeled using a binary logistic regression model. The logistic model included a binary dependent variable to predict the drivers of the decision represented by the dependent variable, "Have you planted field shelterbelts?". The model was estimated using data from a survey of farmers across Saskatchewan's agricultural region conducted in the summer of 2013, 2018 and 2019. The sample population of farmers was drawn from the Black (61 farmers), Brown (60 farmers), and Dark Brown (43 farmers) soil zones. Variables included in the model were those reflecting farmers' personal characteristics (years of farming experience, level of education), farm characteristics (soil zone, farm-level income) and shelterbelt characteristics (farmers' perceptions about the environmental benefits of shelterbelts). In addition to identifying and quantifying factors with significant influence on field shelterbelt adoption, the logistic regression model was used to compute the probability of field shelterbelt adoption given the above set of characteristics.

The research then focused on developing a process of measuring policy effectiveness. A small suite of appropriate policy instruments that may encourage the adoption of field shelterbelts were selected. The selection of the alternative policy instruments followed the recommendations for selecting policy instruments to encourage conservation practice adoption suggested by Uri (1998) and Panell (2008). According to these recommendations, policies are selected based on the level of net private and public returns of the conservation practice. From the small suite of potential policy instruments, two policy instruments were selected for evaluation in the study: (1) distribution of free shelterbelt seedlings to farmers, and ;(2) negative carbon tax. These policy instruments were evaluated in terms of their potential for increasing farm-level net revenue, their probability of increasing field shelterbelt adoption, the total amount of carbon sequestration due to policy implementation and the fiscal cost per tonne of carbon sequestered. Based on the results from these analyses, policy recommendations were made regarding the effectiveness of the select policy on the adoption of field shelterbelts by farmers in Saskatchewan.

6.2 Conclusions

6.2.1 Determinants of field shelterbelts adoption in Saskatchewan.

Results from the binary logistic regression model indicate that farmers in the Brown soil zone are more likely to adopt field shelterbelts compared to those in the Black and Dark Brown soil zones. Particularly, 29.2% of farmers in Brown soil zone will likely adopt field shelterbelts as compared to 24.4% and 14.5% in the Black and Dark Brown soil zones, respectively. Farmer characteristics variables included in the model had a significant positive effect on field shelterbelt adoption. For instance, the study suggests that as farmers obtain higher levels of education, they become more likely to adopt field shelterbelt. Similarly, as farmers gain more years of farming experience, they become more likely to adopt field shelterbelts.

This study found that farmers’ perceptions about the environmental benefits of field shelterbelts (carbon sequestration, water quality improvement, enhanced biodiversity, etc.) also had a positive influence on their decisions to adopt field shelterbelts. This is revealed through the relationship between the probability of field shelterbelt adoption and the estimated coefficient of the environmental quality variable, where a unit increase in the environmental quality index led to a 4.6% increase in the probability of field shelterbelt adoption. This result suggests that perhaps an information-based policy instrument aimed at providing extension services related to shelterbelts may positively affect farmers’ mindsets about understanding the importance of field shelterbelts in promoting healthy environment and bringing forth higher benefits from ecological goods and services to the society.

Although farm income had a positive influence on farmers’ shelterbelt adoption decisions, the influence of income on shelterbelt adoption was relatively less than that of the other farmer characteristics such as education level. This result was a bit surprising since based on the literature review, the farm-level income was expected to have a significantly higher influence on the decision to adopt conservation practices, such as adopting field shelterbelts.

6.2.2 Policy instruments to encourage the adoption of field shelterbelts in Saskatchewan.

The two selected policy instruments were analyzed for effectiveness in encouraging the adoption of field shelterbelts based on: (1) impact on farm-level net revenue; (2) impact on increasing the probability of field shelterbelt adoption; (3) total amount of carbon that could be sequestered from implementing the policy instrument, and ;(4) the fiscal cost per tonne of carbon sequestration. Most of the policy evaluation criteria (3 out of 4) considered in the study were highly interrelated as the impact of the policy instrument on farm-level net revenue was assumed to directly affect the probability of field shelterbelt adoption, which in turn will affect the total amount of carbon sequestered. Therefore, a policy instrument with the greatest impact on farm-level net revenue would automatically have the greatest impact on increasing the probability of field shelterbelt adoption, as well as the greatest impact on the total amount of carbon sequestered.

In this study, applying a negative carbon tax valued at a price of $574.13 provided the highest potential policy impact in encouraging the adoption of field shelterbelts by farmers in Saskatchewan according to most of the evaluation criteria used (3 out of 4 evaluation criteria). This result is not surprising, as mentioned earlier, most of the criteria are directly linked to each other. Particularly, a negative carbon tax set at a carbon price of $574.13 had the greatest impact on farm-level net revenue by increasing the farm-level net revenue by $571/ha, $679/ha, and $620/ha, for the entire 60-year planning horizon, in the Black, Brown, and Dark Brown soil zones, respectively. Similarly, this same instrument had the highest impact on shelterbelt adoption, with adoption rates increasing by 4.2%, 5.4%, and 3.1% in the Black, Brown, and Dark Brown soil zones, respectively. Lastly, a negative carbon tax set at a carbon price of $574.13 had the greatest impact on total amount of carbon sequestration, with sequestration estimates of 59,978 tCO_2(eq), 45,434 tCO_2(eq), and 21,796 tCO_2(eq) in the Black, Brown, and Dark Brown soil zones, respectively. On the other hand, this same policy instrument was less cost-effective, as it had the greatest average cost of carbon sequestration among the alternative policy instruments considered in the study. This is because the fiscal cost of implementing the policy would also be high since the policy would have to be implemented for all farmers with a payment to all farms having field shelterbelts in each soil zone. Thus, the total fiscal cost of implementing this policy at a carbon price of $574.13 would rise to $2.06 billion, $1.57 billion, and $750.79 million in the Black, Brown, and Dark Brown soil zones, respectively (See Appendix F for details).

The results from this study indicate that selecting a policy to encourage the adoption of field shelterbelt by private farmers in Saskatchewan should be made with caution since a policy that works best based on one criterion may perform poorly in terms of another. Based on the study's findings, selecting policy instruments to address field shelterbelt adoption should be based on the policymaker's objective of whether to minimize cost of implementing the policy or maximize the potential benefits associated with the instrument. If the objective is to minimize the cost, then they should consider implementing the distribution of free shelterbelts seedlings since it has the lowest average cost of carbon sequestration, which represents the average cost of policy implementation. On the other hand, if the objective is to maximize the benefits, then they should consider implementing the negative carbon tax valued at a carbon price of $574.13, since it has the highest potential of increasing farmers' farm-level net revenue, the probability of field shelterbelt adoption and the total amount of carbon sequestered. This result reveals that financial incentives must be very high to obtain a low level of GHG emissions savings. That is, the negative carbon tax valued at a carbon price of $574.13 that was associated with the highest level of carbon sequestration was clearly not cost-effective as its average cost of carbon sequestration was the highest among the alternative policy instruments. Therefore, in the light of achieving greater level of carbon sequestration with less cost, other policy instruments, such as education and/or regulatory instruments or a blend of these policy instruments could be explored to achieve more cost-effective retention of field shelterbelts.

Furthermore, the study results suggest that more productive agricultural land may have to be converted into planting field shelterbelts, thereby reducing land available for crop production for the fields where shelterbelts are planted. That is, while policymakers seek to address the issue of climate change by encouraging the planting of field shelterbelts to sequester atmospheric carbons, this same approach may lead to a reduction in food supply, as productive agricultural lands are converted into planting of field shelterbelts. However, the growing demand for food due to the increasing world population suggest that more lands need to be allocated to agricultural production. This means that the reduction in land available for crop production in one location – in this case, to produce shelterbelts would mean increased in land allocation for crop production activities elsewhere to make up for such lose in crop production. The broader effects of government interventions to encourage the adoption of field shelterbelts in Saskatchewan could be the tradeoff between land for crop production and shelterbelt planted, which might impose costs on other farmers elsewhere in the world. Similarly, this tradeoff could also have welfare effects on consumers of higher food prices as well as the environmental costs of marginal lands being converted to annual crop production. Though the scope of the study did not cover the general equilibrium effects (global effects) of the selected policy instruments, it is important to mention that these policy instruments may have bigger effects beyond the ones discussed in the study.

