AN ECONOMIC ANALYSIS OF AFFORESTATION ON AGRICULTURAL LAND IN EAST CENTRAL SASKATCHEWAN

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ABSTRACT

The economic viability of farming in Saskatchewan is eroding and the future of the industry is becoming uncertain given the current economic state. The combination of low commodity prices, increasing input and transportation costs, ongoing drought conditions, inadequate safety net programs, and environmental concerns resulting from agricultural greenhouse gas emissions has led to this uncertainty.

One possible solution for producers to help overcome or at least minimize the negative trends occurring in agriculture, which is proposed, is afforestation of agricultural land. Afforestation not only provides net private benefits of timber income but external benefits, including carbon sequestration, and preservation of native forests, which provides areas for hunting, wildlife viewing, and conservation of land.

The economic efficiency of afforestation was examined using a transitional benefit cost framework for both crop and pasture systems. This allowed for both private and social perspectives, along with the opportunity costs, to be included and the economic efficiency of afforestation from each perspective was determined. The potential conversion of agricultural land to afforestation was based solely on economic efficiency and assumed producers demonstrated an economically rational decision making process.

The results from the benefit cost analysis indicated that the net private benefits from afforestation were never significant enough to warrant the conversion of either crop or pasture systems to afforestation. The results did however show that the net social benefits from afforestation would warrant the conversion of crop systems to afforestation for a limited number of situations. Crop systems on physically marginal land with a carbon payment of either $22.58 or $33.55 tonne of C would warrant conversion to afforestation, using either a single or infinite rotation. The infinite rotation resulted in a larger allocation of land to afforestation.

The role afforestation can play in helping producers diversify and increase income levels is limited. The low price paid for timber and the high costs of establishment for afforestation are the main constraints. In order for afforestation to become economically efficient on a large scale the constraints facing producer's needs to be addressed.

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CHAPTER ONE: INTRODUCTION

1.0 Background

The economic viability of grain and livestock farming in Saskatchewan is eroding and the future of the industry in the province is becoming uncertain given the current economic state. The uncertainty is due to a combination of low commodity prices, increasing input and transportation costs, ongoing drought conditions, inadequate safety net programs, and concerns regarding agronomic practices, which are not considered environmentally friendly. In addition, the concerns regarding climate change could have negative economic impacts on the farming sector in Saskatchewan, as approximately 22 percent of the total GHG emissions in Saskatchewan arise from agriculture (Environment Canada 1999). In comparison, national agricultural emissions account for approximately 9.5 percent of total Canadian emissions (Environment Canada 1999). Saskatchewan agriculture is in a unique situation, as while agriculture is a large source of GHGs, it also has a large sink[1] potential that can help to offset the GHG emissions. The use of soil sinks may help to alleviate part of the financial burden to Saskatchewan because soil sinks can offset non-CO_2 emissions. The adoption of zero tillage and reduced summerfallow is estimated to have the capacity to reduce Saskatchewan's total estimated agricultural GHG emissions in 2010 by 25.1 percent (Boehm, 2002). Depending on the federal government's policies regarding the reduction of GHGs nationally the cost to Saskatchewan agriculture could be substantial.

The farming sector in Saskatchewan has experienced decreasing profit margins, which is forcing many producers to shift the focus of their operations. Decreased profitability, combined with inadequate government safety net programs, has led to an increase in the hectares seeded to specialty crops, diversification into livestock and cultivation of physically marginal lands[2]. The higher prices for specialty crops and the peak of the market cycle for livestock has allowed for increased profitability for producers that were early entrants into these markets. While this has

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1 A sink is a process, activity or mechanism, which sequesters carbon out of the air and stores in biomass or soil (UNFCCC 2001c).

2 In addition the need to obtain off-farm income has increased.

provided a short run solution for some producers, the viability in the long run may be limited. As a greater quantity of producers have diversified their operations the overall profitability levels have fallen due to the limited demand and increased supply of specialty crops and a market cycle for beef that appears to be on the downturn. Producers have also been forced to adopt management systems, which maximize the short-run returns from the land (Belcher and Gray 2001). The maximization of the short-run returns as opposed to the long-run returns may fail to factor in the long-run sustainability[3] of the farm operation and thus creates uncertainty regarding its future.

The concern over increasing levels of GHGs in the atmosphere led to the adoption of an international framework for reduction of GHGs called the Kyoto Protocol. Canada's agreed commitment under the Kyoto Protocol would result in a six percent reduction of GHG emissions below the 1990 level during the first commitment period (2008 – 2012). This equates to an estimated 25.8 percent reduction during the first commitment period under a business as usual scenario[4] (Environment Canada 1999, Saskatchewan Agriculture and Food, SAF 2002a, and van Kooten, et al. 1999). The total estimated abatement costs for the period of 1999 - 2012, which Canada and Saskatchewan may incur, are \$868 billion and \$31 billion, respectively (Yiannaka, et al. 2001). This works out to an average abatement cost of approximately \$58 billion per year for Canada and \$2 billion per year for Saskatchewan, which represents 7.11 percent and 6.99 percent of GDP for Canada and Saskatchewan, respectively. Data obtained from Environment Canada (1999) shows Canadian agricultural emissions would need to be reduced by 20.1 percent for the first commitment period, while Saskatchewan would be required to reduce total GHG emissions by 39.4 percent and agricultural emissions by 29.4 percent[5]. As a result prairie agriculture is expected to play a crucial role in the mitigation and abatement of GHGs.

A potentially viable long-term alternative for Saskatchewan producers to help increase of farm incomes, while helping to offset GHG emissions is afforestation of agricultural land[6]. Afforestation is defined by the UNFCCC (2001d) as the "direct human conversion of land that

3 In the context of this study sustainability implies that farm profitability is either stationary (weak sustainability) or increasing over time (strong sustainability) (van Kooten 1995).

4 Business as usual refers to a continuation of the current practices into the future.

5 The projected emissions from agriculture in 2010 are expected to account for 24.2 percent of total GHG emissions in Saskatchewan. The annual cost to agriculture is calculated as 24.2 percent of \$2 billion

6 In the context of this study agricultural land will include all cultivated cropland and improved pasture. Unimproved pasture is excluded because a large percentage of this land already has trees and thus does not fit the definition of afforestation.

has not been forested for a minimum of 50 years to forested land through planting of trees". Diversification into afforestation may help some producers stabilize or increase income levels, while simultaneously helping to offset GHG emissions. According to the Canadian Cooperative on Intensive Forest Management (CCIFM) (2001, p. 1) that "while long-term forecasts indicate strong growth in world demand for industrial forest products, there is real concern that Canada is poorly positioned to participate in this growth…". Canada's inadequate global position is largely due to uncertainties about adequate wood supplies and land-use constraints. The driving force behind the land-use constraints is the increased societal and environmental awareness regarding the status and importance of Canada's native forests. Thus the objectives of any afforestation project must manage the economic, social and environmental issues currently facing Canada.

The importance of growing trees goes far beyond agricultural diversification. Afforestation has the potential to help contribute to rural economic diversification and sustainability, in addition to exhibiting external benefits. The external benefits include carbon sequestration, providing areas for recreational activities, the preservation of native forests and wildlife, and contributing to biodiversity, as well as improving air, soil and water quality. Saskatchewan agriculture can take advantage of the afforestation potential that exists not only to provide an alternative income source but also aid in the reduction of GHGs.

1.1 Problem

Traditional agricultural practices in Saskatchewan are becoming less viable due to economic, environmental and social issues. In order for producers to maintain, or attain an economically viable future operation they must diversify their operations. Afforestation is an option for producers. The identification and quantification of the private benefits and costs[7] (timber revenue and afforestation establishment and maintenance costs) for producers undertaking such a venture need to be clearly identified. In addition the external benefits and costs[8] (carbon sequestration, land conservation, hunting and wildlife viewing) of afforestation for society as a whole need to be estimated. This will provide the total net benefit to producers and society as a result of afforestation.

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7 Private benefits and costs are those that accrue to the producer via the market or non-market mechanisms (Belcher and Gray 2001).

8 External benefits and costs are those, which accrue to individuals outside the market (Belcher and Gray 2001) and are often referred to as non-market goods.

1.2 Objectives

The main objective of this study is to identify and quantify the private benefits and costs (timber revenues and costs) and external benefits and costs (carbon sequestration, hunting, wildlife viewing and conservation of native forests) of afforestation, through the use of transitional benefit cost[9] analysis. The social benefits[10] and costs are the sum of the private and external benefits and costs.

The specific objectives of the study are:

1. To identify the various private and external benefits and costs of afforestation, specifically hybrid polar trees, in east central Saskatchewan;
2. To quantify the private and external benefits and costs within a transitional benefit-cost framework.

1.3 Scope of the Study

The study deals specifically with crop district 5B in east central Saskatchewan, which includes 23 rural municipalities (RM's). The 14 crop insurance soil classifications will be examined within each RM as the soil productivity decreases from soil class A through P and thus influences the economic returns from the land. The area chosen is located in the Black Soil zone and includes two Ecozones[11]: the Boreal Plains and Prairie Ecozones (Acton, et. al. 1998). This area was chosen because of its location in relation to crown forest and because the area is in close proximity to existing sawmills in Hudson Bay, Saskatchewan and Swan River, Manitoba. The current land use in this area consists mainly of agricultural crops and pasture, but the area has the biophysical characteristics required for tree growth and was primarily forested prior to agricultural development.

1.4 Organization of Study

The remainder of the thesis is organized as follows; Chapter Two contains a literature review, Chapter Three provides the applicability of afforestation practices on agricultural land, Chapter Four provides the theoretical framework utilized, Chapter Five presents the empirical

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9 Transitional B-C analysis includes the opportunity costs from either crop or pasture systems in the B-C ratios. This allows for the B-C ratios to provide the relative gain (loss) from converting the land to afforestation, as opposed to having to compare the individual projects.

10 Social benefits are those that accrue to all individuals (Belcher and Gray 2001).

analysis of the study. Chapter Six describes the various scenarios used in the model and presents the results of the analysis. Finally Chapter Seven summarizes the results of the analysis and provides the limitations of the study along with the need for further research.

[11] Ecozones are broad generalized ecological units having distinctive combinations of physical and biological characteristics.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

The main goal of this chapter is to provide the necessary background information to help identify the need and relevance for this study, as stated in Chapter One. The first Section outlines the current economic state of grain and livestock farming in Saskatchewan and the most prominent issues currently facing producers (Section 2.1). Section 2.2 focuses on climate change literature and the methods of reducing agricultural GHGs. This Section provides the link between agriculture, afforestation and climate change. Section 2.3 introduces the concept of afforestation. Sections 2.Four and 2.5 introduce hybrid poplars and the agronomic practices required for growing them as a crop. Finally Chapter Two is concluded in Section 2.6.

2.1 Farm Profitability

Realized net farm income on the prairies has been declining over the last 20 years (Figure 2.1). The main factors, which have led to this result, are falling commodity prices, increasing production and transportation costs, decreasing government safety net programs, and increasing frequency of drought conditions. Figure 2.1 provides total net realized income, cash receipts and expenses (2001) for Saskatchewan farms from 1981 through 2000, with a trend line through 2005 showing the projected future values. While the realized net income has fluctuated greatly from 1981 to 2000, the trend line shows a decline of approximately $31,097 annually over the last 20 years and the projection through 2005 shows the same.

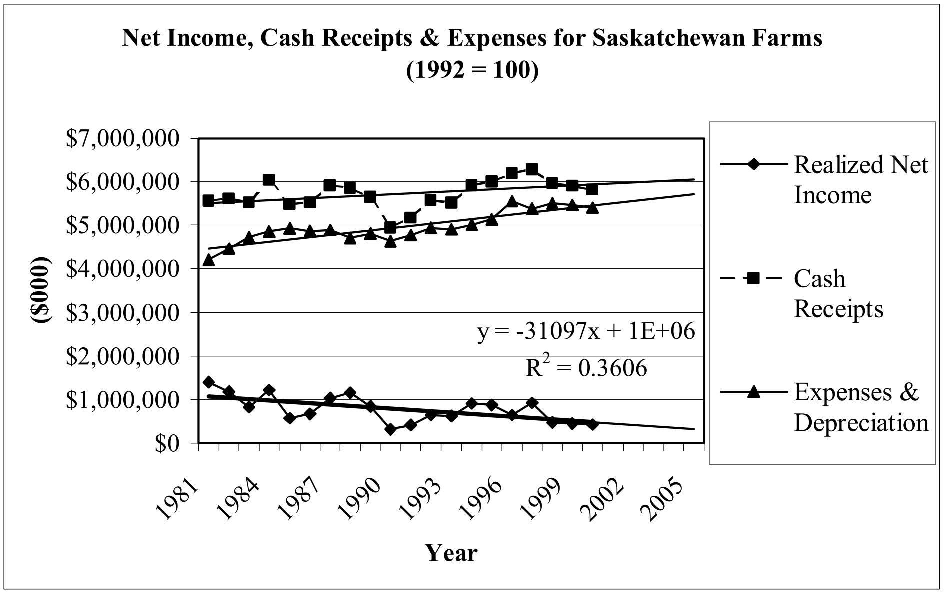

Figure 2. 1: Total realized net income, cash receipts and expenses for Saskatchewan farms (1992 = 100)

Source: SAF (2001)

Given these financial trends, the future economic viability of Saskatchewan agriculture is uncertain. Narrowing profit margins have resulted in a lack of debt serviceability on Saskatchewan farms, which has resulted in an overall reduction in farm profitability. As many producers overextend their debt levels the need for additional income becomes more crucial than ever to ensure the farms future viability. In an attempt to increase profitability many producers are diversifying their operations, reducing input usage, cultivating physically marginal lands and obtaining off farm employment (Prairie Farm Rehabilitation Administration, PFRA 2000). The PFRA (2000) indicates that low profit margins are forcing many producers to farm the land more intensively just to make a profit (Table 2.1).

Table 2. 1: Environmentally marginal land in annual cultivation in Saskatchewan, 1996 (ha)

Soil Type	*Area*
Black	319,000
Brown	897,000
Dark Brown	615,000
Dark Gray	105,000
Gray	79,000
Total	2,016,000

Source: PFRA (2000)

According to the PFRA (2000), given the current land base (Table 2.2), any new cropland will be derived from range and improved forage lands and these lands are poor quality and considered physically marginal[12]. Given that 3-5 million hectares of physically marginal land in crops are both economically and environmentally unsustainable the addition of new physically marginal land to the total cultivated hectares cannot be considered sustainable.

Table 2. 2: Prairie agricultural land base, 2000 (million ha)

Land Description	*Area*
Cultivated Lands in Crops Sustainable Economically and Environmentally	23
Cultivated Land in Crops Economically Unsustainable	4-6
Cultivated Marginal Land in Crops Economically & Environmentally Unsustainable	3-5
Range & Improved Forage Lands	22
Total	52

Source: PFRA (2000)

Diversification or improved production efficiency on existing lands rather than increased production levels achieved through an increase in cultivated land base is an option that may help some producers increase farm income. This is especially true if the increased land base is derived from physically marginal lands. An option for producers looking to diversify their operations is afforestation of agricultural land. The concept and agronomic practices of afforestation will be discussed more thoroughly in Sections 2.3 – 2.5.

2.2 Climate Change and Agriculture

Climate change has become one of the most prominent environmental issues of our time. A large body of environmental research has been and is focused on climate change. Estimating and quantifying the effects increasing levels of GHGs have in the atmosphere has resulted in many different recommendations about what and if any actions should be taken to address the situation. This Section summarizes the background information concerning climate change and provides the direction, which many countries, including Canada, are taking to mitigate climate change. The link between agricultural activities and climate change will be identified and the potential role afforestation can play in helping Canada reduce or offset GHG emissions.

12 The description of physically marginal in this instance includes both environmental and economically marginal land. Going forward physically marginal will describe land that is of poor quality and economically marginal will describe lands that have low or negative economic returns.

2.2.1 Background

The first scientific evidence of climate change was presented in the seminal work of Svante Arrhenius in the late 19th century (Howarth and Hall 2001). The work confirmed the effects GHGs have in allowing short-wave sunlight (solar radiation) into the earth's atmosphere but impeding long-wave radiation (terrestrial radiation) from the earth's surface into outer space (Howarth and Hall 2001, Intergovernmental Panel on Climate Change, IPCC 2001). It is estimated that anthropogenic[13] GHG concentrations will cause the earth's equilibrium temperature to increase anywhere from 1.0 to 3.5°C in the next 100 years (UNFCCC 2002). While it may seem even a 1.0°C increase is insignificant it would be the largest century-time-scale trend in the past 10,000 years (UNFCCC 2002). Grubb et al. (1999) report the potential consequences of climate change include:

- Reduction in biodiversity;
- Composition changes in approximately one third of the forested areas;
- Altered growing seasons and shifts in the boundaries separating grasslands, forests and shrublands;
- Temperature increase in deserts and the increase of desertification is likely;
- The disappearance of approximately one third of the existing glacier mass;
- Changes in the distribution of wetlands and changes in lake and river productivity;
- Greater coastal flooding and erosion;
- Changes in ocean currents, which can lead to major impacts on marine ecosystems, as well as changes to heat and carbon storage capacities within the oceans.

The existence of naturally occurring GHGs has resulted in a non-anthropogenic greenhouse effect, which has been ongoing for billions of years (IPCC 2001). The most important naturally occurring atmospheric GHG is water vapor, which is not significantly affected by human activity (Schmalensee 1993, UNFCCC 2002). Other naturally occurring GHGs include carbon dioxide (CO_2), ozone (O_3), methane (CH_4) and nitrous oxide (N_2O). These naturally occurring GHGs play a vital role in the earth's atmosphere and without any GHGs the temperature on the surface of the earth would be some 30˚ C cooler than present day temperatures (UNFCCC 2001a). The other main GHGs, which are not naturally occurring include, chlorofluorocarbons (CFC-11), hydrofluorocarbons (HFC-23) and perfluoromethane (CF_4) (IPCC 2001). Anthropogenic GHG emissions account for the largest contribution towards climate change and consequently are the main focus of climate change policies.

2.2.2 Greenhouse Gas Emissions and Agriculture

Globally (1996) agricultural activities accounted for nearly 25 percent of the anthropogenic CO_2 (carbon dioxide) emissions, 60 percent of CH_4 (methane) emissions and upwards of 80 percent of the N_2O (nitrous oxide) emissions (Bunyard 1996). In Canada (2000) estimated emissions of GHGs amounted to 693 Mt (CO_2 equivalents[14]), of which agriculture was responsible for 66 Mt, or about 9.5 percent of total emissions (Environment Canada 1999). The breakdown of GHGs attributable to agriculture are as follows: 40 Mt N_2O from soils, 18 Mt CH_4 from animals, four Mt CH_4 from anaerobic manure storage and four Mt N_2O from manure exposed to air (Climate Change Table 2000, Daynard 2000, and Environment Canada 1999). In Saskatchewan (2000) emissions of GHGs amounted to 64 Mt, of which agriculture contributed 14 Mt, or 21.9 percent of total emissions (Table 2.3)[15] (Environment Canada 1999).

It is evident that Saskatchewan and Canadian agriculture are large contributors of GHG emissions. Consequently any GHG reduction policy will likely have a large impact on agriculture. In order to minimize the impact of any policy the agriculture industry needs to be proactive in addressing the need to reduce GHGs. Section 2.2.4 deals with the actions the agriculture industry is undertaking to help in reducing GHGs.

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13 Anthropogenic GHG emissions are derived from human activities including the burning of fossil fuels, such as coal, oil and gasoline, along with agricultural practices.

14 The measures of CH_4 and N_2O are in CO_2 equivalents, with one tonne of CH_4 and one tonne of N_2O equivalent to 21 tonnes and 310 tonnes of CO_2, respectively. Going forward all emission levels will be in CO_2 equivalents unless otherwise stated.

15 It should be noted that Table 2.3 represents the total emissions for some of the selected categories. This was done to comply with the international reporting system and thus do not represent the complete emissions arising from agriculture.

Table 2. 3: Saskatchewan and Canada's GHG emission outlook (Mt yr^{-1})

GHG	*Source*	*1990*	*1995*	*1997*	*2000*[a]	*2005*[a]	*2010*[a]	*2015*[a]	*2020*[a]
CO_2	Ag. Emissions – Canada	7	3	1	0	0	0	0	0
	Total CO_2 Emissions	461	495	520	537	567	595	636	662
CH_4[b]	Ag. Emissions	20	22	23	23	24	24	26	27
	Total CH_4 Emissions	75	87	90	90	91	92	96	97
N_2O[b]	Ag. Emissions	34	38	39	43	45	48	49	50
	Total N_2O Emissions								
SF_6[b]	Total SF_6 Emissions	3	2	1	1	1	1	1	1
PFCS[b]	Total PFCS Emissions	6	6	6	6	6	6	6	6
HFC[b]	Total HFC Emissions	0	1	1	2	4	7	11	14
	Total Ag. Emissions – Canada	61	63	63	66	69	72	75	77
	Total Ag. Emissions – Saskatchewan	12	11	12[a]	14	15	16	16	17
	Total Emissions – Canada	602	654	682	693	728	763	814	845
	Total Emissions – Sask.	47	57	59[a]	64	65	66	67	68
	% of Total Ag. Emissions to Total Emissions – Canada	10.1%	9.6%	9.2%	9.5%	9.5%	9.4%	9.2%	9.1%
	% of Total Ag. Emissions to Total Emissions – Saskatchewan	25.5%	19.3%	20.3%	21.9%	23.1%	24.2%	23.9%	25.0%

[a] Projections
[b] Mt CO_2 equivalents
Source: Environment Canada (1999)

2.2.3 Kyoto Protocol

The United Nations IPCC concluded in 1995 that there is direct correlation between increasing levels of GHGs and climate change (IPCC 1995). This concern over increasing levels of GHGs in the atmosphere led to the adoption of an international framework for the reduction of GHGs called the Kyoto Protocol, which was adopted on December 11, 1997 at the Conference of the Parties (COP) 3.

On July 23, 2001 at the COP 6 convention in Bonn, Germany, a comprehensive series of rules was established which would allow for the implementation of the Kyoto Protocol. The Bonn Agreement establishes principles for governing sinks, definitions and rules for accounting procedures and provides a format for future work and decisions on outstanding issues (UNFCCC 2001b).

2.2.3.1 Kyoto Commitments

Canada has agreed to reduce GHG emissions six percent below the 1990 level, which is equivalent to roughly a 25.8 percent reduction during the first commitment period (2008 – 2012) under a business as usual scenario (Environment Canada 1999, SAF 2002a, and van Kooten, et al. 1999). Environment Canada (1999), SAF (2002a), and van Kooten (2000) indicate that under the business as usual scenario Canada's projected annual emissions in 2010 will be approximately 763 Mt (Table 2.3). Given that emission levels in 1990 amounted to 602 Mt, Canada will have to reduce its emission levels to 566 Mt during the first commitment period. This equates to a net reduction of 197 Mt, or 25.8 percent. Estimated emissions from Canadian agriculture in 2010 are 72 Mt, or 9.4 percent of total emissions. The emission's from agriculture in 1990 were 61 Mt and assuming that commitments are to be spread evenly across all sectors and provinces a six percent reduction would reduce agricultural emissions to 57.3 Mt. This equates to a net reduction of 14.7 Mt, or 20.1 percent. Actual commitments may vary across sectors and provinces, depending on the Federal governments GHG policy, and consequently agricultural emission reductions may be more or less than is estimated here.

Environment Canada (1999) also indicated Saskatchewan's emission levels in 2010 would be approximately 66 Mt. Given emission levels in 1990 were 47 Mt, a net reduction of 26 Mt, or 39.4 percent will be required to achieve the 6 percent reduction below 1990 levels. Agricultural emissions in Saskatchewan are estimated to reach 16 Mt in 2010 and in order to meet the six percent reduction; emissions will have to be lowered to 11.3 Mt, or 29.4 percent. Thus, prairie agriculture is expected to play a crucial role in the mitigation and abatement of GHGs.

2.2.4 Methods of Reducing Agriculture GHG Emissions

The reduction of CO_2 emissions from agriculture can be achieved by one of two methods; 1) abatement[16] and 2) sequestration. The method of choice depends largely on the applicability and cost of implementation.

2.2.4.1 Abatement

Abatement of CO_2 is achievable through adoption of various technologies or processes, which reduce emissions at the source. The agriculture industry in Canada has taken steps to lower GHG emissions through various production and agronomic practices. The agriculture industry has become more fuel-efficient by adopting low and zero tillage practices. The reduction in tillage also helps to prevent soil erosion, as well as promoting carbon sequestration. The livestock industry has reduced the level of GHG emissions by increasing feeding efficiency and grazing management (Climate Change Table 2000). The Climate Change Table (2000) have indicated that these practices reduce the nitrogen content of manure and measures have been

[16] Abatement refers to the overall reduction of emissions at the source.

taken to control the nitrate movement to groundwater, as well odor emissions have decreased from improved manure storage and handling.

2.2.4.2 Sequestration

Sequestration is the process by which atmospheric carbon is removed from the air and is stored in a sink as carbon. The Kyoto Protocol Article 3.4 defines sources and sinks in the land use, land-use change and forestry (LULUCF) categories (UNFCCC 1998)[17]. The UNFCCC (2002) reports LULUCF activities can provide a low cost opportunity to combat climate change through either carbon sinks (planting trees) or by reducing emissions from this sector (deforestation). These activities are identified as forest management and they must contribute to the conservation of biodiversity and sustainable use of natural resources (UNFCCC 2002).

The Kyoto Protocol accounting guidelines for afforestation activities are continually evolving. The inclusion of soil sinks has recently occurred after many rounds of negotiations and current discussions regarding the acceptance of wood products are ongoing. As a result the methodology used in this thesis will not correspond directly to the accounting guidelines as defined under the Kyoto Protocol. Basic concepts may overlap but the intention here is not to conform to what has been defined under the Kyoto Protocol. The specific assumptions for carbon credit accounting derived in this thesis are summarized in Chapter Five, Section 5.4.2.

Various agriculture management practices have been identified that could aid in the sequestration of GHG emissions (Climate Change Table 2000). These practices include conservation of grasslands, improved grazing management, improved soil and soil nutrient management, and sequestering carbon through the use of shelterbelts. While these strategies have the potential to reduce emissions and sequester GHGs they do not address the problem of declining farm incomes and decreased profitability. The use of afforestation can potentially help to address the economic, social and environmental issues facing agriculture, and is discussed in Chapter Three.

2.3 Afforestation

Afforestation of agricultural lands in Saskatchewan is an option that may allow producers to diversify their operations and increase profitability. Afforestation can also offer a potentially low cost method for countries to sequester carbon (Plantinga 1997, Plantinga, et al. 1999, Parks and Hardie 1995, Pfaff, et al. 2000, Stavins 1999, van Kooten, et al. 1999, and van Kooten 2000). The concern with implementing an afforestation project is the long time frame associated with growing trees. This problem can be overcome somewhat by utilizing high yielding trees, such as hybrid poplars. Hybrid poplars are able to reach harvestable age as early as fifteen to twenty years, under optimal growing conditions and depending on geographical location, as compared to forty years and beyond for other softwood and other hardwood trees (Figure 2.2). The growing and managing of hybrid poplars will be dealt with extensively in Sections 2.4 and 2.5.

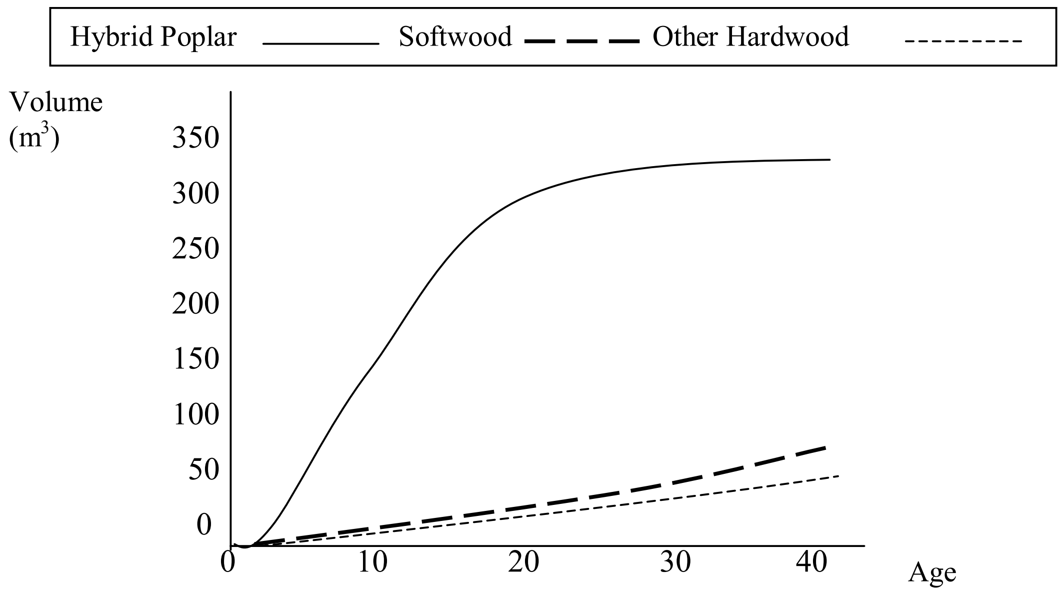

Figure 2. 2: 40-year growth curves for softwood, hardwood and hybrid poplar in the boreal region of western Canada

Source: van Kooten (2000)

2.4 Hybrid Poplars

The use of hybrid poplars in this study is largely due to the long time frame associated with growing other hardwood trees. The genus *Populus* refers to any poplar tree, which are included in the botanical family known as *Salicaceae* (Stanosz and Calabro 1998a). There are over 30 poplar species throughout the world. According to Kort (1999) the vigor of the hybrid poplar can result in selective crossing resulting in substantial growth improvement characteristics of the progeny. The most ideal species of hybrid poplar for shelterbelts on the prairies, as concluded by the PFRA (2001a), are the Walker poplar (an open pollinated *Populus deltoides*) and the

[17] Sinks sequester carbon and for every tonne of carbon sequestered in biomass 3.667 tonnes of CO_2 are removed from the atmosphere (UNFCCC 2001c).

Northwest poplar (a *Populus deltoides X Populus balsamifera* cross) (Kort 1999). In addition to these species the PFRA is conducting work on other clonal varieties potentially suitable for shelterbelts on the prairies (Table 2.4). The clonal varieties for afforestation projects may be somewhat different than the varieties used for shelterbelts.

Table 2. 4: Clonal selection choices for the prairies

Clonal Selection	*Characteristics*
Walker	(a) Female clone used solely in shelterbelts. (b) Extremely hardy and fast growing. (c) Height of 14-18 meters at 15 years. (d) Fairly resistant to canker and leaf rust.
Assiniboine	(a) Male clone used solely in shelterbelts. (b) Extremely hardy and fast growing. (c) Height of 13-17 meters at 15 years. (d) Prone to leaf rust.
Manitou	(a) Male clone used solely in shelterbelts. (b) Extremely hardy and fast growing. (c) Height of 13-17 meters at 15 years. (d) Prone to leaf spot and leaf rust.
Hill	(a) Female clone. (b) Extremely hardy and fast growing. (c) Height of 14-18 meters at 15 years. (d) Fairly resistant to canker and leaf rust.