6.3 Study Limitations

Study limitations refer to challenges encountered during the research process and limitations to the scope and or scale of the research. These limitations need to be acknowledged as they provide insight into future research in the topic area. This study has several limitations including the following:

(1) Inconsistences in the measurement of income used in both the binary logistic regression model and the spreadsheet-based farm-level simulation model. The income variable used in the binary logistic model measured farmer's gross income from their activities, mainly sales from crop and livestock production while the income variable in the spreadsheet-based simulation model measures farm-level net revenue, which is the difference between farm-level gross revenue (sales from crop production) and the cost of production (Islam, 2022). To obtain the impact of a policy instrument on the probability of field shelterbelt adoption, the income variable in the logistic model was assumed to change by a similar magnitude as the change as estimated in the farm-level simulation model. Assuming the same percentage change in farm-level net revenue and gross farm income due to a policy implementation is likely to provide biased estimates.

(2) The study employed several analytical models in carrying out the analyses. Significant among them is the spreadsheet-based farm-level revenue simulation model developed by Islam (2022). The results from this model were used while taking into consideration the limitations experienced by the Islam (2022) study. This included inadequate data regarding yield response of different crops and forage to the presence of field shelterbelts in different soil zones. Results in this study may have been affected by this limitation as well.

Considering the above-mentioned limitations, it is recommended that the study's results should be used with caution. Moreover, the results obtained are recommended not to be generalized to the entire population of farmers in the Saskatchewan agricultural region since the survey included a selected number of farmers in three out of the five soil zones in the region using a snowball sampling method. This method of sampling, not being based on probability of selection of the farms, may have led to the issue of representativeness of the sample.

6.4 Areas for Future Research

Based on existing literature, as well as the limitations encountered during this research, the following areas for future research are recommended:

(1) The binary logistic regression model of field shelterbelt adoption estimated in this study used data obtained from survey a of farmers in the Black, Brown, and Dark Brown soil zones of Saskatchewan. It is believed that the quality of the survey data was limited in its application to the research objectives of this study, and as a result, may have significantly affected the results. Therefore, it is recommended that future studies in this field should consider developing more representative and inclusive surveys that will better capture farmers' relevant characteristics. For instance, the nature of the question used as the dependent variable in this study was "Have you planted field shelterbelts?", which likely did not fully represent farmers' willingness to adopt field shelterbelts, especially under the current context of agricultural production. Future studies could clearly distinguish between either planting new shelterbelts or preserving/maintaining existing shelterbelts. These studies may consider a question like "Will you adopt field shelterbelt under the current agricultural production context?" to estimate farmers' willingness to plant new shelterbelts while a question like "Do you consider continuing using field shelterbelts?" could be used to estimate farmers' willingness to preserve or maintain existing shelterbelts. This distinction is important because these questions represent different shelterbelt management practices associated with different levels of costs. For instance, planting new shelterbelts could impose greater establishment and maintenance costs compared to maintaining existing shelterbelts. This will ensure that more detailed and robust models could be developed to provide a more representative insight into understanding the factors affecting farmers' decisions to adopt field shelterbelts, especially considering the ever-changing methods of agriculture production, as well as the global issue of climate change.

(2) This study only focused on farmer decisions concerning field shelterbelts but excluded farmyard and livestock shelterbelts. Future research on the factors that

may affect farmers' decisions to adopt farmyard shelterbelts, as well as livestock shelterbelts is recommended. The results from these studies together with the current study will provide better understanding of shelterbelts' adoption in the context of changing climate in order to develop appropriate policies to address the adoption of all shelterbelt types within Saskatchewan.

(3) Moreover, the selected policies considered in this study were mainly financial incentives, (1) distribution of free shelterbelt seedlings and (2) negative carbon tax. Future research about the potential impacts of other policy instruments, such as, extension and technical activities, on encouraging the adoption of field shelterbelts in Saskatchewan is recommended.

(4) The total carbon sequestration estimates in the study were based on single species of shelterbelts – caragana. However, since carbon sequestration potential of various species is different, and each shelterbelt species has different growing patterns in the different soil zones, future studies may explore the total carbon sequestration of different species of shelterbelts including, for example green ash, hybrid poplar, Manitoba maple, Scot's pine, and white spruce.

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Appendix A –

Sample questionnaires used for surveys.

I. Questionnaire used for the 2013 Survey of Producers

Part I

1. What is the size of your farm operation? (number of acres) _______________
2. How many of these acres are rented or leased? ______________
3. Is there a livestock enterprise on your farm?

☐ Yes ☐ No (go to question 4)

If yes, what type of livestock do you have? Fill in all that apply

	Dairy	Hogs	Cattle	Poultry	Horses	Other:
Number of breeding stock						
Number of market animals						

4. Is there commercial crop production on your farm?

☐ Yes ☐ No (go to question 5)

Please indicate the types of crops you currently grow and the acres of each in the following table.

Crop	Number of acres
Hard Wheat	
Soft Wheat	
Barley	
Alfalfa (hay)	
Flax	
Canola	
Lentils	
Peas	
Other:	

5. Does your operation include organic production?

Yes ☐ No ☐

If you have shelterbelts on your farm, please go to Part II of this questionnaire. If you do not have shelterbelts on your farm, please go to Part III.

Part II

6. How old are the shelterbelts on your farm? ___________

7. What type of shelterbelts do you have on your farm?
   a) Farmyard shelterbelts
   b) Field shelterbelts
   c) Shelterbelts for livestock protection
   d) Other (explain)__________________
8. Please complete the following table regarding the type of shelterbelts you have, the year that they were planted, the costs incurred associated with planting and maintenance to date. (Use the back of the page if you need more room).

Type of shelterbelt (field, etc.)	Number of rows in shelterbelt	Species in shelterbelt (i.e., caragana, hybrid poplar, etc.)	Year planted	Trees obtained from (i.e., PFRA, nursery)	Planting costs

9. How important do you feel the various attributes are in your decision to plant, keep, and maintain your shelterbelt? Please indicate by circling the influence each of the following factors has/had on your shelterbelt management decisions from highly negative to highly positive.

a) profitability of shelterbelts	Highly Negative	Negative	Neutral	Positive	Highly Positive
b) reduced wind speeds	Highly Negative	Negative	Neutral	Positive	Highly Positive
c) reduced soil erosion	Highly Negative	Negative	Neutral	Positive	Highly Positive
d) reduce evapotranspiration	Highly Negative	Negative	Neutral	Positive	Highly Positive
e) snow capture for moisture	Highly Negative	Negative	Neutral	Positive	Highly Positive
f) control blowing snow	Highly Negative	Negative	Neutral	Positive	Highly Positive
g) trap snow for dugouts	Highly Negative	Negative	Neutral	Positive	Highly Positive
h) protection of livestock	Highly Negative	Negative	Neutral	Positive	Highly Positive
i) protection for buildings	Highly Negative	Negative	Neutral	Positive	Highly Positive
j) beautify the farmyard	Highly Negative	Negative	Neutral	Positive	Highly Positive
k) provide buffer strips around riparian, streams, and shoreline areas	Highly Negative	Negative	Neutral	Positive	Highly Positive
l) habitat for wildlife	Highly Negative	Negative	Neutral	Positive	Highly Positive

m) odor mitigation (i.e. hog odor)	Highly Negative	Negative	Neutral	Positive	Highly Positive
n) improved irrigation efficiency	Highly Negative	Negative	Neutral	Positive	Highly Positive
o) carbon capture	Highly Negative	Negative	Neutral	Positive	Highly Positive
p) enhancement of natural insects (i.e. pollinators)	Highly Negative	Negative	Neutral	Positive	Highly Positive
q) pesticide/herbicide drift	Highly Negative	Negative	Neutral	Positive	Highly Positive
r) reduced home energy use	Highly Negative	Negative	Neutral	Positive	Highly Positive
s) establishment and maintenance	Highly Negative	Negative	Neutral	Positive	Highly Positive
t) improved feed use efficiency of livestock	Highly Negative	Negative	Neutral	Positive	Highly Positive
u) biodiversity	Highly Negative	Negative	Neutral	Positive	Highly Positive
v) interception of dust from the air	Highly Negative	Negative	Neutral	Positive	Highly Positive
w) land taken out of production	Highly Negative	Negative	Neutral	Positive	Highly Positive

x) crop price	Highly Negative	Negative	Neutral	Positive	Highly Positive
y) suitability of land/tree species	Highly Negative	Negative	Neutral	Positive	Highly Positive
z) Neighbors’ management	Highly Negative	Negative	Neutral	Positive	Highly Positive

Are there any other attributes that influenced your decision to include shelterbelts in your management decisions? Please list these and indicate how this factor influenced your decision.