Source: PFRA (2001a)

2.4.1 Hybrid Poplars as a Crop

Growing hybrid poplars is management intensive and more representative of traditional agriculture than forestry with regards to capital, labour and expertise requirements. Stanosz and Calabro (1998b) indicate, as with traditional agriculture, poplar yields are a function of soil quality, tree spacing, clonal selection and management. The commitment to grow hybrid poplars is long-term, with the economic benefits from timber components not being realized for a number of years. With the projected increased demand for wood products and low returns from traditional agriculture the adoption of hybrid poplars, as a crop may be a feasible alternative (PFRA 2001a).

In addition to the private economic benefits from timber revenue, the growing of hybrid poplars can provide a range of external environmental benefits. The PFRA (2001a) identifies the environmental benefits as greenhouse gas mitigation, riparian zone protection and wastewater management. These external benefits combined with the other external benefits listed previously can play a significant role in society's willingness to pay for the preservation of Canada's native forests. This could have a positive social effect on the potential for afforestation of agricultural land as afforestation could potentially displace harvesting activities in the native forest provided the forest companies total annual allowable cut for crown forests is reduced proportionately to the trees harvest on private land. Chapter Four discusses the potential external benefits of afforestation activities.

2.5 Agronomic Management

2.5.1 Site Selection, Preparation and Tree Spacing

Site preparation practices for hybrid poplars are very similar to traditional agricultural crop practices. The amount of site preparation required is dependent upon the soil type, current crop cover and climatic conditions of the region (PFRA 2001a). The PFRA also indicates intensive site preparation is required for pastureland or forage crop cover, as controlling perennial plants and weeds is crucial. Site preparation for land in grains or oilseeds is less intensive and standard agricultural equipment can be utilized for these operations. Other considerations for site selection as indicated by the PFRA (2001b) are field access, proximity to markets and access to labor (Table 2.5).

Table 2. 5: Summary of site selection criteria

Site Characteristic	*Acceptable*	*Unacceptable*
Precipitation	> 400 mm annually (or ground water within 1 to 5 meters)	< 400 mm annually (unless supplemental moisture is available)
Soil Texture	Loams	Excessively coarse, fine or organic
Soil Drainage	Well drained	Water logging or extended flooding (> 1 week)
Rooting Conditions	> 100 cm	< 100 cm
Soil pH	5.5 – 8.0	< 5.5 or > 8.0
Slope	Level or gradually undulating	> 8%
Salinity	Conductivity < 2.0 ms cm^{-1}	Conductivity > 2.0 ms cm^{-1} will be limiting and values > 4.0 ms cm^{-1} will result in reduced growth and severe die-back
Field Access	All season roads, requiring minimum upkeep	Poor or no roads
Proximity to Markets	Close as possible to reduce transportation costs	Far from markets
Access to Labor	Local labor source	Lack of labor
Field Shape	Rectangular or square	Irregular

Source: PFRA (2001a)

Tree spacing affects tree growth, health, management and end use alternatives. The choice of spacing, according to the PFRA (2001a), is dependent upon the hybrid poplar's optimum growth rate and the desired end product (Table 2.6). Close spacing is only recommended if the trees are going to be harvested on a short rotation. The short to medium rotations is generally used for pulp or OSB end products, whereas long-term rotations are for solid wood products.

Table 2. 6: Recommended spacing for planting hybrid poplars

Recommended Spacing (m)	*Stock (trees ha^{-1})*
3.0 x 3.0	1111
3.6 x 2.4	1157
3.6 x 3.6	772

Source: PFRA (2001a)

2.5.2 Other Considerations

The PFRA (2001b) lists other factors, which should be considered prior to undertaking a conversion to a hybrid poplar plantation. These factors are:

1. The skill requirement for growing hybrid poplars differs considerably from traditional agriculture so limited opportunity exists to obtain local experience from other producers.
2. The equipment requirements can for the most part be met from traditional agricultural equipment resources but some specialized equipment (i.e. sprayers) will be required.
3. Market demand is often difficult to predict due to the lengthy time frame from planting to harvest. As a result risk management tools are essential.
4. The financial requirements are substantial with establishment costs comprising the majority of the rotation expenses.

2.6 Conclusion

This chapter provided information regarding declining farm incomes and the resulting low profitability levels. The relationship between climate change, agriculture and afforestation was also discussed. The concept and status of afforestation activities in Saskatchewan was introduced, along with the agronomic practices of growing hybrid poplars. Chapter Three will deal with the applicability of afforestation of agricultural lands in Saskatchewan.

CHAPTER THREE: THE STATUS AND ECONOMIC APPLICABILITY OF AFFORESTATION ON AGRICULTURAL LAND

3.0 Introduction

The main objective of this chapter is to summarize the current status of afforestation (Section 3.1) and applicability of afforestation practices in Saskatchewan (Section 3.2). Section 3.3 highlights the important concepts introduced in this chapter, as well as introduces the next chapter.

3.1 Status of Forestry in Saskatchewan

Forested land represents approximately 54 percent (35 million hectares) of the total area of the province of Saskatchewan (Saskatchewan Interactive 2002a and Saskatchewan Environment and Resource Management, SERM 2001). Approximately 44 percent (15.4 million hectares) of forested land is considered productive for commercial purposes, while only 42 percent (14.7 million hectares) is considered non-reserved, productive and available for commercial timber harvesting. However, due to accessibility and timber quality problems only 20 percent (seven million hectares) is commercially exploitable (Saskatchewan Interactive 2002a).

The province owns roughly 97 percent of the forested land, with the remaining 3 percent being divided up between the Federal government (2 percent) and private landowners (1 percent) (Eco-Link 2000). It is estimated that as much as 700,000 hectares of private lands in Saskatchewan could be allocated to afforestation (Johnston 2001). In addition to the private lands Johnston (2001) indicates another 100,000 ha of forests are on First Nations lands, 40,000 ha on PFRA pastures, and 15,000 ha in private woodlots.

The annual timber harvest from provincial crown lands in Saskatchewan is approximately 3.49 million m^3 (harvested from 21,168 hectares[18]), which is roughly half of the annual allowable cut as set out in the annual provincial volume schedule[19] (SERM 2001). Provincial surpluses were estimated to be 1.6 million m^3 and 2.3 million m^3 for softwoods and hardwoods,

[18] This equates to approximately 164.9 $m^3\ ha^{-1}$.

respectively in 1998 (KPMG 1999). The harvest of hardwood trees in Saskatchewan (2000) was approximately 1.79 million m^3, with 97.2 percent being harvested from crown land and the remaining 2.8 percent harvested from private lands (National Forestry Database 2001).

The allocation of harvesting rights to the private sector is conducted via a forest land-tenure system. This tenure system stipulates the private sector must invest in timber processing facilities and management must commit to certain obligations, in addition to the payment of stumpage fees to the provincial government (KPMG 1999, SERM 2001). The allocation of harvesting rights to the private forest industry is governed by the Forest Management Act (FMA), which provides long term (20 year) operating agreements to individual forest companies (SERM 2001). The FMA sets the regulations for forest companies to adhere to in exchange for harvest rights. The FMA requires forest companies to submit operating plans for specific sites, which detail the activities occurring and timeframe for being at a particular location. The FMA also requires land tenure holders to completely reforest all harvested areas within their license area, including roads and mill sites. The two other methods of allocating harvesting rights to either forest companies, or individuals, is by Forest Product Permits (FPP) or Term Supply License (TSL) (KPMG 1999). The FPP is primarily used for allocating small volume timber rights to individuals, which is intended for their own private use, while TSL are negotiated timber permit agreements covering a longer time frame (KPMG 1999).

Timber prices are based on stumpage charges the provincial government charge tenure holders for harvesting on crown land (Table 3.1). The lumber companies pay the stumpage charges to the provincial government for timber harvested on crown land. The reforestation charges are the costs for replanting trees in the harvested area including roads and mill sites. Provincial stumpage and other charges can vary significantly depending on the type of tenure a company has. The various tenure types include information such as: stumpage charges, rent charges, area/holding charges, reforestation levies, protection fees, permit and license fees, sales and rentals, and other items such as bonus bids, penalties and fines and interest charges for late payment (National Forest Database 2002).

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[19] The AAC in Saskatchewan is 7.1 million m^3, with softwoods and hardwoods comprising 3.9 million m^3 and 3.2 million m^3, respectively (National Forestry Database 2002)

Table 3. 1: Tenure holders' rights – Saskatchewan, 2000 ($ m^{-3})

Tenure Type	*Stumpage charges*	*Reforestation charges*
Weyerhaeuser		
- Softwood	6.01	6.00
- Hardwood	0.50	1.40
NorSask		
- Softwood	1.70	2.30
- Hardwood	0.62	0.50
L & M		
- Softwood	4.98	1.30
- Hardwood	0.50	0.50
Regulation Rates (permits)		
- Softwood	1.25	6.00
- Hardwood	0.42	2.00

Source: National Forestry Database (2002)

Given the low stumpage charges private forestry companies are required to pay on crown land the economic efficiency of afforestation projects on private land making profit at these prices is extremely low. A study by KPMG found a positive *NPV*[20] would be realized with a price of \$10 m^3 for hardwood. Van Kooten (2000) uses a stumpage value of \$3 m^3 but also includes a shadow value for carbon sequestration ranging from \$20 tonne to \$50 tonne of carbon in order to determine the amount of physically marginal agriculture land to be converted to trees. The value of carbon is a potential payment to producers for growing the trees and is paid in addition to the stumpage revenue. This enables the estimation of a supply response for physically marginal land converted to trees at the various carbon values. It should be noted that in van Kooten's (2000) study a carbon value of \$10 tonne would result in zero hectares of physically marginal agricultural land being converted to trees.

For comparative purposes stumpage price data from Georgia Pacific (2002) was obtained for mixed hardwoods[21] in the U.S., (Table 3.2). Stumpage prices are higher in the U.S. compared to Canada because of differences in both the distribution of ownership rights and in the price discovery mechanism utilized in the U.S. The majority of the harvestable trees in the U.S. are grown on private land. According to the U.S. Census Bureau (2000) the percentage of private timberland ownership in the entire U.S. in 1996 compared to State and Federal ownership was 68.9 percent to 30.7 percent. From these lands approximately 90 percent of the harvested timber (softwood and hardwood) originates from private lands (Canadian Embassy 2001). State

[20] *NPV* – Net present value.

level ownership rights can vary substantially and in Ohio and adjoining states nearly 80 percent of the hardwood stumpage is controlled by private landowners (Powell et al. 1993). Luppold et al. (1998) indicates landowners' range from individuals controlling only a few hectares to large institutional owners such as insurance companies. Forest industry companies (mainly sawmills and pulpmills) control an additional 4.4 percent, while natural forest and other public sources own less than 16 percent. Most of the timber on industry land is not available on the open market and most public timber is either unavailable for harvesting or is sold to achieve some multiple use objective. Consequently private lands are the primary open market source for hardwood timber (Luppold, et al. 1998). The stumpage prices are determined via an open market system with many buyers and sellers (Luppold, et al. 1998). This results in a timber price that is competitive and based on the concept of supply and demand (Williams 1998).

Table 3. 2: Stumpage prices in the U.S. for mixed hardwoods, 2002 ($Cdn m^{-3})

Product	*Price – Low*	*Price – High*	*Avg.*
OSB	19.00	29.56	24.02
Pulp & Paper	23.23	35.90	29.21
Chip Mills	17.95	35.90	24.75

Source: Georgia Pacific (2002)

3.2 Application of Afforestation

Afforestation has the potential to increase producer's incomes, while simultaneously aiding in the sequestration of carbon. The Canadian Cooperative on Intensive Forest Management (CCIFM) has developed a business plan to accelerate the development of Intensive Forest Management and improve Canada's forest product industries in projected high growth markets (CCIFM 2001). The current high-growth market for Canadian hardwood trees is particleboard[22] (Table 3.3). The increase in the quantity of particleboard exports between 1994 and 2001 was 230 percent, while the increase in the value of these exports between 1992 and 2001 was 830 percent (Figures 3.1 and 3.2, respectively).

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21 There was insufficient price data for hybrid poplars so mixed hardwoods were used as a substitute. An exchange rate of $0.625 Can was used for conversion purposes.

22 Particleboard is defined as any board made from wood particles. The generic product includes particleboard, flakeboard, oriented strandboard and waferbaord. The differences among the various products depend on particle size, orientation and position (Forestry Insights 2002).

Table 3. 3: Canadian particleboard exports – quantity (m^3) and value ($'000)

Year	*Quantity* [a]	*Value 1992=100* [b]
1992		278,913
1993		227,930
1994	479,000	475,984
1995	854,600	752,726
1996	893,400	1,058,267
1997	877,000	1,207,351
1998	953,600	1,260,234
1999	755,400	1,252,718
2000	262,786	1,939,250
2001	1,605,028	2,593,000

[a] Source: Faostat Database (2002)
[b] Source: Canadian Forest Service (2002)

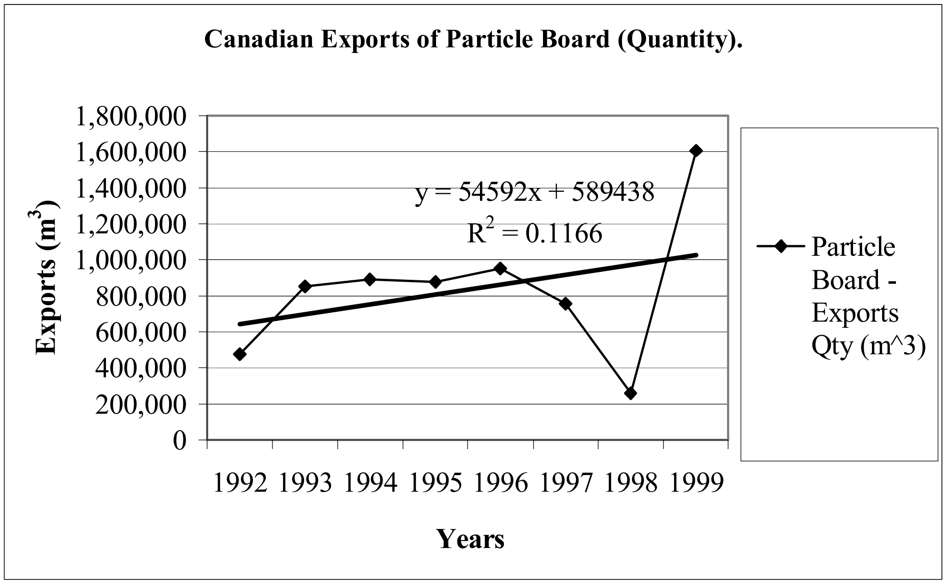

Figure 3. 1: Canadian exports of particleboard (quantity)

Source: Faostat Database (2002)

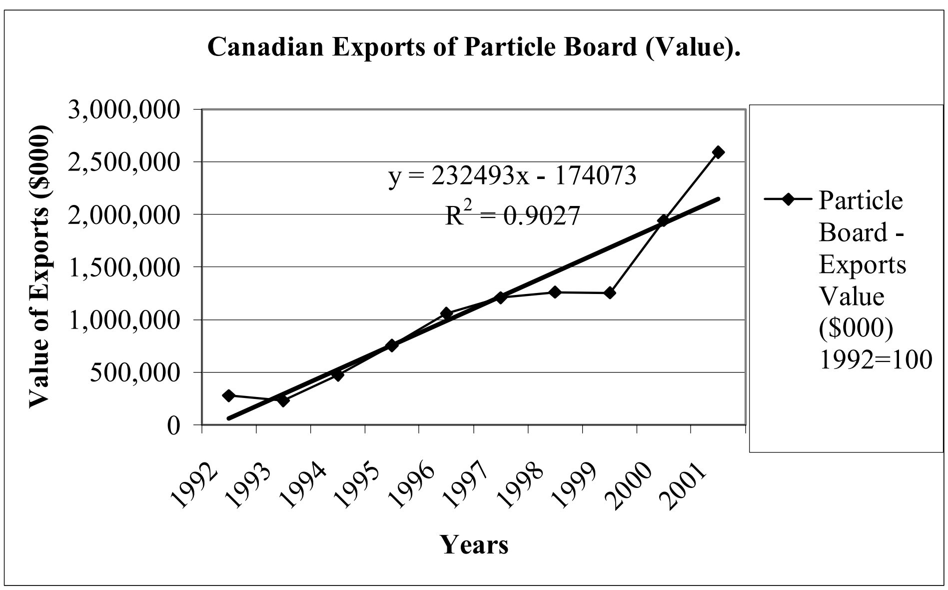

Figure 3. 2: Canadian exports of particleboard (value)

Source: Canadian Forest Service (2002)

Long-term forecasts indicate that there will be strong growth in world demand for industrial wood products but Canada's position in this market is limited due to uncertainties over wood supply and land use constraints (CCIFM 2001)[23]. The CCIFM (2001) indicated Canada is losing its historical comparative advantage in the forest products industry as timber costs increase due to increasing stumpage fees, environmental regulations and the need to access remote areas for harvestable trees.