____
____
____
____
____

10. Were there any other constraints/challenges that you faced and/or had to overcome in order to establish and maintain your shelterbelts?

____
____
____
____
____
____

Please go to Part IV

Part III

11. Did you ever have shelterbelts on your farm?
Yes ☐ No ☐

If yes, i) when did you have these shelterbelts? __________ (Year)

ii) when did you remove these shelterbelts? _________ (Year)

iii) what type of shelterbelts were these? _________________________________

iv) why did you remove these shelterbelts?

____
____

If no, have you considered planting shelterbelts?

Yes ☐ No ☐

12. Do you feel that there is adequate information available regarding the costs and benefits of using shelterbelts in your operation?

Yes ☐ No ☐

13. Please indicate how important the following attributes were in your decision to remove shelterbelts or not include them in your management decisions. Indicate by circling the influence each of the following factors has/had on your shelterbelt management decisions from highly negative to highly positive.

a) profitability of shelterbelts	Highly Negative	Negative	Neutral	Positive	Highly Positive
b) reduced wind speeds	Highly Negative	Negative	Neutral	Positive	Highly Positive
c) reduced soil erosion	Highly Negative	Negative	Neutral	Positive	Highly Positive
d) reduce evapotranspiration	Highly Negative	Negative	Neutral	Positive	Highly Positive
e) snow capture for moisture	Highly Negative	Negative	Neutral	Positive	Highly Positive
f) control blowing snow	Highly Negative	Negative	Neutral	Positive	Highly Positive
g) trap snow for dugouts	Highly Negative	Negative	Neutral	Positive	Highly Positive
h) protection of livestock	Highly Negative	Negative	Neutral	Positive	Highly Positive
i) protection for buildings	Highly Negative	Negative	Neutral	Positive	Highly Positive
j) beautify the farmyard	Highly Negative	Negative	Neutral	Positive	Highly Positive
k) provide buffer strips around riparian, streams, and shoreline areas	Highly Negative	Negative	Neutral	Positive	Highly Positive
l) habitat for wildlife	Highly Negative	Negative	Neutral	Positive	Highly Positive

m) odor mitigation (i.e., hog odor)	Highly Negative	Negative	Neutral	Positive	Highly Positive
n) improved irrigation efficiency	Highly Negative	Negative	Neutral	Positive	Highly Positive
o) carbon capture	Highly Negative	Negative	Neutral	Positive	Highly Positive
p) enhancement of natural insects (i.e., pollinators)	Highly Negative	Negative	Neutral	Positive	Highly Positive
q) pesticide/herbicide drift	Highly Negative	Negative	Neutral	Positive	Highly Positive
r) reduced home energy use	Highly Negative	Negative	Neutral	Positive	Highly Positive
s) establishment and maintenance	Highly Negative	Negative	Neutral	Positive	Highly Positive
t) improved feed use efficiency of livestock	Highly Negative	Negative	Neutral	Positive	Highly Positive
u) biodiversity	Highly Negative	Negative	Neutral	Positive	Highly Positive
v) interception of dust from the air	Highly Negative	Negative	Neutral	Positive	Highly Positive
w) land taken out of production	Highly Negative	Negative	Neutral	Positive	Highly Positive

x) crop price	Highly Negative	Negative	Neutral	Positive	Highly Positive
y) suitability of land/tree species	Highly Negative	Negative	Neutral	Positive	Highly Positive
z) Neighbors’ management	Highly Negative	Negative	Neutral	Positive	Highly Positive

Are there any other attributes that influenced your decision to remove/not include shelterbelts in your management decisions? Please list these and indicate how this factor influenced your decision.

____

____

____

____

____

Please go to Part IV

Part IV

13. What is your age? ________ (years)

14. How many years have you been farming since the age of 18? _________ (years)

15. What is the highest level of education that you have completed?

- Elementary school (0-6 years) ☐
- Junior high school (7-9 years) ☐
- High School (10-12 years) ☐
- Technical diploma ☐
- University ☐

16. Do you belong to any agricultural organizations?

Yes ☐ No ☐

If yes, please list those that you actively participate in:

____

____

17. When you require information on agricultural matters, where do you get it from? Check all that apply.

Farm radio ☐
Agricultural publications ☐
Government extension representatives ☐
Internet ☐
Agricultural industry representatives ☐
Other Farmers ☐
Other, specify ____

Part V

The farm level information requested in this section is very important to our analysis of the questionnaire. We hope that asking for ranges will make it easier for you to answer this section. Please be assured that this information, like that in the rest of the questionnaire is strictly confidential.

18. What is the legal land description of your farm? ______________________

19. What was the gross farm sales last year? (Check range)

☐ $0-$29,000 ☐ $30,000-59,999 ☐ $60,000-89,999
☐ $ 90,000- 119,999 ☐ $120,000-149,999 ☐ above $150,000

What percentage of gross sales were from:

Crops? ____________ %

Livestock? __________%

Other? (Specify)______%

20. Please fill out the following information related to the costs and benefits of including shelterbelts in your management plans

Cost	($/acre)
Planting cost	
Maintenance cost	
Cost per tree	
Acres out of production cost	
Costs of overlap from going around shelterbelts	
Removal Cost	
Other:	
Other:	

Benefit	**($/acre)**
Snow moisture management benefits	
Yield benefits	
Livestock protection benefits	
Erosion prevention benefits	
Carbon sequestration benefits	
Wildlife habitat benefits	
Aesthetic benefits (i.e., beautiful landscape)	
Other:	
Other:	

21. As a producer, do you think that the benefits associated with shelterbelts are greater than the costs?

Yes ☐ No ☐ Uncertain ☐

22. What impact do you think shelterbelts have on land values? Why?

____

____

____

Please provide the following contact information in case any clarification is needed regarding your responses.

Name: ____

Phone: ____

Email: ____

Thank you for completing this survey. Your participation is very important.

II. Questionnaire used for the 2018/2019 Survey of Producers

Survey ID (RM of farm): _ _ _ _ _ _ _ _ _ _ _

Part I - Operation Information

1. What is the size of your farm operation (in acres)? ______________________
2. How many of these acres are rented or leased? ________________
3. Please indicate the type of crops you currently grow and the acres of each in the following table. Fill out all that apply:

Crop type	Acres currently grown
Wheat	
Barley	
Alfalfa (hay)	
Flax	
Canola	
Legumes (Peas, Lentils, Beans, etc.)	
Other:	

4. Is there a livestock enterprise on your farm?

If yes, what type of livestock do you have? Fill in all that apply. (If no, leave blank)

Type of Livestock	Dairy Cattle	Hogs	Beef Cattle	Poultry	Horses	Other:
# of mature animals						

5. Does your operation include organic production?

□Yes □No

6. Do you use irrigation on your operations?

□Yes □No

Part II - Shelterbelt Information

7. Do you have shelterbelts on your land?

□Yes □No

a. How old are the shelterbelts on the land? (years)

b. What type of shelterbelts do you have on your land? (Check all that apply)

☐ Farmyard shelterbelts ☐Field (crop) shelterbelts ☐Shelterbelts for livestock

☐ Riparian shelterbelts (along/surrounding water bodies)
☐ other:

8. Where did you get trees for your shelterbelts? (PFRA, anywhere else?)

9. Where would you get them if you were planning to plant more? **(Now** that PFRA is closed)

10. Did you receive the tree/shrubs as clippings or plugs?

11. Shelterbelt **Details** - Complete the following questions regarding your shelterbelts. Part A relates to farmyard shelterbelts, Part B relates to field shelterbelts, and Part C relates to livestock shelterbelts.

Part A - Farmyard Shelterbelts

a. What is the size of the shelterbelt (length in meters)? __
b. How many rows are there? __
c. When was the shelterbelt planted? __
d. What tree species are included in your shelterbelt?

Part B - Field Shelterbelts

a. What is the size of the shelterbelt (length in meters)? __
b. How many rows are there? __
c. When was the shelterbelt planted? __

d. What tree species are included in your shelterbelt?

Part C - Livestock Shelterbelts

a. What is the size of the shelterbelt (length in meters)? __
b. How many rows are there? __
c. When was the shelterbelt planted? __
d. What tree species are included in your shelterbelt?

12. **Planting Shelterbelts** (Answer this section if you have planted shelterbelts)

a. What type of shelterbelts have you planted?

☐ Farmyard shelterbelt ☐Field shelterbelt ☐Livestock shelterbelt
☐ Riparian shelterbelt ☐other:

b. Did you till the land prior to planting your shelterbelt (s)? Was machinery or garden tools used?

c. What did the preparation activities cost prior to planting the shelterbelt? (Time/labour/fuel/approx. hrs.)

d. What incentives would encourage you to plant shelterbelts?