The need to access remote areas is a result of lumber companies historically harvesting timber that is in close proximity to the mill to minimize economic costs. Removal of the forest in close proximity has resulted in lumber companies being forced to harvest further from the mill in order to access the harvestable trees as set out in Saskatchewan's annual allowable cut schedule. This reason, along with lack of northern timber roads, it is estimated that only 20 percent of Saskatchewan's forests are considered commercially exploitable. As a result, lumber companies' face-increased costs for timber harvesting. These costs include increased transportation and labour costs, as well as increased costs for road building as remote harvesting areas are currently difficult to access.

In 1998 there was a surplus of harvestable trees but since then harvesting activities, combined with the increased environmental and social concerns over Canada's native forests, has resulted in CCIFM (2001) predicting a future timber shortage on accessible crown land. In addition the CCIFM (2001) indicated that competing demands for native forests, including recreational activities, wildlife preservation, and carbon sequestration, is also impacting the future timber supply from crown land. As a result, the CCIFM concluded that a combination of afforestation and selective harvesting on crown land would help to mitigate regional wood shortages and expand the long-term wood supply in Canada.

Producers are in an excellent position to take advantage of the predicted increased demand of afforestation projects. Afforestation of agricultural land offers the potential for increased farm profitability, while helping to promote diversification and economic stability for rural areas. Afforestation could also help address the challenge of managing native forests to help balance the economic, social and environmental objectives facing Canada.

Private, social and environmental systems are all connected as policy decisions in one area have effects on the other systems, whether direct or indirect. Afforestation provides both

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23 Three initiatives, which have been created to help with the development of afforestation in Saskatchewan, are the Green Cover Program, the Saskatchewan Forest Center and Forest 2020. Forest 2020 main objective is to increase the conservation of forests while ensuring the continued growth of the forest industry in Canada (Forest 2020 2002).

private benefits to the producer, while providing external benefits to both the social and environmental systems (Figure 3.3).

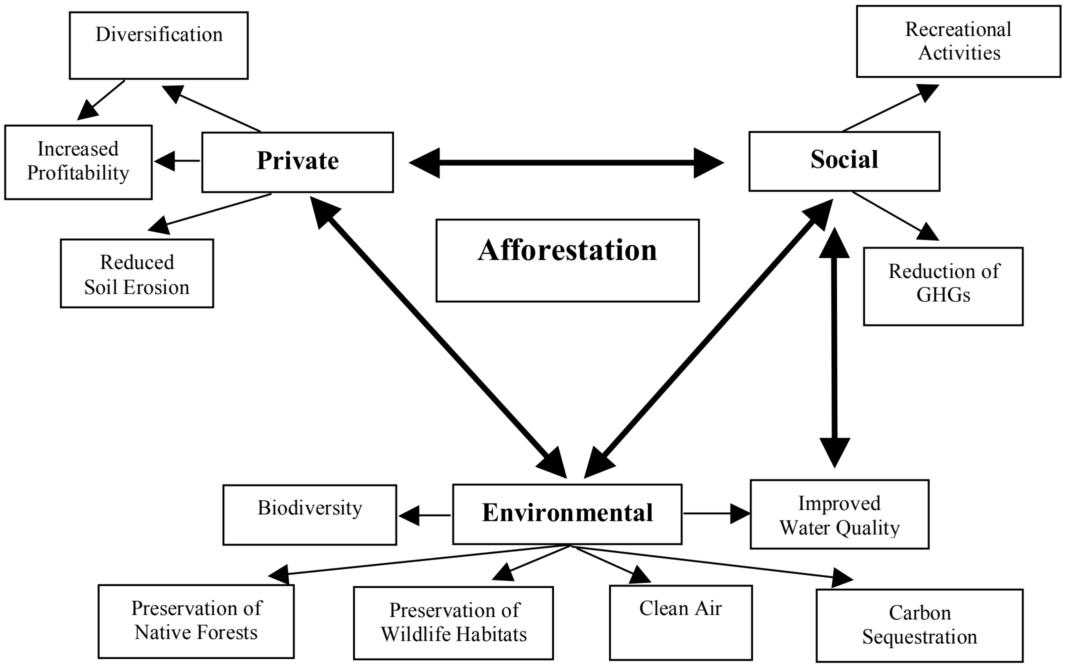

Figure 3. 3: Private and external benefits of afforestation

Source: Author

3.3 Conclusion

This chapter provided information on the current status of afforestation in Saskatchewan along with the potential opportunities of afforestation practices in Saskatchewan. The private, social and environmental issues were also introduced. Chapter 4 will introduce the benefit cost framework. The criteria for determining the economic efficiency of afforestation will be looked at.

CHAPTER FOUR: THEORETICAL FRAMEWORK AND MODEL SPECIFICATION

4.0 Introduction

The purpose of this chapter is to develop the conceptual benefit cost framework to be used in this study. The benefit cost analysis is the fundamental methodology used because it enables both private and social components of afforestation to be addressed simultaneously. This allows for total net benefits to society to be determined, rather than just private benefits.

The first part of the chapter will provide an overview of the benefit cost framework (Section 4.1). Section 4.2 examines the investment criteria for which the economic efficiency of the afforestation will be based upon. The next Section examines the marginal benefits and costs of afforestation (Section 4.3). Section 4.4 provides the model specification utilized in this thesis and Section 4.5 provides the foundation for estimation of the environmental benefits of afforestation. Finally the chapter is summarized and the next chapter is introduced in Section 4.6, the conclusion.

4.1 Overview

The reason why benefit cost analysis is used in this project is it provides an easy to use and very popular analytical framework for which private and public projects can be examined. A public sector project is considered economically efficient if it makes society better off. Private sector projects, on the other hand, are viewed financially efficient solely from the perspective of the firm undertaking the project (Townley 1998). There are two main principles involved in choosing a project using the benefit cost framework: (1) maximization of net benefits when choosing among various projects and (2) choosing a project which is the most cost effective (Tietenberg 1992). The two main factors used in the decision making process are benefit cost ratios and *NPV* criteria. These two concepts will be discussed more comprehensively later in this chapter (Section 4.2).

The main rules of benefit-costs analysis are as follows:

1. The estimated benefits and costs of a project must be from the private or societal point of view rather than the governments.

2. The analysis should include both private and social benefits and costs.
3. Costs should be expressed in terms of opportunity costs (discussed below) and incremental benefits and costs should be employed, rather than sunk costs.
4. The benefit calculations should use real economic values[24] rather than transfer payments.
5. Consumer and producer surplus must be used in the benefit and cost calculations.
6. Market prices should be used but in the presence of market failure and price distortions, other monetary valuation methods should be used.
7. *NPV* must be used to determine the project's economic efficiency.
8. The discount rate should be estimated from the average rate in the private sector and a sensitivity analysis should be used for alternative discount rates. (Nas 1996).

4.1.1 Opportunity Costs

The concept of opportunity cost plays an important role in the benefit cost framework. The opportunity cost of afforestation can be defined as the costs associated with the project measured as the benefits forgone from the next best alternative. In this thesis the next best alternative will be the current land use (i.e. crops or pasture). The implementation of an afforestation project (either from the private or public perspective) requires the use of some inputs, which could be used to produce other products or provide other services. These inputs include labour, materials, equipment and land. The opportunity cost thus measures what the producer must forego (crop or pasture net revenue) to convert the land to afforestation.

According to Boardman et al. (1996) the most obvious and natural way to value the opportunity cost of a project is via a direct budgetary outlay for the resources. The authors' contend that under certain circumstances the direct budgetary outlay will accurately represent the theoretical opportunity cost measure (area under the private marginal cost curve) but under other circumstances it will not. The two main circumstances that are most applicable to this thesis are as follows:

(1) When the market for the resources is efficient (i.e. no market failures) and there is no effect on market prices for the transfer of these resources and,

(2) When the market for the resources is inefficient (i.e. market failure exists).

In the first situation budgetary expenditures accurately measure the opportunity cost of the resources, while in the second situation the budgetary expenditures may over or underestimate the opportunity costs[25]. The authors' also indicate that the relevant measure of opportunity cost is what will be given up in the future and not what has already been given up. The latter refers to

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24 Economic values refer to the fact that consumers demonstrate a willingness to pay (WTP) for a good, which may be higher than the prevailing market price.

sunk costs and unlike variable costs is not represented by the area under the private marginal cost curve.

4.2 Investment Criteria

The *NPV* and benefit-cost ratios criteria can be used for either private or public projects, depending on the underlying circumstances. The advantages and disadvantages of these techniques will be examined below.

4.2.1 Net Present Value Criteria

The *NPV* criterion is the discounted benefits and costs of a project. The future net benefits are discounted to the present value using the following equation (Levy and Sarnat 1994, Nas 1996, Townley 1998):

$$NPV = \sum_{n=1}^{N} \frac{NB\ n}{(1+r)^{n}} - I_0 \qquad (4.1)$$

Where: I_0 is the initial investment cost,

r - is the discount rate,

NB_n - is the net benefit stream beginning in year 1 (n=1), and,

N - is the projects lifespan.

The *NPV* of a project is calculated by discounting the net benefits (revenue less expenses) of the project at a discount rate which reflects the opportunity cost of the investment, adding them up over the life of the project and subtracting the initial investment. Referring to equation (4.1) the resulting *NPV* for a given project can lead to three possible solutions. If $NPV > 0$, then the project is profitable if private, or if public the project increases societal welfare. If $NPV = 0$, then profits are zero (private perspective), or welfare remains unchanged (public perspective), while if the $NPV < 0$, the project is unprofitable from the private perspective, or from the public perspective there is no increase in welfare.

One advantage of using the *NPV* criteria is it enables ranking of mutually exclusive projects (Townley 1998). If various projects are being considered then using the *NPV* criteria allows for each of the projects to be ranked according to their *NPV*. The project with the largest value, assuming there is no capital budget constraint, will be the most viable project. If,

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[25] These concepts will be used in Chapter Six, Section 6.2.

however, there is a capital budget constraint then in order to utilize the *NPV* criteria a matrix of all the *NPV* combinations, which satisfy the constraint, must be calculated (Townley 1998). Thus for every budget constraint there would be a separate ranking and this allows for the appropriate project or combination of projects that maximize societal welfare to be chosen.

4.2.2 Benefit-Cost Ratio Criteria

The benefit-cost ratio of a project is calculated as the present value of benefits (PV_B) / present value of costs (PV_C.) *NPV* and benefit-cost criteria are equivalent when determining the economic efficiency of a single project. If the *NPV* is negative then the benefit-cost ratio is less than one. Conversely, if the *NPV* were positive the benefit-cost ratio would be greater than one. The problem with using the *NPV* criteria occurs when ranking projects. Projects of different scales will lead to irrational decisions when deciding upon a project. For example suppose there are two possible projects, *A* and *B*. Suppose project *A* has PV_B of \$100M and PV_C of \$50M and project *B* has PV_B of \$25M and PV_C of \$10M. Project *A* thus has a *NPV* of \$50M and a benefit-cost ratio of 2.00. Project *B* has a *NPV* of \$15M and a benefit-cost ratio of 2.50. It is clear project *A* has a larger *NPV* but project *B* has a larger benefit-cost ratio. The difference in the above criteria results from the lack of a capital constraint for the *NPV* criteria. Project *A* has a significantly higher capital expenditure than project *B* and this allows for a greater *NPV* for the project. While the *NPV* for project *A* is higher the benefit cost ratio indicates that the benefits above costs are not as economically efficient as for project *B*. As a result the benefit-cost ratio must be used in the decision making process as to ensure the most economically efficient project is chosen.

The applicability of using the benefit cost framework in this thesis is a result of the varying scope of the project. Different land use practices (crop and pasture systems) and differing land quality characteristics may affect the optimal rotation decision. With differing harvest years the *NPV* of the project may lead to a false assumption regarding the economic efficiency of an afforestation project. In order to overcome this constraint the benefit cost framework will be utilized so all afforestation scenarios are comparable, regardless of their scope.

4.3 Economic Framework

Economic theory can be utilized to explain the benefits and costs of afforestation of agricultural land. This theory can help explain why market failures can lead to an allocation of land, which is not socially optimal (i.e. the benefits from afforestation of agricultural land outweigh the costs). There are two possible relationships, which are evident in this analysis:

(1) The producer equates his optimal land allocation on private marginal benefits (MB_P) and private marginal costs (MC_P) of afforestation. Equilibrium is reached when the following relationship is achieved:

$$MB(P) = MC(P) \qquad (4.2)$$

If equation (4.2) did not hold net private benefits could be increased by reducing output when (MC_P) > (MB_P), or increase output when (MB_P) > (MC_P). When equation (4.2) holds total net private benefits are maximized.

For the above analysis to hold a few economic assumptions have to be made. First the private market is competitive, with many consumers and producers of timber products. Secondly producers are price takers and as such their level of output has no effect on market prices. Thirdly with producers being price takers their output demand function will be perfectly elastic (horizontal) and finally producers will maximize profits given prevailing market prices.

(2) The net social benefits to society are maximized when marginal social benefits (marginal private benefits plus marginal external benefits (MB_E)) are equal to marginal social costs (marginal private costs plus marginal external costs (MC_E)). Equilibrium is reached when:

$$[(MB_P + MB_E) = (MC_P + MC_E)] \qquad (4.3)$$

The same logic from equation (4.2) holds true for equation (4.3).

The two possible relationships will fail to maximize net social benefits in the presence of externalities. Externalities will result in differing marginal private benefits and costs and marginal social benefits and costs. Producers will maximize net private benefits from afforestation and this level will differ from the maximization of net social benefits. This will lead to a non-optimal allocation of land from society's perspective.

4.3.1 Marginal Benefits and Costs

The economic model introduced above is used to describe the producer's land allocation decision. For simplicity the assumption will be made that the land can be allocated to either traditional agricultural practices or afforestation at a particular point in time. The MB_P curve is the private marginal benefit the producer receives from the conversion of agricultural land to afforestation, while the MC_P curve is the private marginal cost to the producer for conversion to afforestation (Figure 4.1). The MB_P is perfectly elastic due to the fixed output price for timber. The MC_P combines the private costs of afforestation (i.e. planting and maintaining the trees), as well as the opportunity cost of the land. Point *c* on the graph represents the land, which will be converted at the lowest cost. This land is physically marginal and has little or no alternative economic use. The slope of the MC_P is increasing due to the fact the inputs for afforestation are output specific and changing the output quantity will change the price structure. Movement along the MC_P indicates the cost of allocating land into afforestation increases due to the increasing opportunity cost of these lands. As stated earlier physically marginal lands will be taken out of production first because they have little alternative economic use[26]. The more productive agricultural lands will have a higher opportunity cost because they will tend to have alternative uses that have higher economic values. Once equilibrium is achieved (Figure 4.1), (point *b*), there will be no additional land converted to afforestation. The net benefit received by the producer is equal to area p^*bc. This equilibrium occurs at a market price for timber of p^* and a quantity of land converted to afforestation of q^*.