13. **Maintaining Shelterbelts**

a. What types of herbicides do you use for weed control in shelterbelts? How often do you apply herbicides to your shelterbelts per year?

b. What types of fertilizers do you use in shelterbelts? How often do you apply fertilizers to your shelterbelts per year?

c. Are your shelterbelts irrigated? How often are they irrigated per year?

d. Have you done any maintenance activities to your shelterbelts? (Grooming/pruning/trimming/removing dead wood/approx. hrs. a week)

e. What were the costs of these maintenance activities?

f. List any other maintenance activities you exercise for your shelterbelts.

14. **Removing Shelterbelts** (Answer if you have removed or are planning to remove your shelterbelts)

a. What type of shelterbelts have you removed/plan to remove?

☐ Farmyard shelterbelt ☐Field shelterbelt ☐Livestock shelterbelt
☐ Riparian shelterbelt ☐other:

b. How much of the shelterbelt did you remove/how much will you remove?

c. When did you remove the shelterbelts/when are you planning to remove the shelterbelt(s)?

d. What was the age of the shelterbelt at the time of removal?

e. Which species were removed?

f. What are the reasons for removal of shelterbelts?

g. What did you do with the removed shelterbelt biomass? (e.g., burned, used for lumber, etc.)

h. What did the removal of shelterbelts cost? (Time/labour/fuel, approx. hours of work)

15. List all the benefits you receive from your shelterbelts:

Likert Scale Questions – Level of Agreement with Statements regarding benefits and costs of Economic, Social and Environmental aspects in Farmyard, Field, and Livestock Shelterbelts

16. Indicate your level of agreement by circling your answer (1 = strongly disagree, 2 = disagree, 3 = unsure/neutral, 4 = agree, 5 = strongly agree) to the following statements.

Economic Benefit/Cost Statements (FARMYARD SHELTERBELTS)	**Strongly Disagree**	**Disagree**	**Unsure/ Neutral**	**Agree**	**Strongly Agree**
Shelterbelts help to reduce pesticide drift into yards from fields	1	2	3	4	5
Shelterbelts reduce wind speeds and protect my home and/or other farm infrastructure	1	2	3	4	5
Shelterbelts positively influence land values	1	2	3	4	5
The establishment and maintenance of shelterbelts is quite costly	1	2	3	4	5

Economic Benefit/Cost Statements (FIELD SHELTERBELTS)	**Strongly Disagree**	**Disagree**	**Unsure/ Neutral**	**Agree**	**Strongly Agree**
Shelterbelts have positive impacts on crop yield	1	2	3	4	5
Shelterbelts help to reduce pesticide drift	1	2	3	4	5
Shelterbelts reduce soil erosion from wind and water movement	1	2	3	4	5
Shelterbelts help to improve irrigation efficiency	1	2	3	4	5
Shelterbelts reduce wind damage to my crops	1	2	3	4	5
Shelterbelts positively influence land values	1	2	3	4	5
The establishment & maintenance of shelterbelts is quite costly	1	2	3	4	5
I would rather use land for agricultural production	1	2	3	4	5
Having shelterbelts will negatively impact crop revenues	1	2	3	4	5
Economic Benefit/Cost Statements (LIVESTOCK SHELTERBELTS)	**Strongly Disagree**	**Disagree**	**Unsure/ Neutral**	**Agree**	**Strongly Agree**
Shelterbelts provide my livestock protection from elements	1	2	3	4	5
Shelterbelts improve livestock feed/water use efficiency	1	2	3	4	5
The establishment and maintenance of shelterbelts is quite costly	1	2	3	4	5
Shelterbelts allow a habitat for predators to hide in	1	2	3	4	5

Environmental/Social Statements (ALL SHELTERBELTS)	**Strongly Disagree**	**Disagree**	**Unsure/ Neutral**	**Agree**	**Strongly Agree**
Shelterbelts increase the visual aesthetic of my land (Specify which type: ……………………….)	1	2	3	4	5
Shelterbelts improve air quality	1	2	3	4	5
Shelterbelts are beneficial to protect water sources (buffers around streams, shoreline) N/A if not on land	1	2	3	4	5
I am in favour of the protection and provision of wildlife habitats that shelterbelts provide	1	2	3	4	5
I support the enhancement of natural insects (pollinators) that shelterbelts provide	1	2	3	4	5
Species biodiversity in shelterbelts in agricultural landscapes is important to me (i.e., different tree species versus one)	1	2	3	4	5
I am in favour of the carbon sequestration abilities found in shelterbelt trees	1	2	3	4	5

17. Do you think the benefits from shelterbelts outweigh the costs?

☐ Yes ☐ No ☐ Unsure/Neutral

18. Additional comments and opinions on shelterbelts:

____

____

____

____

Part III – Participant Demographic Information

Participant information is used to compare that AGGP II research is an appropriate sample of the population when compared to census 2011 data. **All answers collected on this survey are kept confidential and information used in research is anonymous. Questions can be skipped if participant does not want to answer.**

19. What is your age? ________________ (Years)

20. What is your sex/gender identity?

☐ Male ☐ Female ☐ Other

21. How many years have you been farming? ________________ (Years)

22. Does the succession plan of the farm include relatives inheriting the land?

☐ Yes ☐ No

If yes, please elaborate ________________

23. What is the highest level of education that you have completed?

Elementary school (Grade 1 through 8)	☐
Some high school	☐
High school graduate, diploma, or equivalent (i.e. GED)	☐
Trade/technical training (post-secondary diploma/certificate)	☐
University Bachelor’s degree	☐
University Master’s degree	☐
University Professional or Doctorate degree	☐

24. What is the gross farm sales from last year (Check range)

☐ $0-49,999	☐ $50,000-99,999	☐ $100,000-149,999
☐ $150,000-199,999	☐ $200,000-249,999	☐ $250,000-499,999
☐ $500,000-749,999	☐ $750,000-999,999	☐ $1,000,000 and over

25. If you have a mixed operation, what proportion of the gross farm sales were from crop revenue versus livestock revenue?

_________________ % crops _________________ % livestock

26. What proportion does your farming operation account for in total family income?

_________________ % revenue from farming

27. Do you use a smartphone/tablet to plan and manage your farm operation?

☐ Yes ☐ No

28. Do you use digital mapping to plan and manage your farm operation?

☐ Yes ☐ No

29. If not, why not:

____

____

Appendix B –

Principal Component Analysis for Creating an Environmental Quality Index

The principal component analysis (PCA) was used to compute the weights (loads) of each of the six environmental quality attributes. The PCA is a factor analysis method used to describe the process of creating indices for categorical (Likert-scale questions) variables. The objective of the PCA is to aggregate several environmental attributes into a single index. The PCA estimates weights (factor loads) to each attribute, based on the strength of their inter-correlation.

As noted earlier, farmers were asked the extent to which they agree or disagree to the environmental impacts of shelterbelts as revealed through the six attributes (reduce wind erosion, improve air quality, provide wildlife habitat, enhance insects, enhance species biodiversity, and carbon sequestration). Their responses to these questions were measured on a Likert-scale ranging from strongly agree to strongly disagree. The responses were coded as: Strongly agree = 5; Agree = 4; Neutral = 3; Disagree = 2, and Strongly disagree = 1. The factor loads (weights) obtained from the PCA (Table B.1) were multiplied by farmers' response to each of the six environmental quality attributes to produce the index of environmental quality for each farmer. Thus, the environmental quality index (EQI) for each farmer was calculated using the equation (B.1):

$$EQI_i = \sum_{j=1}^{6} W_j * {R^i}_j \tag{B.1}$$

Where EQI_i is the environmental quality index for farmer i (i = 1, 2, …, 96). Similarly, W_j is the weight or factor load for each jth attribute of environmental quality, and ${R^i}_j$ is farmer i's response to attribute j. Weights based on the PCA are shown in Table B.1. These weights were used to estimate the EQI for each farmer in the sample, as shown in Figure B.1. In this calculation, farmers' responses from the survey were used.

Table B.1 Estimated weights for the attributes of environmental quality of shelterbelts.

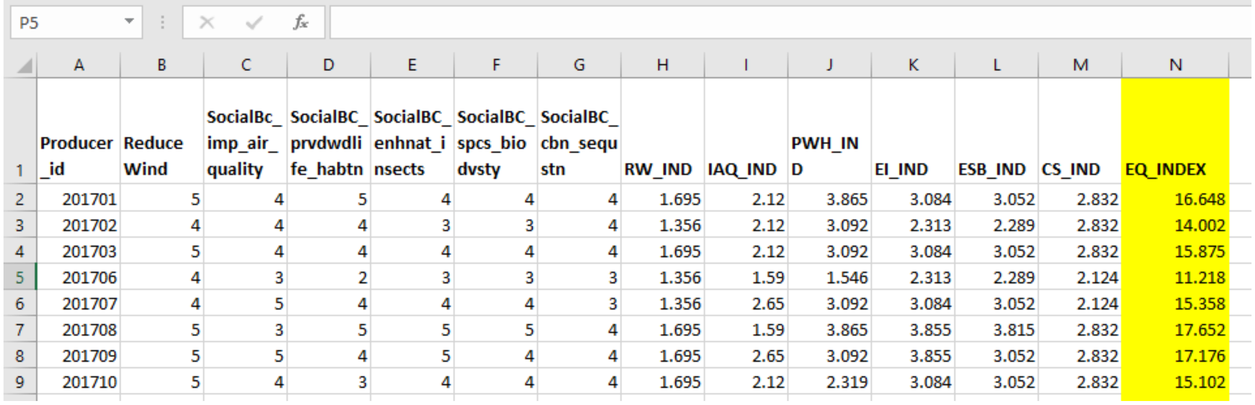
Principal Component Analysis (PCA)

Sample: 96

Included Observations: 96

Extracting 6 of 6 possible components

Indicators of shelterbelts' environmental benefits	**Weights obtained from PCA**
Reduce Wind Erosion (RW)	0.339
Improve Air Quality (IAQ)	0.530
Provide Wildlife Habitat (PWH)	0.773
Enhance Insects (EI)	0.771
Enhance Species Biodiversity (ESB)	0.763
Carbon Sequestration (CS)	0.708



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Producer_id	Reduce Wind	SocialBc_imp_air_quality	SocialBC_prvdwdlife_habtn	SocialBC_enhnat_insects	SocialBC_spcs_biodvsty	SocialBC_cbn_sequstn	RW_IND	IAQ_IND	PWH_IND	EI_IND	ESB_IND	CS_IND	EQ_INDEX
2	201701	5	4	5	4	4	4	1.695	2.12	3.865	3.084	3.052	2.832	16.648
3	201702	4	4	4	3	3	4	1.356	2.12	3.092	2.313	2.289	2.832	14.002
4	201703	5	4	4	4	4	4	1.695	2.12	3.092	3.084	3.052	2.832	15.875
5	201706	4	3	2	3	3	3	1.356	1.59	1.546	2.313	2.289	2.124	11.218
6	201707	4	5	4	4	4	3	1.356	2.65	3.092	3.084	3.052	2.124	15.358
7	201708	5	3	5	5	5	4	1.695	1.59	3.865	3.855	3.815	2.832	17.652
8	201709	5	5	4	5	4	4	1.695	2.65	3.092	3.855	3.052	2.832	17.176
9	201710	5	4	3	4	4	4	1.695	2.12	2.319	3.084	3.052	2.832	15.102

Figure B.1. Image showing spreadsheet calculation of the environmental quality index.

Appendix C –

Estimating farmers’ farm- level revenue from negative carbon tax across soil zones.

Farmers’ farm-level revenue from negative carbon tax was obtained by multiplying the per tonne amount of carbon (carbon dioxide equivalent) sequestered by the price per tonne of carbon. The sequestration estimates were obtained from Amichev et al. (2016). The sequestration estimates by Amichev et al. (2016) were provided on a 5-year interval scale over the 60-year period, in tonne per kilometer (t/km). However, since the annual net amount of Carbon was required, an average amount sequestered during the period was used. Moreover, because the estimates provided by Amichev et al. (2016) were in t/km, conversion of farm area into length of shelterbelt was needed. A conversion scale developed by Islam (2022), which estimates the length of a single-row shelterbelt on a quarter section of land to be 0.75 km was used.

Using this scale, I estimated the total kilometer length of a single-row shelterbelt that could occupy the representative farm in each soil zone in the study. The average area of the representative farm in the study was estimated as 384, 462, and 515 ha, in the Black, Brown, and Dark Brown soil zones, respectively (Islam 2022). Overall, the kilometer length of field shelterbelts planted on the representative farms was estimated as 13 km, 16 km, and 18 km in the Black, Brown, and Dark Brown soil zones, respectively. Afterwards, the total amount of annual net carbon sequestered by the shelterbelts per farm was obtained by multiplying the total kilometer length of shelterbelts by the annual net carbon sequestered in t/km.

The next thing was to determine the appropriate per t price of carbon. These prices were based on a literature review and were reported in price per t of CO_2 (eq). Details are shown in Table C.1. Each of these prices were converted into Canadian currency using current exchange rates, and further adjusted to reflect 2021 values using the 2021 average rate of inflation in Canada (Statistics Canada, 2021).

From the list of prices in Table C.1, four prices were selected for further analysis

Table C.1. Social Cost of Carbon (SCC) Estimates (in 2021 CAD)

Author (s)	Year	SCC estimate in original currency (t/CO_2)	$ equivalence (t/CO_2)	SCC estimate adjusted for inflation (2021) ($/t$CO_2$)
Ackerman & Stanton	2012	USD 900	904.5	1,059
Nordhaus William	2014	USD 18.6	20.6	23.3
Nordhaus William	2017	USD 31	40.3	44
Government of Canada	2017	CAD 40 (2021)	40	40
Ricke et al.	2018	USD 417	540.3	574.1
World Bank Group	2019	CAD 106	106	110.5
Pindyck et al.	2019	USD 175	232.2	242.1
EU’s Emission Trading Scheme (ETS)	2021	£ 50	74.60	74.6

in this study. (1) The world trading carbon price of $74.60 was selected to be consistent with the current price of carbon in the world carbon market as traded in the European Union Emissions Trading Scheme (EU-ETS, 2021). (2) A carbon price of $110.49 was selected for this study to be consistent with the World Bank Group's estimation of carbon price required to achieve the emissions level committed under the 2016 Paris Agreement temperature target (World Bank Group, 2019). (3) A carbon of $574.13 was selected to reflect the social cost of carbon (SCC), which measures the monetary value of the harm done by emissions, and thus could be regarded as the marginal impacts of climate change (Adler et al., 2017). The SCC is considered an efficient way of pricing carbon as it internalizes the negative externality of carbon emissions (Ricke et al., 2018). (4) Lastly, a carbon price pegged at the Canadian carbon tax rate (CCTR) was selected for the study to be consistent within the current Canadian context. After obtaining the carbon prices, the total revenue that landowners could receive from the negative carbon tax policy was estimated by multiplying the annual total net carbon sequestered by the shelterbelts by the per t price of carbon.

Appendix D –

Estimating NPV of farm-level net revenue under field shelterbelt establishment.

As already discussed, estimates of the NPV of farm-level net returns for each of the representative farms with field shelterbelts in the three soil zones were obtained from Islam (2022). This section of the study provides a summary of the systematic procedures involved in estimating the NPV of farm-level net revenue for a farm with field shelterbelt establishment, as provided in Islam (2022).

D.1. Determination of areas of the three soil zones.

This estimation begun by developing a representative study farm in each of the three soil zones considered in the study, which is crucial since the agricultural practices and climatic conditions vary across the three soil zones (AAFC 2000). Selection of representative study farm in each soil zone was based on an average farm in the soil zone, which was determined by the crop production area and the number of farms in each soil zones. These data were obtained from Statistics Canada (2016a) but were available for Census Agricultural regions (CARs). Table D.1 represents CARs that constituted the representative farm area in each soil zone considered in the study.

Table D.7. Selected Census Agricultural Regions (CARs) based on soil zones.

Soil Zones	Selected CARs
Black soil zone	1,5,6
Dark Brown soil zone	4
Brown soil zone	3

Adopted from Islam (2022).

D.2. Development of representative farm area in each of soil zone.

The next step was to estimate the average area of the representative grain farm in each soil zone. This estimate was obtained by dividing the total crop production area in each soil zone by its total number of farms. It is important to note that since the effect of field shelterbelts is largely on crop production, other land uses were excluded from the economic performance studies (Islam 2022). The representative farm in the Black soil zone had the smallest area (441 ha), followed by the Dark Brown soil zone (580 ha), and then the Brown soil zone (599 ha). Table D.2 shows the average size of the study grain farm in each of the three soil zones.