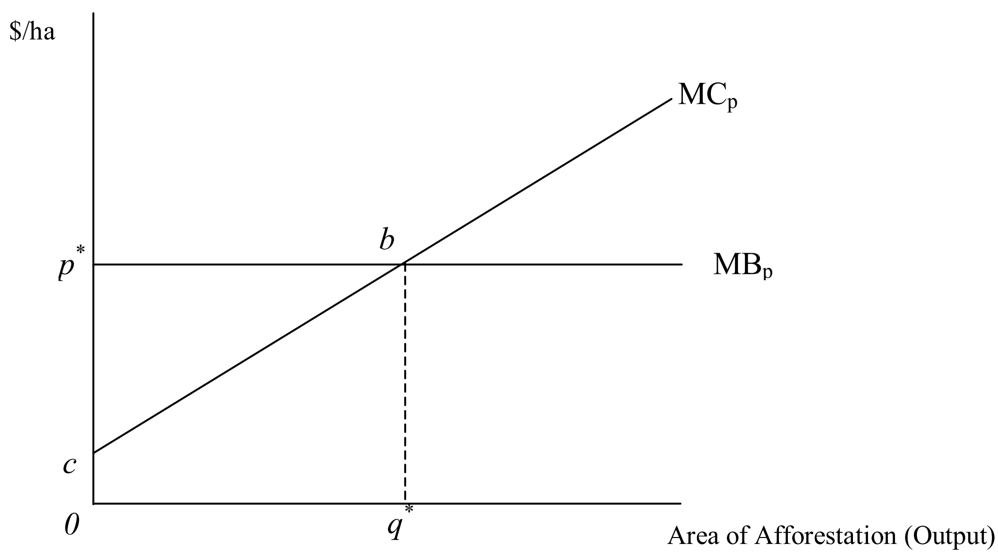

Figure 4. 1: Private MB and MC of afforestation

Source: Author

The allocation of land may be optimal to the producer but the existence of external marginal benefits and costs causes a market failure. This market failure results in a non-optimal allocation of land when viewed from the social perspective. The social marginal benefit curve (MB_S), will lie above the private marginal benefit curve implying society values afforestation of

26 These lands may have little value for tree production as well but this will be determined in the thesis.

agricultural land more than the producer does. This leads to components of the social benefits not being reflected to the producer (Figure 4.2). The MB_S is downward sloping which implies that an additional unit of land converted to afforestation will provide less value to society than the previous unit. This result is from the increased cost of converting more productive land to afforestation and that only a certain amount of external benefits will be received regardless of the amount land converted to afforestation (except for carbon sequestration). It should be noted that this assumption would probably not hold true for the first units of land that are converted to afforestation and the MB_S curve would be increasing. A threshold would eventually be reached where the MB_S would reach a maximum and then would start to decline. In Figure 4.2 the assumption is made that the threshold is maximized at point *0* and the graph depicts the social marginal benefits after this threshold has been attained. For simplicity the assumption can be made that there are no external marginal costs[27] for increased afforestation, and as a result the private marginal cost curve is equal to the social marginal cost curve. At the market level of afforestation, q_P, the level of net social benefits is equal to area *aebc*. The market optimum (privately efficient) level of afforestation will result in social marginal benefits being greater than the social marginal costs, $MB_S > MC_S$, indicating that increasing the level of afforestation could increase net social benefits. The socially optimal level of afforestation occurs at quantity q_S and the resulting net social benefit is equal to area *afc*. The increase in net benefit from moving from an afforestation level of q_P to q_S is equal to area *efb*. The loss to producers from increasing the area of afforestation to the social optimal level, q_S, is equal to area $q_p bf q_s$. Producers would not increase levels of afforestation to the social optimum unless they were required to do so, or were compensated for making this change because at the socially optimal level of afforestation private marginal costs exceeds private marginal benefits.

27 Due to data and time constraint the assumption that the external costs of afforestation mentioned previously will be zero.

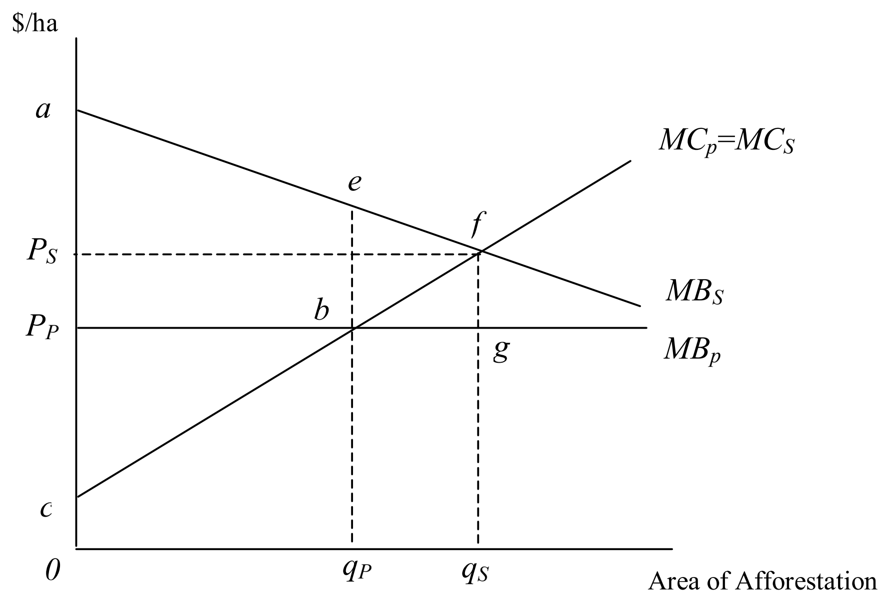

Figure 4. 2: Social MB and MC of afforestation

Source: Author

As the above theory indicates the optimal level of private afforestation is less than the socially optimal level. The reason for the market failure results from the external benefits derived from afforestation. These external benefits are not reflected in the market and as such the producer fails to receive any monetary compensation for them. In order for the producer to increase the level of afforestation to the socially optimal level there must be some type of incentive or compensation payment made. One type of payment may come in the form of a carbon payment. Producers could receive compensation for carbon sequestered in the trees. If the payment where set equal to the difference between P_S - P_P, as shown in Figure 4.2, the optimal private level of afforestation would equal the socially optimal level. If the carbon payment were less then P_P - P_S it is unlikely the payment would correct the entire market failure but if all the net external benefits are factored in the market failure could be corrected. To estimate the value of the net external benefits resulting from afforestation non-market evaluation techniques described below must be used.

4.4 Model Specification

The purpose of this Section is to relate the theoretical framework from above to the model utilized in this thesis. The benefit cost and *NPV* framework will provide the basis for the model. The first step is the identification of the private benefits and costs of afforestation, followed by the external benefits and the reason why each are included in the model.

4.4.1 Identification of Benefits and Costs of Afforestation

To determine the economic efficiency of converting agricultural land to afforestation the relevant benefits and costs associated with afforestation must be estimated. The implementation of an afforestation project will divert resources from alternative production processes (i.e. crop and pasture systems). These resources will be used in the afforestation project to produce outputs, while at the same time the opportunity cost of these resources will result in a loss of output in the crop and pasture systems. The aim should be to maximize net social benefits (public perspective), or profits (private perspective) of afforestation. The benefits accrued, as a result of increased output from afforestation should be greater than losses accrued as a result of foregone output from the crop and pasture systems (Nas 1996).

- Private Benefits and Costs of Afforestation

The private benefits and costs of afforestation are the benefits and costs that accrue to the producer undertaking the afforestation project, either directly or via the market place. The private benefits in this study include timber revenue and carbon credits.

- Timber Revenue

The major private benefit of afforestation is timber revenue. Timber revenue will be estimated by multiplying the timber price by the growth estimates. This will provide gross revenue for timber.

- Carbon Values

The value of carbon will be examined from both the societal and private perspectives. In the absence of a carbon credit market the value of carbon sequestration will be from society's point of view. This will be the value society would be willing to pay for carbon sequestration. With a carbon credit market the value of carbon will be viewed from the private perspective. When the carbon value is viewed from the private perspective it will be assumed that this value fully represents the societal value of carbon. This will avoid any over (under) estimation for the carbon value. The total carbon value is estimated by multiplying the carbon price times the total carbon sequestered in the trees.

- Afforestation Costs

The private costs of afforestation include the costs of planting and maintaining the trees, and the opportunity cost of the land. The costs of planting and maintaining the trees are the direct costs of afforestation. The harvesting of the trees is assumed to be the responsibility of the lumber company.

- Opportunity Costs

The opportunity costs of afforestation are the costs of the land and resources in the next best alternative. For the purposes of this thesis these will be the current land use practices in the study region. The opportunity costs will be the returns from crop or pasture systems.

4.4.2 External Benefits and Costs of Afforestation

The external benefits and costs of afforestation can have a significant influence on the social perspective of whether to adopt afforestation practices on agricultural land. While producers may not find it economically efficient (from a private perspective) to transfer land into afforestation, if the external benefits are factored in then the conversion may be socially efficient. In order to convince the producer to adopt afforestation, assuming private benefits fail to outweigh private costs, a compensation payment may be required. The size of the payment would have to be large enough so that the private net benefit plus the compensation payment would yield a positive return.

The external benefits and costs of afforestation are the benefits and costs that accrue to individuals outside the market place and can be divided into use and non-use values. The use values are derived from the consumption of a good or service (van Kooten 1993) by consumptive and non-consumptive users. These goods and services include hunting, and wildlife viewing. The non-use (option, existence, and bequest) values are the benefits derived from the demands of afforestation (van Kooten 1993). The option value represents an individual's willingness to pay for a particular future benefit of afforestation even if the benefit is not currently being utilized. The existence and bequest values are an individual's willingness to pay for preservation or improving benefits of afforestation, which the individual may never utilize.

Estimation of use benefit values can be accomplished using such techniques as the travel cost method; hedonic pricing and damage cost avoided method[28]. It is believed these methods provide reasonable estimates of the use benefits because they rely on market data (van Kooten 1993). Non-use benefits are often more difficult to determine because of the lack of market data. Techniques such as contingent valuation and contingent choice methods are used to determine a value. These methods inquire about an individual's willingness to pay for a particular good or

[28] For a description of the use and non-use valuation methods refer to www.ecosystemvaluation.org.

service within a contingent market. While these methods have technical difficulties associated with them they are widely accepted.

The external benefits from afforestation estimated in this thesis include carbon sequestration, wildlife use values (hunting and wildlife viewing) and conservation of native forests associated with annual crop and pasture systems.

- Carbon Sequestration

As mentioned previously the value of carbon sequestration will be viewed from both the private and social perspective. The carbon sequestration value is society's value of carbon multiplied by the total carbon sequestered in the trees. The price of carbon will be the same as under the private benefits to ensure continuity throughout the analysis and will be estimated using the same methodology.

- Wildlife and Conservation Benefits

The wildlife use values (hunting and wildlife viewing) are estimated using the expenditures spent on these activities for the area of interest in this thesis. The expenditures include accommodation, transportation, food, equipment, other items and costs for other nature related activities. The conservation of native forest is estimated as expenditures spent on preserving or converting land to permanent vegetation cover. The values are adjusted to the study area using a habit indicator (Neave and Neave 1998).

The estimation of the private and external benefits and costs used in this thesis are conducted in Chapter Five, Sections 5.3 and 5.4.

Table 4. 1: Summary of private and external benefits and costs included in the model

Private or Social Perspective	*Revenue / Costs Included*
Private Benefits	Timber Revenue Carbon Payment[1]
Private Costs	Afforestation Costs Opportunity Costs
External Benefits	Wildlife Viewing Hunting Land Conservation Carbon Values[1]

[1] As noted previously the value of carbon is either from the private or social perspective when estimated in the model

Source: Author

4.5 Valuing Benefits and Costs

The second step in the afforestation analysis involves valuing benefits and costs, which can prove to be extremely difficult, as both private and social benefits and costs must be estimated. For private benefits and costs existing price mechanisms usually exist, while external benefits and costs generally lack a well-developed pricing mechanism, or even comparable pricing mechanism (Nas 1996). Private benefits and costs have pricing information easily attainable via the competitive market. While market prices are often used for estimating private benefits and costs, caution must be used, as unless the market is truly competitive some level of uncertainty may exist as to the accuracy of the price discovery mechanism (Nas 1996).

The valuing of external benefits and costs proves difficult when trying to assign monetary values to such things as carbon sequestration, hunting, wildlife viewing and conservation of native forests. The lack of market information, or the existence of a market failure, restricts the availability of accurate prices. As a result the determination of prices for external benefits and costs is derived either from direct surveys or indirect surrogate markets (Nas 1996). The method used for valuing environmental factors will be discussed next.

4.5.1 Environmental Valuation Methods

As mentioned previously the estimation of private benefits and costs of afforestation can be computed using readily available market prices and quantity data. Difficulties arise when trying to estimate the external benefits and costs of afforestation. Non-market environmental valuation methods include the market price method, travel cost method, damage cost avoided method, contingent valuation method and the benefit transfer method[29]. It should be noted that for the purposes of this study the benefit transfer was used, as the availability of data for the other valuation methods is difficult and costly to obtain.

4.5.2 Benefit Transfer Method

The benefit transfer method uses available information from existing studies in another location, and/or context, to place a monetary value on non-market environmental resources. The benefit transfer method is used when a financial or time constraint on a project exists but an estimate of benefits is required. Estimation of the benefits is only as good as the initial study.

[29] Refer to www.ecosystemvaluation.org

To overcome the problem of data extrapolation from different locations, and/or contexts, the benefit function can be transferred from the other study. The benefit function identifies the consumer's WTP for a particular environmental resource and thus adjustments can be made to make the benefit function more specific to the study at hand. The more closely related the original site and the study site are the more reliable the benefit transfer method will be. When using the benefit transfer method three main steps are involved:

1. Identification of applicable existing studies, or values, that can be transferred,
2. Determination of whether values are transferable to the project at hand based on the physical characteristics of the site and the demographics of the population,
3. Assessment of the creditability of the study, or values. The better quality the initial study the more reliable the values, and
4. Adjust the existing values to better reflect the values for the study area. Additional data may be required to accomplish this task.

The hunting, wildlife viewing and conservation values were obtained from Environment Canada (2000). These values were obtained from a survey of Saskatchewan residents in 1996 and represent the total expenditures for the above external benefits for the entire province. In order to determine the appropriate values for the study area habitat use units for Neave and Neave (1998) were used and adjusted accordingly to the study area. Chapter Five, Section 5.4 and Appendix F provide a more comprehensive description of the methodology used to estimate these values.

4.6 Conclusion

This chapter introduced benefit cost analysis, as this is the economic framework being utilized in this thesis. The methodology of the benefit cost framework was introduced and the necessary investment criterion was examined. This chapter illustrates the private and social benefits and costs of afforestation and the optimal allocation of agricultural land to afforestation under each perspective. The next chapter will estimate the empirical values of afforestation, which will be used in the benefit cost analysis.