Table D.8. Average size of the representative farm for each soil zone.

	Black SZ*	Brown SZ*	Dark Brown SZ*
Area used for crop production (ha)	6,720,341	4,169,135	3,195,176
Number of farms	15,248	6,970	5,514
Average farm size (ha)	441	599	580

* Soil Zone. Adopted from Islam (2022).

D.3. Salient Features of representative farm area in each of soil zone.

Once the average size of the representative grain farm in each soil zone was determined, the next step was to construct the agricultural activity details for the farm, so they represent a typical grain farm for each soil, including the land use patterns and selection of crops produced on the farm. Each representative grain farm was modeled to grow various types of crops, with each crop covering specific areas. For instance, the representative farm in the Black soil zone grew seven major crops, with canola and spring wheat being the primary crops. Similarly, the study crop in the Brown soil zone grew seven major crops, with durum wheat and lentils being the major crops, while the representative farm in the Dark Brown soil zone grew eight crops where, the primary crops were canola, spring wheat, and lentils. Details of the crops grown, and their share of farm area are shown in Table D.3.

Table D.9. Land use pattern of the representative farm for each soil zone.

Black SZ*		Brown SZ*		Dark Brown SZ*	
Types of crops	Area (ha)	Types of crops	Area (ha)	Types of crops	Area (ha)
Canola	171	Durum Wheat	187	Canola	167
Spring Wheat	87	Lentils	155	Spring Wheat	127
Feed Barley	36	Alfalfa	49	Lentils	93
Oats	30	Peas	38	Feed Barley	43
Alfalfa	30	Feed Barley	19	Peas	40
Peas	19	Oats	7	Alfalfa	28
Tame Hay	11	Flax	7	Flax	9
-	-	-	-	Tame Hay	10
Crop cultivated area	384	Crop cultivated area	462	Crop cultivated area	515
Other Land Use area	57	Other Land Use area	137	Other Land Use area	65
Total area	441	Total area	599	Total area	580

*Soil Zone

Adopted from Islam (2022).

D.4. Cost of Production (COP) under field shelterbelt for a representative farm area in each of soil zone

The COP for each representative farm consisted of two types of costs, namely (1) fixed costs and (2) variable costs. Fixed costs included land investment, building and machinery investment, etc. on the other hand, the variable costs included costs of crop seeds, fertilizer, chemicals, machine operation, and hired labor. Estimates of the COP for each year in the 60-year planning horizon were obtained through forecasting. To do this, the ten years data (2009 – 2018) on COP was collected for each crop in each soil zone from the crop Planning Guide (Government of Saskatchewan 2009; 2010; 2011; 2012; 2013; 2014; 2015; 2016; 2017, 2018). The mean and standard deviation was then calculated, after which the resulting values were converted into the 2018-dollar value using a Farm Input Price Index (FIPI). Using the calculated mean and standard deviation for each variable, an excel-based random generator was used to forecast future values for COP for each crop in each soil zone over the 60-year planning horizon. In addition to the COP, field shelterbelts impose additional costs to the farmer, known as shelterbelt establishment and maintenance cost, including costs of purchasing shelterbelt seedlings, herbicide and fertilizer costs, irrigation, and tillage costs. Shelterbelt costs were incurred for the first five years (Rudd 2020). Particularly, seedling purchase costs was incurred in the first year of establishment (Islam 2022), while the herbicide and irrigation costs typically occurred during the first five and three years, respectively. Fertilizer and tillage costs were incurred only once before planting shelterbelts (Rudd 2020).

D.5. Farm revenue under field shelterbelt for a representative farm area in each of soil zone

Farm revenue was assumed to be generated only through crop production (Islam, 2022), which depended on each crop's yield and the price received by farmer (farm-level price). That is, other sources of farm revenue, such as investment were held constant. Field shelterbelts impact farm revenue by (1) reducing the total area of land under crops, and (2) modifying crop yield due to its protection of crops from extreme weather conditions. These impacts depend on the design of shelterbelts on the farm field, which are typically based on tree species' feature and shape, space between rows, direction, etc. The estimation of farm revenue under field shelterbelt is discussed in the subsequent paragraphs.

D.5.1 Design of field shelterbelts on the representative farm field

The design of field shelterbelts on the representative farm field was guided by Agriculture and Agri-Food Canada's (AAFC) guidelines and experts' opinions (Amichev 2020 and Mood 2020). The study (Islam 2022) assumed that field shelterbelts on the representative farms consisted of one row of caragana shrubs, with a linear shape representing the most common design of field shelterbelts in Saskatchewan (AAFC 2010). A one – quarter section sized (64.8 ha) field, dimensions 805 metres by 805 metres (Figure D.1), was used a base unit for each crop the farm when designing field shelterbelts for the farm (Islam 2022). Moreover, it was assumed that one-row caragana field shelterbelts were aligned north to south within the field boundaries. Because a single row of shelterbelts can only protect a limited area of field, the study used three rows of shelterbelts in the quarter section field (Figure D.1), planted approximately 200-250 metres apart, with the first shelterbelt planted on the extreme west side of the field (AAFC 2010), ensuring that the crops obtain maximum protection under the shelterbelts.

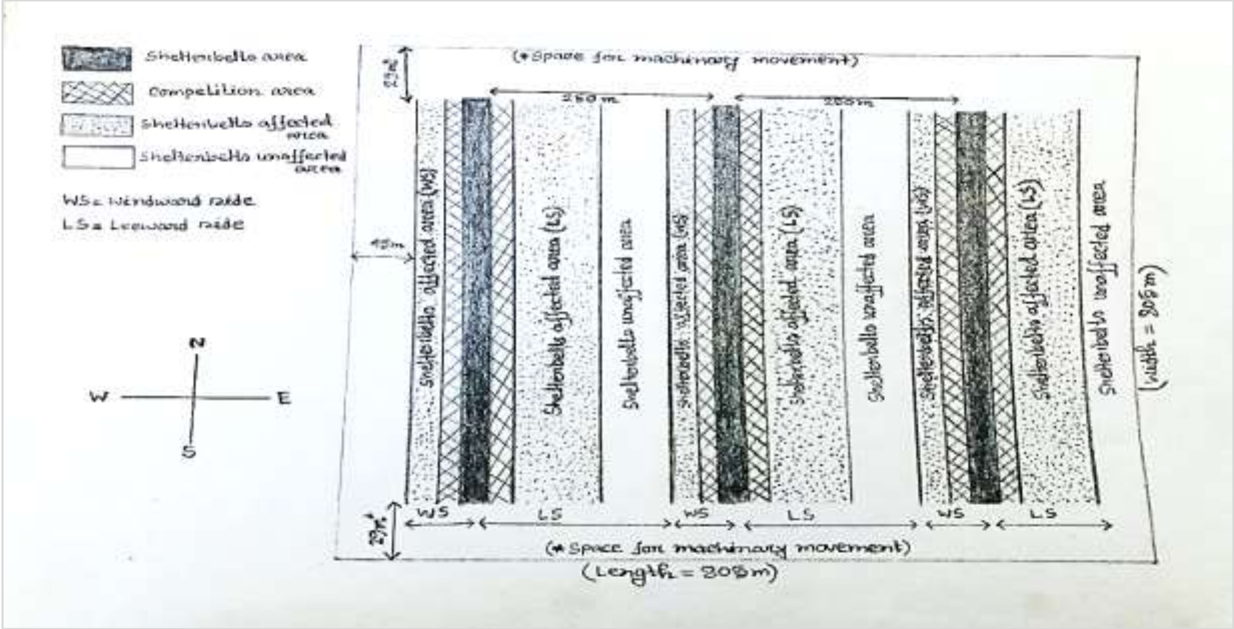


Figure D.1. Caragana field shelterbelts design on a 64.8 ha farm field

Adopted from Islam (2022)

D.5.2 Crop yield estimation under field shelterbelt protection

As mentioned earlier, a key impact of field shelterbelts on farm revenue considered in the NPV calculation is its impact on crop yields. Field shelterbelts affect crop yield by protecting crops from extreme wind conditions by altering winds patterns. Moreover, they increase soil moisture available for crops by capturing snow in the surrounding field areas (Kort et al. 2012). Crop protection under shelterbelts is influenced by the side of shelterbelts where the crops are located, namely the windward and leeward sides. The windward side of the field is the area in the field where the wind blows towards the west side of the shelterbelts. Here, shelterbelts are not very effective in protecting the crops against the wind. In Figure D.2, the windward area extends from 2H to 5H[14]. The leeward side of the field, on the other hand, is the area where the wind passes through and above the shelterbelts towards the east side. This section is more significant and ranges from 10H to 20H and has a more extensive impact on crop yield, as shown in Figure D.2.