CHAPTER FIVE: EMPIRICAL ANALYSIS

5.0 Introduction

The main objective of this chapter is to link the theoretical model from Chapter Four to the afforestation study area in Saskatchewan. The first part of the chapter (Section 5.1) outlines the characteristics of the study area. The geographic and environmental characteristics are introduced and why the area is appropriate for afforestation will be explained. Section 5.2 deals with estimation of the random variables. The random variables estimated include crop and livestock prices, interest rates and inflation. Section 5.3 estimates the private benefits and costs of afforestation. The opportunity and establishment costs of afforestation will be estimated. Section 5.4 deals with estimation of the external benefits and costs of afforestation. Section 5.5 estimates the growth and carbon sequestration potential of hybrid poplars and the optimal rotation length for hybrid poplars being used in OSB is estimated in Section 5.6.

5.1 Area of Study

The area of focus in this thesis is crop district 5B, specifically the 23 Rural Municipalities (RMs) within the crop district and the 14 soil classifications within each RM. The total cultivated land base in the crop district is approximately 1.2 million hectares and the total tame or seed pasture area is approximately 80,972 hectares (Statistics Canada 1997a, 1997c). The crop district falls within two Ecozones: (1) the Boreal Plains and (2) Prairie Ecozones. Within the Boreal Plains Ecozone there are two Ecoregions present in the study area: (1) the Mid-Boreal Upland and (2) the Boreal Transition Ecoregions. The Prairie Ecozone within the study area is comprised solely of the Aspen Parkland Ecoregion (Saskatchewan Interactive 2002a). Of note is that the Boreal Transition and Aspen Parkland Ecoregions represent the majority of the land base, while the Mid-Boreal Upland only represents a small portion of the study area and as such will be excluded from the analysis. The geographical and environmental characteristics of each Ecoregion are summarized in Table 5.1.

Table 5. 1: Geographical and environmental characteristics of the study area

Ecoregion	*Topography*	*Soil Types*	*Soil pH*	*Land Use*	*Agriculture Activities*	*Total Annual Prec. (mm)*	*Mean July Temp. (˚C)*
Mid-Boreal Upland	Rolling hills	Loamy, clay and sandy soils	N/A	Forestry, limited cropping	Livestock production, limited cropping	456	16.3
Boreal Transition	Level plain	Well drained gray and black soils	5.5–8.0	Mixed forests and farmland	Cereals, oilseeds, forages and livestock practices.	452	17.4
Aspen Parkland	Gentle undulations	Well drained fertile loamy, black soils	5.5–8.0	Forestry, grasslands and farmland	Extensive livestock practices, cereals, oilseeds & forages.	420	18.0

Source: Saskatchewan Interactive (2002a)

The study area selected is well suited for growing hybrid poplars (refer to Table 2.5). The soil characteristics, which are best suited for growing hybrid poplars, are well drained, loam-texture, having a pH level range of 5.5 - 8.0 and with a slope that is level or gently undulating. The necessary climatic conditions include precipitation levels in excess of 400 mm annually.

Proximity to markets is another crucial site selection characteristic, as accessibility to markets will help reduce transportation charges. Two oriented strand board (OSB) plants and a plywood plant (MacMillan Bloedel) are located just north of the study region in Hudson Bay, Saskatchewan. Another OSB plant (Louisiana Pacific Canada Ltd.) is located east of the study area in Swan River, Manitoba. The characteristics of the study area fit well within the guidelines for growing hybrid poplars and as such tree productivity levels should not be constrained by site selection criteria.

5.2 Estimation of Random Variables

The optimal harvest time depends on prices, costs, interest rates, soil productivity and quality and the use of the timber. The length of an afforestation project varies according to the end use of the trees. For example the harvest age of hybrid poplars in OSB production is 12 to 15 years[30]. The opportunity cost of the land would be the next best use and this cost would have

[30] Van Kooten (2000) uses rotation lengths of between 9 and 12 years; depending on growth rates, for hybrid poplars in western Canada, while BCMAFF (2001) use rotation lengths of 10 to 12 years for hybrid poplars grown in BC.

to be calculated for the same time period as the afforestation project. A complication of projects extending many years into the future is that prices, costs and interest rates are difficult to predict and most models are static in that these variables are held constant for the life of the project. This restricts the applicability of the results as price trends, along with inflation and interest rate fluctuations, create risk and uncertainty and thus plays a large role in determining the economic efficiency of the project. To compensate for this limitation the model utilized in this project allowed for prices, costs and interest rates to fluctuate yearly for the life of the project. This allowed for the model to be dynamic and thus incorporates risk and uncertainty. Appendix C provides the process for the estimation this model.

5.3 Estimation of the Private Benefits and Costs of Afforestation

5.3.1 Afforestation Returns and Agricultural Values

It is assumed agricultural land examined in this project is privately owned[31] and the owner's goal is to maximize the financial returns from the land. Thus the cost of afforestation not only consists of the cost of planting and maintaining the trees but the opportunity cost of the land as well. As a result, producers attempt to maximize the returns from afforestation subject to the private costs of afforestation. The research at hand identifies two alternative uses of agricultural land based on the dominant land uses in the study region; 1) crop systems and 2) pasture systems. It is assumed each operation is independent of the other, (i.e. there is no diversification in crops and pasture), due to data limitations on land use practices for diverse farm operations. Before the opportunity cost of afforestation is estimated the afforestation revenues and costs will be identified.

5.3.2 Financial Analysis of Afforestation

The private benefits from afforestation are timber revenue. For the purposes of this thesis the end product of the hybrid poplars was assumed to be particleboard (OSB). The main reason OSB was chosen as the primary end product is because of the predicted shortage of harvestable timber in Canada and OSB products are considered a high growth market (refer to Chapter Three, Section 3.2). This increased in future demand is largely due to the projected housing demands for the next 20 years. In addition another important factor is the earlier harvestable age

[31] The area of land rented or leased from the government is excluded from this analysis.

for the hybrid poplars, as compared to other end products (i.e. pallets, logs, lumber. The shorter rotation length is favorable because of the timing of cash flow. The majority of the expenses occur early in the rotation and revenues are not realized until harvest, so producers may find an earlier harvest more attractive. This holds true unless there is an interim payment, some type of financing package-enabling producers to delay some or all of their payments until harvest, or a government support payment. The other categories of end products may be economically more attractive for landowners but at the margin the decision on whether the increased costs of extending the rotation period are less than the increased revenues expected from higher value products must be determined.

5.3.2.1 Afforestation Revenue

The determination of an accurate mill price for hybrid poplar trees is extremely difficult. Traditionally, lumber mills harvest trees from crown land and in return pay the provincial government a stumpage fee (refer to Table 3.1). The average stumpage fee in 2000 for a hardwood tree paid by the three major lumber companies in Saskatchewan was \$0.54 m^3. This value does not represent the actual cost to the lumber companies for harvesting, reforestation and reclamation of lease roads but only the tenure costs. Previous studies by Lindenbach (2000) and KPMG (1999) estimated timber prices for hardwood trees at \$37.50 m^3 and \$2.00 m^3, respectively. The price used in the Lindenbach study was based on the stumpage fee plus the average cost for Weyerhaeuser in Prince Albert to bring timber from the crown land back to the mill. It was assumed producers were responsible for harvesting and delivering the timber to the mill.

The KPMG study used a stumpage fee of \$2.00 m^3 for the prevailing market price. At this price a negative internal rate of return was achieved. KPMG concluded that a price of \$16.00 m^3 was required to achieve an internal rate of return of 4 percent. It was assumed in the KPMG study that lumber companies would incur the harvesting and delivery costs. Of note is that the KPMG study did not look at the opportunity cost of the land but rather compared the returns from various alternative projects.

The price for timber in this study was estimated as the price paid to producers for standing timber. The lumber company will be responsible for harvesting and trucking the trees from the producer's land to the mill. The lumber companies currently perform these activities in the native forest and have the equipment and expertise to do so[32]. If the producer were responsible for these activities the marginal cost to the producer would undoubtedly be greater than the cost to the lumber company. The price utilized was the price the lumber companies were willing to pay for access to an even aged hybrid poplar plantation with spacing between the rows being large enough to allow for harvesting equipment and an ultimate end product of OSB. The lumber company would not be responsible for reforestation, roads or any reclamation charges. The stumpage price used in this thesis was \$1.93 m^3 (2001) and was estimated as the average stumpage and reforestation charges incurred by Weyerhaeuser (Table 3.1)[33]. This price was adjusted annually using the CPI from Appendix C. The total *PV* of afforestation revenue was calculated as the timber price multiplied by the average annual growth. The estimation of the growth curves for hybrid poplars are discussed in Chapter Five, Section 5.5.

Given the uncertainty in determining a fair market value for trees a breakeven analysis was used to estimate the market price of hybrid poplars necessary to promote afforestation on the various soil classifications. The breakeven analysis was calculated for the various scenarios estimated in this thesis and are reported in Chapter Six. The methodology for the break-even analysis is summarized in Appendix D.

5.3.2.2 Afforestation Costs

The total afforestation costs for hybrid poplar stands are substantial. The majority of the costs are incurred within the first two years of the afforestation rotation[34]. The following Section deals with the total establishment costs[35] as they are the most significant costs incurred and occur early in the rotation period. Total *PV* of afforestation costs is shown in Appendix G.

Estimated total establishment costs for hybrid poplar differs greatly across North America and is largely dependent on current land use. The majority of the establishments cost estimates are based on studies conducted in the U.S. There has been limited research conducted in Saskatchewan on establishment costs for hybrid poplars, with the majority of the research being undertaken by the PFRA. Establishment costs used in the present study were adapted from data obtained from the PFRA (2002). The establishment costs from the PFRA were for

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32 Lumber companies may contract this work out to private firms.

33 This price is provides the lower bound of the price distribution since it is based on a native stand and not a managed stand.

34 Approximately 65 percent of the *NPV* of afforestation costs (based on a 12-year rotation) are incurred in the pre-planting and planting years.

35 Total establishment costs are the sum of the costs in the pre-planting and planting years.

shelterbelts and consist of a single row of trees spaced 3.6 meters apart with a length of 5/12 km. The *PV* of costs was converted into a cost per hectare, assuming spacing of 3.6 meters x 3.6 meters (773 trees ha^{-1}) (Table 2.6). The estimated afforestation total establishment costs for annually cultivated land in this study was \$1125.26 ha^{-1} (Table 5.2). These costs are consistent with the other projects (Table 5.3). The estimation of the total establishment costs on permanently vegetated land is similar to annually cultivated land, with the exception of an extra herbicide application and an extra cultivation pass (Crookston and Auri 1998). The *PV* of the establishment cost for the pasture system was \$1231.65 ha^{-1} [36] or \$106.39 ha^{-1} more than the cropping system.

Table 5. 2: Establishment costs on annually cultivated land for hybrid poplar trees in Saskatchewan, 2002 (\$ ha^{-1})

Operation	*Pre-planting Year*	*Operation*	*Planting Year*
Marking Site	7.58	Planting Material	341.97
Herbicide – Roundup	101.34	Planting Trees	130.12
Herbicide Application	20.25	Cultivate Tree Rows	112.73
Working Planting Site	81.02	Spray Weeds– Glyphosate	129.48
Pre-emergent Herbicide – Treflan	50.09	Fall Herbicide – Linuron	56.59
Pre-emergent Herbicide Application	40.51	Misc. Expenses	46.36
Misc. Expenses	15.04		
Total Cost	315.84	Total Cost	809.42
PV Total Costs			1,125.26

Source: Adapted from PFRA 2002

36 The breakdown of the extra costs is \$40.51 ha^{-1} for cultivation, \$50.68 ha^{-1} for roundup and \$10.13 ha^{-1} for herbicide application.

Table 5. 3: Comparison of establishment costs on annually cultivated land for hybrid poplar trees ($\$$Can ha^{-1})

Study	*Country of Origin*	*Year of Study*	*2001 Cost*
Present Study	Canada	2002	1,133.08
KPMG[a]	Canada	1999	1,165.99[1]
Minnesota[b]	U.S.	1994	1,279.14[2]
University of Minnesota[c]	U.S.	1998	1,078.01[2]
University of Oregon[d]	U.S.	1997	2,456.56[2]
University of Wisconsin[e]	U.S.	2000	987.63[2]
van Kooten, et al.[f]	Canada	1999	1,347.29[1]
van Kooten[g]	Canada	2000	1,273.46[1]
Average			1,359.69

1 Costs adjusted for inflation at two percent annually
2 Exchange rate of Can.$0.625 used
a Source: KPMG (1999)
b Source: Lindenbach (2000)
c Source: Crookston and Auri (1998)
d Source: Moore (1997)
e Source: Brannstrom and Schoessow (2000)
f Source: van Kooten, et al. (1999)
g Source: van Kooten (2000)

Due to data limitations on hybrid poplar establishment and maintenance costs in Saskatchewan the assumption was made that the total costs are the same regardless of soil classification. The estimated afforestation costs will thus be average values and caution will have to be used when interpreting these results.

5.3.3 Agricultural Systems

The two agricultural systems included in this thesis are annual crop and pasture systems. As mention previously in Section 5.3.1 the cost of converting agricultural land to trees includes both the establishment and maintenance costs of the trees and the opportunity cost of the land.

5.3.3.1 Crop Systems

The economic value of cropland was calculated by first determining the land use practices in each RM. Data for the land use practices in Saskatchewan was obtained from the 1996 Census (Statistics Canada 1997c). The six major crops seeded in the region were spring wheat, barley, oats, field peas, flax and canola. Summerfallow was also included, as it also represented a significant land use practice (Statistics Canada 1997a) in the target region. The area seeded to the six crops plus summerfallow represent over 87 percent of the total cultivated land in the Crop District (Statistics Canada 1997a, 1997c).

The economic returns to agricultural land in crops were calculated based on estimates of gross annual production. The gross crop production was calculated as an average based on the area seeded for each of the crops in each RM multiplied by the respective crop yield. The yields per hectare for each of the crops, based upon the soil classification, were obtained from Saskatchewan Crop Insurance Corporation (2001) for each of the risk areas present in the crop district. The yields used were 10-year average yields for stubble-seeded crops. The gross crop production was used to calculate revenue based on crop prices estimated using the random walk model described in Appendix C. The *PV* of crop revenue per hectare for each soil classification in each of the RM's over the life of the project was calculated based on the discount rate as determined in the random walk model (Appendix C).

Crop revenues only make up a portion of the total farm revenues and to adjust for this the other revenues where included. The other revenues are comprised of government support payments (refer to Table 5.4). Agriculture and Agri-Food Canada (2002) reported that total program payments, less premiums paid, to producers in Saskatchewan totaled $676 million in 2000 ($685.9 million in $2001). The amount paid to grain and oilseed producers was estimated at $595 million ($603.6 million $2001) and $81 million ($82.2 million $2001) for livestock producers. The average level of support payments for all crop systems[37], using the 1996 land use statistics (Statistics Canada 1997a, 1997b and 1997c) was $32.06 ha^{-1} in $2001. Pasture systems[38], included tame pasture, tame hay, alfalfa and natural lands for pasture and received on average $11.08 ha^{-1} in $2001. These values represented the averages for the entire province on all cultivated land and may not be indicative for the six crops chosen in Crop District 5b.

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37 Total land in crops was 14.40 million hectares and summerfallow was 4.43 million hectares in 1996.

38 The breakdowns for area in pasture systems (in million hectares): tame pasture - 3.05, tame hay - .68, alfalfa - 2.01 and natural land for pasture – 12.59.