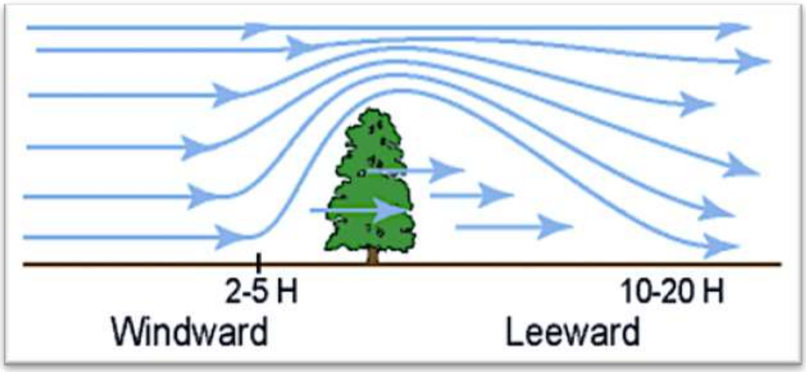


Figure D.2. Windward and leeward side of shelterbelts

Adopted from Islam (2022)

The study considered both sides of shelterbelts while evaluating the impacts of field shelterbelts on crop yield. As the yield of the crop varied with different levels of influence of the shelterbelts on the field, the area between two shelterbelt rows was divided into four areas namely (1) shelterbelts area; (2) competition area; (3) shelterbelt affected area; and (4) shelterbelt unaffected area. The shelterbelt area is the "area under the crown width" of the linearly planted shelterbelts and it is not available for crop production (Amadi 2016). Similarly, the competition area is located immediately adjacent to the shelterbelt area. There's increased competition for soil nutrients and moisture between crops and planted shelterbelts in this area, resulting in low crop yields. Depending on the species of shelterbelts, crop species, and the geographical location, crop yields may be reduced in the shelterbelt area (Kort 1988). Moreover, the area adjacent to the competition area where there is increased crop yields due to adequate wind protection and no competition between shelterbelts and crops is called the shelterbelt affected area (AARD 2004). Finally, shelterbelt unaffected area is the remaining area of the field where the shelterbelt does not influence crop growth.

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[14] The size of the shelterbelts affected area mainly depended on the shelterbelt's height (H) (Brandle et al. 2009). Here (H) means distance from the shelterbelts in units of its height (Osorio et al. 2019).

The initial estimate of crop yields for each crop in each year in the 60-year planning horizon was obtained through forecasting. Firstly, ten years data (2009 – 2018) were collected each for crop's yield for each crop in each soil zone from the crop Planning Guide (Government of Saskatchewan 2009; 2010; 2011; 2012; 2013; 2014; 2015; 2016; 2017, 2018). The mean and standard deviation of the crop yields were then calculated. Using the calculated mean and standard deviation for each variable, an excel-based random generator was used to forecast future values for crop yield for each crop in each soil zone over the 60-year planning horizon. Estimates of field shelterbelt's impact on crop yield was then computed to determine crop yield under field shelterbelt. This was done by estimating the weighted yield of each crop in a year by considering three areas in the field: competition area, shelterbelt affected area (including leeward side and windward side), and shelterbelt unaffected area. The weighted yield for the representative farm area in each soil zone estimated using equation D.1. This estimated process was repeated 60 times to get 60 years weighted yield of each crop in each soil zone.

$$W_t = \frac{[(Y_{plt} * A_{plt}) + \ (Y_{blt} * A_{blt})] + [(Y_{pwt} * A_{pwt}) + (Y_{bwt} * A_{bwt})] + (Y_{ut} * A_{ut})}{(A_{plt} + A_{blt} + A_{pwt} + A_{bwt} + A_{ut})} \quad \text{D.1}$$

Here,

W = Weighted crop yield

Y = Estimated yield (tonne/ha) of each crop.

A = Area (ha)

Subscript t = Time period

Subscript plt = Competition area of leeward side in year t.

Subscript blt = Shelterbelt affected area of leeward side in year t.

Subscript pwt = Competition area of windward side in year t.

Subscript bwt = Shelterbelt affected area of windward side in year t.

Subscript ut = Shelterbelt unaffected area in year t.

Finally, the farm-level revenue under shelterbelt establishment for the representative farm in each soil zone was estimated by multiplying the weighted crop yield of all crops by their respective farm-level prices. It is important to note that field shelterbelts require a certain time (i.e., ten years) to reach a certain height to protect and influence crop. Therefore, following Mize et al. (2008), there was no shelterbelt effect on crop yield over the first ten years of planting field shelterbelts (Islam 2022). This assumption applied to competition and shelterbelts affected areas for crop yield estimation.

D.6. Method for Calculating NPV

The method for calculating the NPV of farm-level net revenue under shelterbelt for each representative farm considered the time value of the streams of farm revenue and COP generated over the 60-year planning horizon. The calculation of the NPV was adopted from Boardman et al. (2018), and shown in equation (D.2):

$$NPV = \sum_{t=1}^{60} \frac{NR_t}{(1+i)^t} \qquad \text{(D.2)}$$

Where NR_t refers to the net revenues of the representative farm under field shelterbelt establishment over the 60-year planning horizon. Similarly, i is the discount rate, and t is the number of years, with $t =$ 1,2,3,…,60.

Islam (2022) estimated a discount rate value of 8.68% using equation (D.3), as suggested by Mendoza (2019). It was calculated based on the weighted average cost of borrowed capital and equity funds.

$$\begin{aligned} i &= K_e W_e + K_d (1 - x) W_d \qquad \text{(D.3)} \\ &= (10.2\%)(80.5\%) + (3.64\%)(1 - 0.125)(14.9\%) \\ &= 0.0821 + 0.0047 \\ &= 0.0868 \\ &= 8.68\% \end{aligned}$$

Where K_e is return on equity (ROE) = 10.2% (obtained from Farm Credit Canada (FCC) (2018)). Similarly, W_e is equity asset ratio = 80.5% and K_d is interest rate on debt = 3.64% (obtained from Mendoza (2019)). W_d is debt asset ratio = 14.9% (obtained from

Statistics Canada (2017)). Finally, x is income tax = 12.50% in Saskatchewan for taxable income between \$45,225 up to \$129,214 based on Government of Saskatchewan (2018b).

Appendix E –

Comparing the total annual carbon sequestered due to alternative policy instrument against total annual agricultural GHG emissions in Saskatchewan.

Total amount of Saskatchewan's GHG emissions in 2018 = 76.4Mt/CO_2 (Government of Saskatchewan, 2020).

Agricultural sector's contributed 24% to the total GHG emissions in 2018 (Government of Saskatchewan, 2020).

Therefore,

$$GHG\ Emissions_{Agriculture\ Sector} = \frac{24}{100} * 76.4MtCO_2(eq) = \mathbf{18.34MtCO_2(eq)}$$

I. Free Seedlings Policy Instrument

$$GHG\ Mitigation = \frac{Total\ Annual\ amount\ of\ Carbon\ Sequestered\ from\ Free\ Seedlings}{Total\ Annual\ of\ GHG\ emissions\ from\ the\ Agriculture\ Sector} * 100\%$$

Total Annual amount of Carbon sequestered due to Free Seedlings Policy Instrument (All 3 Soil Zones):

$$= 10{,}124tCO_2(eq) + 6{,}422tCO_2(eq) + 3{,}379tCO_2(eq) = 19{,}925tCO_2(eq)$$

Therefore,

$$GHG\ Mitigation = \frac{19{,}925tCO_2(eq)}{18.4MtCO_2(eq)} * 100\% = \mathbf{0.11}\%$$

II. Negative Carbon Tax Policy Instrument

1. **Carbon Price = $74.60**

$$GHG\ Mitigation = \frac{Total\ Annual\ amount\ of\ Carbon\ Sequestered\ from\ NCT\ @\ \$74.60}{Total\ Annual\ of\ GHG\ emissions\ from\ the\ Agriculture\ Sector} * 100\%$$

Total Annual amount of Carbon sequestered due to Negative Carbon Tax valued at Carbon Price of $74.60 (All 3 Soil Zones):

$$= 7{,}475tCO_2(eq) + 5{,}702tCO_2(eq) + 2{,}731tCO_2(eq) = 15{,}908tCO_2(eq)$$

Therefore,

$$GHG\ Mitigation = \frac{15{,}908tCO_2(eq)}{18.4MtCO_2(eq)} * 100\% = \mathbf{0.09}\%$$

2. **Carbon Price = $110.49**

$$GHG\ Mitigation = \frac{Total\ Annual\ amount\ of\ Carbon\ Sequestered\ from\ NCT\ @\ \$110.49}{Total\ Annual\ of\ GHG\ emissions\ from\ the\ Agriculture\ Sector} * 100\%$$

Total Annual amount of Carbon sequestered due to Negative Carbon Tax valued at Carbon Price of $110.49 (All 3 Soil Zones):

$$= 11{,}069tCO_2(eq) + 8{,}484tCO_2(eq) + 4{,}027tCO_2(eq) = 23{,}580tCO_2(eq)$$

Therefore,

$$GHG\ Mitigation = \frac{23{,}580tCO_2(eq)}{18.4MtCO_2(eq)} * 100\% = \mathbf{0.13}\%$$

3. Carbon Price = $574.13

$$GHG\ Mitigation = \frac{Total\ Annual\ amount\ of\ Carbon\ Sequestered\ from\ NCT\ @\ \$574.13}{Total\ Annual\ of\ GHG\ emissions\ from\ the\ Agriculture\ Sector} * 100\%$$

Total Annual amount of Carbon sequestered due to Negative Carbon Tax valued at Carbon Price of $574.13 (All 3 Soil Zones):

$$= 59{,}978tCO_2(eq) + 45{,}434tCO_2(eq) + 21{,}796tCO_2(eq) = 127{,}208tCO_2(eq)$$

Therefore,

$$GHG\ Mitigation = \frac{127{,}208tCO_2(eq)}{18.4MtCO_2(eq)} * 100\% = \mathbf{0.70}\%$$

4. Canadian Carbon Tax Rate (CCTR)

$$GHG\ Mitigation = \frac{Total\ Annual\ amount\ of\ Carbon\ Sequestered\ from\ CCTR}{Total\ Annual\ of\ GHG\ emissions\ from\ the\ Agriculture\ Sector} * 100\%$$

Total Annual amount of Carbon sequestered due to Negative Carbon Tax valued at CCTR (All 3 Soil Zones):

$$= 17{,}880tCO_2(eq) + 12{,}600tCO_2(eq) + 5{,}971tCO_2(eq) = 36{,}451tCO_2(eq)$$

Therefore,

$$GHG\ Mitigation = \frac{36{,}451 tCO_2(eq)}{18.4 MtCO_2(eq)} * 100\% = \mathbf{0.21}\%.$$

Appendix F –

Estimating the fiscal cost of negative carbon tax.

I. Black Soil Zone

Total number of crop farms in the black soil zone. **Source:** Statistics Canada, Land Use Website

Total number of farms = 15,248 Farms.

1. Carbon Price: $74.60

Total amount of carbon sequestered over the 60-year planning period $= 448{,}495 tCO_2$

Price of carbon= $\$74.60 t/CO_2$

Total Fiscal Cost $= Price\ of\ carbon * total\ amount\ of\ carbon\ sequestered$

$$= \$74.60 t/CO_2 * 448{,}495 tCO_2$$

$$= \$\mathbf{33.46}\ \boldsymbol{million}$$

2. Carbon Price: $110.49

Total amount of carbon sequestered over the 60-year planning period $= 664{,}118 tCO_2$

Price of carbon= $\$110.49 t/CO_2$

Total Fiscal Cost $= Price\ of\ carbon * total\ amount\ of\ carbon\ sequestered$

$$= \$110.49 t/CO_2 * 664{,}118 tCO_2$$

$$= \$\mathbf{73.38}\ \boldsymbol{million}$$

3. Carbon Price: $574.13

Total amount of carbon sequestered over the 60-year planning period $= 3{,}598{,}641 tCO_2$

Price of carbon= $\$574.13 t/CO_2$

Total Fiscal Cost $= Price\ of\ carbon * total\ amount\ of\ carbon\ sequestered$

$$= \$574.13 t/CO_2 * 3{,}598{,}641 tCO_2$$

$$= \$\mathbf{2.06}\ \boldsymbol{billion}$$

4. Carbon Price: CCTR (Average rate = \$157)

Total amount of carbon sequestered over the 60-year planning period $= 1{,}072{,}775tCO_2$

Price of carbon= $\$157t/CO_2$

Total Fiscal Cost $= Price\ of\ carbon * total\ amount\ of\ carbon\ sequestered$

$$= \$157t/CO_2 * 1{,}072{,}775tCO_2$$

$$= \$\mathbf{168.43}\ \boldsymbol{million}$$

II. Brown Soil Zone

Total number of crop farms in the brown soil zone. **Source:** Statistics Canada, Land Use Website

Total number of farms = 6,970 Farms.

1. Carbon Price: \$74.60

Total amount of carbon sequestered over the 60-year planning period $= 342{,}070tCO_2$

Price of carbon= $\$74.60t/CO_2$

Total Fiscal Cost $= Price\ of\ carbon * total\ amount\ of\ carbon\ sequestered$

$$= \$74.60t/CO_2 * 342{,}070tCO_2$$

$$= \$\mathbf{25.52}\ \boldsymbol{million}$$

2. Carbon Price: \$110.49

Total amount of carbon sequestered over the 60-year planning period $= 509{,}011tCO_2$

Price of carbon= $\$110.49t/CO_2$

Total Fiscal Cost $= Price\ of\ carbon * total\ amount\ of\ carbon\ sequestered$

$$= \$110.49t/CO_2 * 509{,}011tCO_2$$

$$= \$\mathbf{56.24}\ \boldsymbol{million}$$

3. **Carbon Price: $574.13**

Total amount of carbon sequestered over the 60-year planning period $= 2{,}726{,}096tCO_2$
Price of carbon= $\$574.13t/CO_2$
Total Fiscal Cost $= Price\ of\ carbon * total\ amount\ of\ carbon\ sequestered$

$$= \$574.13t/CO_2 * 2{,}726{,}096tCO_2$$

$$= \$\mathbf{1.57}\ \boldsymbol{billion}$$

4. **Carbon Price: CCTR (Average rate = $157t/C0$_2$)**

Total amount of carbon sequestered over the 60-year planning period $= 756{,}011tCO_2$
Price of carbon= $\$157t/CO_2$
Total Fiscal Cost $= Price\ of\ carbon * total\ amount\ of\ carbon\ sequestered$

$$= \$574.13t/CO_2 * 756{,}011tCO_2$$

$$= \$\mathbf{118.70}\ \boldsymbol{million}$$

III. Dark Brown Soil Zone

Total number of crop farms in the dark brown soil zone. **Source:** Statistics Canada, Land Use
Total number of farms = 5,514 Farms.

1. **Carbon Price: $74.60**

Total amount of carbon sequestered over the 60-year planning period $= 163{,}845tCO_2$
Price of carbon= $\$74.60t/CO_2$
Total Fiscal Cost $= Price\ of\ carbon * total\ amount\ of\ carbon\ sequestered$

$$= \$74.60t/CO_2 * 163{,}845tCO_2$$

$$= \$\mathbf{12.22}\ \boldsymbol{million}$$

2. Carbon Price: $110.49

Total amount of carbon sequestered over the 60-year planning period $= 241{,}617 tCO_2$
Price of carbon= $\$110.49 t/CO_2$
Total Fiscal Cost $= Price\ of\ carbon * total\ amount\ of\ carbon\ sequestered$

$$= \$110.49 t/CO_2 * 241{,}617 tCO_2$$

$$= \$\mathbf{26.70}\ \boldsymbol{million}$$

3. Carbon Price: $574.13

Total amount of carbon sequestered over the 60-year planning period $= 1{,}307{,}702 tCO_2$
Price of carbon= $\$574.13 t/CO_2$
Total Fiscal Cost $= Price\ of\ carbon * total\ amount\ of\ carbon\ sequestered$

$$= \$574.13 t/CO_2 * 1{,}307{,}702 tCO_2$$

$$= \$\mathbf{750.79}\ \boldsymbol{million}$$

4. Carbon Price: CCTR (Average rate = $157)

Total amount of carbon sequestered over the 60-year planning period $= 358{,}274 tCO_2$
Price of carbon= $\$157 t/CO_2$
Total Fiscal Cost $= Price\ of\ carbon * total\ amount\ of\ carbon\ sequestered$

$$= \$157 t/CO_2 * 358{,}274 tCO_2$$

$$= \$\mathbf{56.25}\ \boldsymbol{million}.$$