Table 5. 4: Gross private producer payments for Saskatchewan, 2000 (million $)

Program	*2000*[a]	*2001*[b]
Crop Insurance[c]	117	118.7
NISA[d]	187	189.8
Income Disaster	109	110.6
Provincial Stabilization	0	0.0
Other Payments[e]	361	366.3
Input Rebates	36	36.5
Total Payments	810	821.9
Producer Premiums	134	136.0
Net Payments	676	685.9

[a] Source: Agriculture and Agri-Food Canada (2002)
[b] Converted to $2002 using the CPI – Appendix C
[c] Excludes private hail insurance
[d] Net Income Stabilization Account
[e] Includes private hail insurance, GRIP (Gross Revenue Insurance Plan), NTSP (National Tripartite Stabilization Program) and special assistance programs

The crop expenses for the Black Soil zone were obtained from the Saskatchewan Agriculture and Food Crop Planning Guide (2001) (SAF 2002b) (Table 5.5). The expenses were adjusted to exclude machinery and building depreciation, machinery, building and land investment costs. These costs (refer to Chapter Four, Section 4.1.1) are classified as sunk costs and thus are not a true measure of the opportunity costs. In addition the investment costs for growing either crops or trees was assumed to be similar, as many of the buildings and machinery are substitutable in either operation. The cost data from SAF are averages for the Black Soil zone and were not broken down into soil classifications. There were a number of assumptions made in the Crop Planning Guide 2001 (SAF 2002b) and these assumptions may not apply to individual farm operations. In addition the guide states each farms costs and yields differ according to different soil types, climatic conditions and agronomic practices. For the purpose of this thesis the average costs were assumed to be constant across each soil classification. As a result caution should be exercised when interpreting the results for specific operations.

Table 5. 5: Average annual crop expenses in the black soil zone, 2001 ($ ha^{-1})

Expenses per hectare		*Spring Wheat*	*Barley*	*Oats*	*Field Peas*	*Flax*	*Canola*
VARIABLE EXPENSES							
Seed		17.76	16.43	24.13	44.46	14.70	29.64
Fertilizer:	Nitrogen	38.53	38.53	38.53	3.85	38.53	38.53
	Phosphorus	17.78	17.78	17.78	14.82	17.78	17.78
	Sulfur & other	0.00	0.00	0.00	0.00	0.00	11.36
	Total Fertilizer	56.32	56.32	56.32	18.67	56.32	67.68
Chemical:	Herbicides	39.89	41.30	22.28	54.12	56.14	53.64
	Pesticides	4.47	0.00	0.00	0.00	0.00	2.32
	Others	5.29	5.57	4.72	8.89	2.17	10.37
Machinery:	Fuel	17.64	17.64	17.64	19.71	19.71	18.67
	Repair	18.53	18.53	18.53	26.68	22.23	18.53
Custom Work & Hired Labour		15.44	10.50	10.50	7.41	10.50	10.50
Crop Insurance Premium		5.24	4.50	4.50	5.58	4.74	5.14
Utilities & Misc.		10.77	10.77	10.77	10.77	10.77	10.77
Interest on Variable Expenses		5.01	4.77	4.45	5.15	5.17	5.97
Total Variable Expenses per acre		*252.66*	*242.62*	*230.13*	*220.11*	*258.77*	*300.90*
FIXED EXPENSES							
Building Repair		3.95	3.95	3.95	3.95	3.95	3.95
Property Taxes		13.04	13.04	13.04	13.04	13.04	13.04
Insurance & Licenses		5.29	5.29	5.29	5.29	5.29	5.29
Total Fixed Expenses per acre		*22.28*	*22.28*	*22.28*	*22.28*	*22.28*	*22.28*
TOTAL EXPENSES PER HECTARE		274.94	264.90	252.41	242.39	281.05	323.17

Source: SAF (2002b)

Freight rates are for the delivery point of Wynyard, SK. with the port location dependent on the crop[39] (SAF 2001). The freight rates were used to estimate the average freight rate for each crop based on gross crop production. This value was converted to an average cumulative value in $ ha^{-1} for each soil class in each RM. The same methodology used for calculating freight rates was used to determine a $ ha^{-1} value for the elevator and handling charges[40] for each soil class in each RM (SAF 2001). Once the cost data was estimated the same procedure used for estimating crop revenue was used to obtain an average crop expense per hectare for each soil class in each RM. The average costs are adjusted annually for inflation based on the forecasted farm price input index (Appendix C).

The *NPV* of crop income per hectare was calculated as the difference between the *PV* of crop revenue per hectare and *PV* of crop expenses per hectare. Appendix E (Table E.1) provides the results from this analysis. Over a 15-year period the average *NPV* and standard deviation of

[39] The destination for spring wheat, barley, oats, peas and flax was the St. Lawrence, while canola was shipped to Vancouver.

[40] The elevator charges include receiving, elevation, shipping and dockage.

crop systems (Table 5.6) indicate an average economic loss for soil classes J, K, L, M, O and P. The implications of the loss to producers will be dealt with more comprehensively in Chapter Six, Section 6.2.

Table 5. 6: Average annual *NPV* of crop system returns over 15 years (\$ ha^{-1})

Soil Class	*Crop Returns*[1]	*Standard Deviation*
A	27.70	10.04
B	25.53	9.76
C	23.42	9.52
D	20.91	9.27
E	17.95	9.06
F	14.19	8.91
G	9.89	8.94
H	4.55	9.23
J	(1.60)	9.89
K	(8.70)	11.02
L	(17.42)	12.79
M	(27.83)	15.25
O	(39.79)	18.36
P	(54.03)	22.31

[1] Brackets indicate a loss
Source: Author's estimation

5.3.3.2 Pasture Systems

The economic value of pastureland used for cattle grazing was calculated for tame or seeded pasture based on the assumption that this land is suitable for afforestation. Data on the areas of tame or seeded pasture was obtained from the 1996 Census (Statistics Canada, 1997b). The area per farm was calculated as the total tame or seeded pasture hectares divided by the number of farms reporting in each RM. The land quality for pastures is considered poor quality (PFRA 2000) and for the purposes of this thesis the tame or seeded pasture was the average economic values for land classifications L, M, O and P. Yield and carbon sequestration functions were based on the averages for these four land classifications.

The total number of cattle on each farm was determined by multiplying the number of hectares in pasture by the animal unit months (AUM's) for the pasture class and dividing by the number of months the cattle were on grass. Saskatchewan Agriculture, Food and Rural Revitalization (SAFRR) (1999) indicated an AUM of 1.25 for tame or seeded pasture with the cattle having been on pasture for 4 months.

It is assumed that spring calves were born on March 1 with an initial birth weight of 36 kg. It was further assumed that there was no backgrounding of calves, as the calves were marketed on October 1. The calves had a rate of gain of 1.14kg day^{-1} and thus the market weight was approximately 240 kg (Marleau 2002).

The revenues from the farm operation consisted of calf sales and government support payments (refer to Table 5.4). Government support payments were held constant for the lifespan of the project. This allowed for the isolation of the cattle revenue and expenses only for the lifespan of the project. The expenses were obtained from the Western Beef Development Center (WBDC) (2002) for the eastern part of the province (Table 5.7) and were adjusted to exclude sunk costs (unpaid labour[41] and depreciation). The *PV* of the livestock income and expenses were converted to \$ ha^{-1} for ease of comparison. The *NPV* of livestock income was the difference between the *PV* of livestock revenue and *PV* of livestock expenses. Appendix E (Table E.2) summarizes these results.

Due to data limitations on the exact number of cows per farm and the associated revenue and expenses for each operation the returns per hectare were assumed to be the same for each farm operation. Because averages were used for both income and expenses the results implied that an operation with only 10 cows would have the same returns per hectare as an operation with 150 cows. The data used failed to take into account contrasting management strategies and practices and the resulting efficiencies among the various operations. This led to a generalization about farm operations and caution should be used when interpreting the results for specific farm operations.

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41 Unpaid labour is management wages.

Table 5. 7: Cow calf expenses for eastern Saskatchewan, 2001 ($ cow^{-1})

2001 Cow Calf Expenses	*Cost*
Variable Expenses	
Winter feed	197.62
Bedding	15.80
Pasture	117.53
Vet & Medicine	20.84
Bull Rental/ Breeding Fees	3.66
Trucking & Marketing	4.16
Fuel	13.92
Repairs - Machinery	14.47
Repairs - Buildings & Corrals	3.65
Utilities & Misc.	19.12
Custom Work & Labour	14.87
Operating Interest Paid	4.85
Paid Labour & Benefits	19.29
Total Variable Costs	449.78
Fixed Expenses	
Livestock Share Payments	25.22
Taxes/License/Insurance/Lease	8.80
Capital Interest	12.24
Total Fixed Expenses	46.26
TOTAL COSTS - 2001	496.04

Source: WBDC (2002)

5.4 Estimation of the External Benefits and Costs of Afforestation

The external benefits and costs associated with afforestation practices were values for hunting and wildlife viewing, land conservation values (option, bequest and existence demand) and carbon sink values. These values were estimated using the benefit transfer method as described in Chapter 4, Section 4.5.2. The values used were modified for use in the thesis study area.

5.4.1 Estimation – Use and Non-Use Values

Wildlife populations provide benefits to both consumptive (hunting) and non-consumptive (wildlife viewing and conservation practices) users. Neave and Neave (1998) indicated that woodlands[42] provided greater habitat quality and diversity for certain species as opposed to crop and pasture systems. The conversion of agricultural land to afforestation would thus provide

[42] Woodlots are undefined in the Neave and Neave (1998) study and thus the assumption was made that woodlots and afforestation are the same.

greater habitat quality in both the study area and native forests. Afforestation could help to displace harvesting activities in the native forests and thus help to address Canada's concerns over preserving native forests[43].

Environment Canada (2000) estimated that in 1996 Saskatchewan residents spent approximately $263.7 million on outdoor activities in natural areas. The breakdown of these activities was as follows: wildlife viewing $39.3 million, recreational fishing $95.4 million, hunting $33.7 million and other miscellaneous outdoor activities $22.2 million. Environment Canada (2000) listed the miscellaneous outdoor activities as expenditures on maintaining, restoring, or purchasing land for conversion, nature related organizations and residential wildlife activities. The breakdown of the total expenditures included accommodation, transportation, food, equipment, other items and costs for other nature related activities.

In order to estimate the use (hunting) and non-use values (wildlife viewing and option, bequest and existence demands) of wildlife habitat resulting from afforestation of agricultural land, an indicator for the availability of wildlife habitat on various land types was determined (Tables F.4 and F.5). Appendix F provides a detailed description of the methodology used to estimate the habitat use units in Saskatchewan.

5.4.1.1 Native Forest Values

Calculation of the use (hunting) and non-use values (wildlife viewing) for wildlife habitat was based on the total expenditures Saskatchewan residents spent on wildlife use and non-use values (Section 5.4.1). According to Environment Canada (2000) Saskatchewan residents spent $39.3 million and $33.7 million on wildlife viewing and hunting, respectively. While these values represented averages for the entire province, applying the adjusted habitat use units derived from Neave and Neave (1998) allowed for a breakdown of these expenditures in the thesis study area. Before this could be accomplished an assumption was made regarding the distribution of these expenditures throughout the three Ecozones in Saskatchewan. The Prairie and Boreal Plains Ecozones represent approximately 36.98 percent and 27.15 percent (aggregate total of 64.14 percent) of the provinces total area, receptively (Table F.2 - Appendix F) and over 68 percent of the habitat use units are located in these two Ecozones. These facts combined with the geographic location of the two Ecozones, which encompass the southern two thirds of the province, will allow for the assumption to be made that 70 percent of the wildlife viewing and

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43 Refer to Chapter Three, Section 3.2.

hunting expenditure will occur in these two Ecozones. Unless actual expenditures in each Ecozone are available then the derived assumptions will have to suffice.

Of the total expenditures in the Prairie and Boreal Plains Ecozones the distribution between the two was 90 percent in the Boreal Plains Ecozone and 10 percent in the Prairie Ecozone (Table 5.8). The reason for this distribution was because the Boreal Plains Eco-District accounted for approximately 90 percent of the total estimated habitat use units for the habitat types chosen. In reality the actual distribution of expenditures may differ from the above assumption but given the large proportion (88 percent)[44] of the total estimated habitat use units that are located in the Boreal Plains Ecozone, the assumption seems reasonable.

Table 5. 8: Summary of wildlife expenditures for the Prairie and Boreal Plains Ecozone (million $)

Ecozone	*Wildlife Viewing* [a]	*Hunting* [b]	*Option, Bequest and Existence* [c]
Prairie	2.75	2.36	8.20
Boreal Plains	24.76	21.23	6.03
Total	27.51	23.59	14.23

a Based on 70 percent of $39.3 and divided 90 percent Boreal Plains and 10 percent Prairie
b Based on 70 percent of $33.7 and divided 90 percent Boreal Plains and 10 percent Prairie
c Based on $22.2 multiplied by the percentage area for each Ecozone (Table F.2)

The value placed on the native forest, as a result of the conversion of both cropping and pasture systems to afforestation in Crop District 5B, resulted from displaced harvesting activities in the native forest. The estimated habitat values for wildlife viewing and hunting were the same for all agricultural land converted to afforestation, as the impacts in the native forest are independent of the land use practices in Crop District 5B. The estimated value of the native forest in the Boreal Plains Ecozone was 9,632 habitat use units and these lands provided approximately 43.31 percent of the 22,237 total use units as estimated in Table F.5. The values placed on wildlife viewing and hunting in the native forests was $10.72 million and $9.19 million[45], respectively. The value per hectare was calculated based on the total estimated area of woodlands from Table F.5. The value of wildlife viewing and hunting for the native forest was $1.53 ha^{-1}yr^{-1} and $1.31 ha^{-1}yr^{-1}[46], respectively. The option, bequest and existence values for the native forest were calculated using the same methodology and a value of $0.86 ha^{-1}yr^{-1} was

44 Boreal Plains Ecozone is estimated to have 22,237 habitat use units compared to 2,914 for the Prairie Ecozone.

45 Wildlife viewing is $24.76 million x 43.31 percent and hunting is $21.23 million x 43.31 percent

46 Wildlife viewing is $10.72 million / 7.02 million ha and hunting is $9.19 million / 7.02 million ha. The estimated area for woodlots and plantations was calculated by dividing the habitat use units for woodlots

obtained. This value represents the expenditures placed on the conservation of the existing woodlands. The value estimated above represents an average for the entire Ecozone and the distribution for the study area was based on these average values.

5.4.1.2 Crop District 5B Values.

The benefit from converting crop and pasture systems to afforestation was calculated as the net gain from the land use change. This methodology differs from the values placed on the native forest as the habitat use units per hectare were estimated and the net increase is used in the determination of the appropriate monetary values. The habitat use units per hectare (Table F.4) were used to estimate the net change from converting the crop and pasture systems to afforestation (Table 5.9).

Table 5. 9: Estimated total habitat use units for conversion of crop and pasture systems to afforestation

		Crop Systems			*Pasture Systems*		
	Net Gain (habitat use units ha^{-1})[a]	Area	Habitat Use Units[b]	% of Total	Area	Habitat Use Units[c]	% of Total
Crops & Summerfallow	0.0011088	16,322,470	0	0.0%	16,322,470	395	19.0%
Pasture	0.0010737	1,084,043	78	0.4%	1,084,043	0	0.0%
Natural Land for Pasture	-	4,895,237	350	1.9%	4,895,237	350	16.9%
All Other Land	-	144,660	166	0.9%	144,660	166	8.0%
Woodlands	-	1,663,590	18098	96.8%	1,663,590	1,164	56.1%
Total	-		18692	100.0%		2075	100.0%

Source: Author's estimation

[a] Calculated as the net habitat use units for woodlands less crops and summerfallow, or pasture

[b] The estimated net habitat use units resulted from the conversion of the entire crops and summerfallow area to woodlands

[c] The estimated net habitat use units resulted from the conversion of the tame pasture area to woodlands

In the Prairie Ecozone the net gain from converting cropping systems to afforestation comprised approximately 96.8 percent of the estimated total habitat use units. The conversion of tame or seeded pasture systems to afforestation resulted in a net gain, of 56.1 percent of the total available habitat use. Using the same methodology, as was done for native forests, the gain in value as a result of afforestation of crop and pasture systems is summarized in Table 5.10.

and plantations by the total habitat use units for all woodlands. This value was then applied to the total estimated area to obtain an estimated area for these specific categories

Table 5. 10: Summary of the use and non-use values of afforestation ($ ha^{-1} yr^{-1})

	Crop Systems		*Pasture Systems*		*Other*
Ecozone	Wildlife Viewing	Hunting	Wildlife Viewing	Hunting	Option, Bequest and Existence
Prairie	0.16	0.14	1.43	1.23	4.93
Boreal Plains – Native Forest	1.53	1.31	1.53	1.31	0.86
Total	1.69	1.45	2.96	2.54	5.79
Total ($2001)	1.83	1.57	3.20	2.74	6.25

Source: Author's estimation

The values derived above are the averages for wildlife activities and do not in include the marginal benefits for wildlife activities. The total benefit for conversion of crop systems to afforestation was estimated to be $9.65 ha^{-1} yr^{-1} ($2001) and for pasture systems the estimated benefit was $12.19 ha^{-1} yr^{-1} ($2001) (Table 5.12). The estimated benefits calculated above are based on area and since pasture areas are less than crop areas pastures provide a greater benefit. These values were used in the benefit cost analysis as an external benefit that accrues to all of society.

5.4.2 Carbon Credit Values

Growing trees sequesters carbon in the biomass of the tree[47]. The importance of this external benefit is due to the potential for afforestation to aid in helping Saskatchewan and Canada in reducing GHGs. The reduction in GHGs will help to reduce the effects of climate change, as well as potentially allowing producers to receive monetary compensation for the carbon sequestered through afforestation practices. Producers could receive a carbon credit for each tonne of carbon sequestered and sell these credits to other individuals or firms requiring them. In order to calculate the benefits of carbon sequestration a value for carbon was determined. One of the problems of trying to estimate a value for carbon is that no well established market currently exists for carbon. A literature review of available studies was undertaken to obtain various values for carbon. The carbon value depends on the type of activity utilized for sequestration purposes (Parks and Hardie 1995, Plantinga 1997 and Swift and Donnelly 1998) and varies in these studies from $3.68 to $52.96 per tonne of carbon ($13.49 to $194.20 per tonne of CO_2). Other studies (Maggiora 2001 and Natsource 2001) estimated the value of carbon based on various carbon transactions that had already taken place. From these limited transactions the studies estimate the value of from \$3.68 to \$78.29 per tonne of carbon sequestered, with a mean value of \$33.55 and a standard deviation of \$25.65. The median value is \$26.57 per tonne of carbon. If only forestry and afforestation projects are examined the mean value is \$22.58 per tonne of carbon, with a standard deviation of \$32.56. The median value for the afforestation and forestry projects is \$7.75 per tonne of carbon.

Table 5. 11: Summary of carbon values (\$Can tonne^{-1})

Type of Activity	*Source*	*Year of Estimate*	*Value* [1]
Forestry	Parks and Hardie	1995	3.68-4.27
Government Issue Permits	Maggiora	2001	24.68-78.29
Carbon Emission Reduction	Maggiora	2001	11.46-19.57
CDM	Maggiora	2001	16.93-64.71
VER – Annex B	Natsource	2001	3.87-9.70
Dutch ERUs	Natsource	2001	28.45-51.66
European ERUs	Natsource	2001	45.26-77.58
Afforestation	Plantinga	1997	11.23-71.15
Earnings Basis	Swift and Donnelly	1998	52.96
Coal Burning	Swift and Donnelly	1998	33.86-47.41

1 Based on the following conversion factors: 1.102 tons = 1 tonne, 1 US\$ = 1.60 Can\$ and 1 tonne of Carbon = 3.6667 tonnes of atmospheric carbon dioxide. All values were adjusted to 2001 value using the CPI (refer to Appendix A)

The estimated value for carbon credits used in this thesis was the median value (\$7.75 tonne C^{-1}) as determined above. This value was chosen because it represents the estimated value for afforestation/forestry projects, while excluding the extreme values. To examine the effect carbon values can have on afforestation two additional values (\$22.58 tonne $C^{-1}$and \$33.55 tonne C^{-1}) were included as a part of a sensitivity analysis. This enabled the estimation of a supply response for agricultural land converted to afforestation based on the value of carbon. The estimated value of carbon was the price of carbon per tonne multiplied by the carbon sequestration potential of hybrid poplars (Appendix B). When the carbon value was viewed from the social perspective the assumption was made that producers did not receive any direct financial benefits for sequestered carbon. Conversely, when carbon values were viewed from the private perspective the assumption was made that society did not receive any benefits from sequestered carbon because the carbon payment reflected society's willingness to pay for the benefits of sequestered carbon.

47 Refer to Chapter Five, Section 5.5

The total value of carbon was estimated as the carbon price multiplied by the total carbon sequestered. The growth functions and carbon sequestration potential are estimated in Section 5.5. Before the total value of carbon can be estimated several assumptions regarding carbon credits and the carbon market in general need to be made:

1. For a single rotation period the carbon credit value was based on the bole[48] component of the tree. It was assumed that the harvested trees were used in only OSB production and the stored carbon was not released into the atmosphere[49]. The carbon sequestration capacity for trees used in OSB production is calculated as approximately 80 percent of the tree bole. The remaining 20 percent becomes waste during the production of OSB (van Kooten 2000). The waste enters the litter pool which consists of dead or dying biomass on the forest floor and carbon is released back into the atmosphere through fire or decay (van Kooten 2000)
2. For an infinite rotation the carbon credit value for the first cycle is based on the total above ground biomass (leaves and branches), including the bole. For subsequent rotation periods the producer only receives credit for the bole component. The total above ground biomass other than the bole can only be counted in the first cycle as when harvested the leaves and branched enter the litter pool where decay releases the carbon back into the atmosphere.
3. There is no harvest penalty as it is assumed that the wood products retain the carbon and the producer receives the carbon credit.
4. The below ground biomass (roots and soils) are excluded from this analysis.

The above analysis yielded two possible carbon values for producers. If the producer only decided upon one rotation period the carbon value was estimated for only the bole component. This is because the above ground biomass entered the litter pool and decayed with no re-growth occurring. In the case of an infinite rotation length the carbon value included the total above ground biomass, including the bole. If the tree stand is replanted there has been no net change in the carbon sequestered and the producer will be able to collect a carbon payment for the entire above ground biomass. It should be noted that the above assumptions are not in accordance with the Kyoto Protocol accounting guidelines for afforestation. The Kyoto Protocol differs from the above assumption in that soils are included under Kyoto guidelines[50] and wood products are not.

48 Bole is the merchantable component of the tree.

49 Winjum et al (1998) reports the half-life for wood products used in housing is 80 – 100 years.

50 When the model in this thesis was being estimated soils were not included in the Kyoto Protocol but discussions were ongoing.

The debate over inclusion of wood products has been ongoing but no consensus has been reached.

The previous Sections estimated the external benefits and costs of afforestation in Crop District 5B. These external benefits and costs accrue to all of society and thus play an important role in society's desire to promote afforestation of agricultural land (Table 5.12). In order to utilize these benefits in the benefit cost analysis it was assumed that benefits were constant (adjusted for inflation) for the duration of the afforestation project. The values were also discounted using the *NPV* criteria from Chapter Four, Section 4.2.1. Once the optimal rotation length was estimated (Section 5.6) the social benefits were estimated for the duration of the afforestation project. This will be conducted in Chapter Six.

Table 5.12: Summary of the external benefits of afforestation, 2001 ($ ha^{-1} yr^{-1})

Benefit	*Crop System ($2001 ha^{-1} yr^{-1})*	*Pasture System ($2001 ha^{-1} yr^{-1})*
Wildlife – Viewing	1.83	3.20
Wildlife – Hunting	1.57	2.74
Conservation demand for nature	6.25	6.25
Sub-total	9.65	12.19
Carbon Value – Mean[a]	16.84	14.49
Total	26.49	26.68

[a] Carbon value is based on the average annual growth for a 13 year period × median value from Section 5.4.2

5.5 Growth Functions and Carbon Sequestration of Hybrid Poplars

Growth functions for hybrid poplars are crucial in properly calculating the revenue stream from afforestation, as if done incorrectly; the harvesting decision will be inaccurate resulting in a non-optimal allocation of resources and will bias the results. The use of accurate growth functions also allows for estimation of the carbon sequestration potential of hybrid poplars.

The first part of this Section deals with the calculation of the bole and total above ground biomass (other than the bole)[51] of hybrid poplars, and secondly the carbon sequestration potential of the bole and total above ground biomass is estimated.

The Chapman-Richards growth function was used in the present study to estimate the growth curves for hybrid poplars (Pienaar and Turnbull, 1973):

[51] Going forward the above ground biomass will exclude the bole, unless otherwise indicated.

$$v(t) = \gamma\left(1 - e^{-kt}\right)^{m} \tag{5.1}$$

Where: $v(t)$ - represents the bole volume of timber ($m^3\ ha^{-1}$),
γ - is the maximum stem wood volume,
k, m – are estimated parameters, and
t – is time in years.

Hybrid poplar trees in western Canada have k, and m parameter estimates for either the most productive soil class (A) or least productive soil class (P) (Table 5.13). The Chapman-Richards growth function was used because of the relative ease with which it could be applied to the growth of a single tree or an entire stand. The growth model was deemed as an acceptable model for determining the basal growth area and yield for even aged monocultural tree stands (Pienaar and Turnbull 1973). The total above ground biomass (excluding the bole) was estimated using a conversion factor of 0.57 of the bole biomass (van Kooten 2000). This conversion factor implied that of the total above ground biomass (excluding the bole) had a volume that was 57 percent size of the bole volume. Appendix B presents the estimates for both the growth and carbon sequestration potential for hybrid poplars.

Table 5. 13: Parameter estimates for hybrid poplars in western Canada

Ecozone	γ	*K*	*M*
A Soil Class [a]	380	0.180	3.0
P Soil Class [b]	330	0.160	3.0

[a] Author's estimation
[b] Source: van Kooten (2000)
The values used in the van Kooten study are for forage crops and it is assumed that the least productive soil class (P) will have the same estimates

To determine the total carbon sequestration potential of the bole a conversion factor of 0.187 is used (van Kooten 2000). Equation 5.1 can thus be modified as follows,

$$C(t) = (v(t) \times 0.187) \times 0.80 \tag{5.2}$$

Where: $C(t)$ – represents the carbon stored (tonnes ha^{-1}),
$v(t)$ - represents the bole volume of timber ($m^3\ ha^{-1}$),
0.187 – is the factor which converts growth into carbon, and
0.80 – is the amount of the bole which stores carbon.

The better quality soils had higher growth rates than poor quality soils. The factors for determining soil productivity included climatic conditions, organic matter, soil texture and profile and topsoil depth. The A soil classification had the highest productivity while soil class P had the lowest. A simple linear trend analysis was used to estimate the yield functions based on interpolation. This was conducted by first calculating the slope of a straight line connecting the endpoints. Once the slope was obtained the values for each soil class were then estimated by dividing the slope value by the number of remaining soil classifications. For pasture systems given the land is poor quality and considered physically marginal (PFRA 2001) the growth and carbon sequestration functions were estimated from the L, M, O and P soil classifications. These estimates are summarized in Appendix B.

5.6 Optimal Rotation Length

The producer's decision to harvest the timber was based on a profit maximizing objective function. The producer attempted to maximize profits subject to the growth function of the trees. The producer's optimal rotation length incorporated timber prices, afforestation costs, land quality and growth rates. The rotation length also took into account the time value of money, which was the same as the opportunity cost of letting the tree stand grow for another year. If the producer decided to let the trees grow for one more year interest would be lost on the timber revenue for that additional year (assuming the money would be put in a deposit account, or other type of investment). The subsequent Section provides the mathematical model behind the optimal rotation length.

5.6.1 Maximizing Profits

The parameter estimates in Table 5.13 were used in equation 5.1 to estimate the growth curves for A and P soil classifications, respectively. Hybrid poplars grow very rapidly up to approximately 30 years of age at which time growth rates approach zero (Figure 5.1). In the case of afforestation the optimal rotation depended on the costs and benefits of the rotation and the growth rates of the hybrid poplar trees. The choice of an optimal rotation length, according to Khan (1998) is conceptually a simple problem. Do the benefits from allowing the trees to grow an additional year outweigh the costs? The forest manager's objective is to maximize the *NPV* stream of benefits and costs.

The optimal harvest timing decision of a stand of even aged hybrid poplars requires specification of an economic model. Hartwick and Olewiler (1998) and Kahn (1998) indicate the economically efficient rotation length incorporates an infinite cycle of planting, harvesting[52] and replanting a tract of land. For the purposes of this thesis a single rotation cycle will be

[52] As stated earlier the harvesting and trucking costs will be borne by the lumber company and the producer will receive revenue for the stand of trees less the costs incurred by the lumber company.

estimated and once harvest occurs the producer will go through the same process to determine whether to grow hybrid poplars or convert the land back to agricultural use. The *NPV* of a series of rotations was estimated within the model and the objective was to maximize the *NPV* of growing trees on a tract of land. There are two types of private costs which Hartwick and Olewiler (1998) and Kahn (1998) include in the economic model. The first types of costs are those associated with planting, and maintaining the hybrid poplar stand and the second private cost is the time value of money. The time value of money refers to the foregone interest on income by delaying harvest (which is the opportunity cost of money). This interest component includes the money, which could be obtained from a new stand of trees or from an alternative land use practice. The author's classify the land as an external cost, which receives the rent from growing trees. The optimization problem for growing trees for a single rotation series can be expressed mathematically as follows, (adapted from Hartwick and Olewiler 1998)[53],

$$\pi = PV[(p)V(T_1 - T_0)] - E \tag{5.3}$$

Where π – is the profit function,
p - is the producer price for timber ($ m^3),
$V(T_0 - T_1)$ – is the growth function (m^3),
E – is the establishment costs ($ m^3),
PV – is the present value discount factor, and
T_0 and T_1 – are the planting and harvesting dates, respectively.

The derivative of equation 5.3 is shown in equation 5.4, which determines the optimal time to harvest the hybrid poplars:

$$(p)V'(T_0 - T_1) = r(p)V(T_0 - T_1) + rW^* \tag{5.4}$$

Where $V'(T_0 - T_1)$ is the derivative of $V(T_0 - T_1)$) with respect to time[54] and W^* is the opportunity cost of the land and r is the interest rate. The left-hand side of equation 5.4 refers to the marginal product of timber if the rotation is allowed to grow for another period. The first term on the right-hand side of equation 5.4 represents the revenue interest foregone if the stand is allowed to grow for another period. The second term on the right-hand side of equation 5.4 is the interest foregone by not cutting the stand and converting the land back to the next best alternative (Hartwick and Olewiler 1998). In this thesis the opportunity cost of land will be the foregone revenue interest from the next best alternative (i.e. crop and pasture systems).

[53] For a complete derivation of the economic model refer to Hartwick and Olewiler (1998).

The inclusion of a carbon payment to producers will have the potential to change the optimal rotation length. Equation 5.4 has to be modified to include the carbon payment and can be rewritten as follows:

$$pV'(t)+(CV'(t))\times 0.187 = rpV(t)+rcV(t)+rW^{*} \tag{5.5}$$

Where: all previous variables are the same with the exception of,
c - is the price of carbon (\$ tonne C^{-1}),
t – is $T_0 - T_0$, and
0.187 – is the conversion factor from bole growth into carbon sequestered.

The left-hand side of equation 5.5 now includes both the marginal product of timber and the marginal product of carbon if the rotation is extended for another period. The only difference to 5.5 as compared to equation 5.4 is the inclusion of the carbon revenue interest foregone if the stand is allowed to grow for another period. The estimation of the optimal rotation length varies for each land classification and the results are summarized in the Chapter Six.

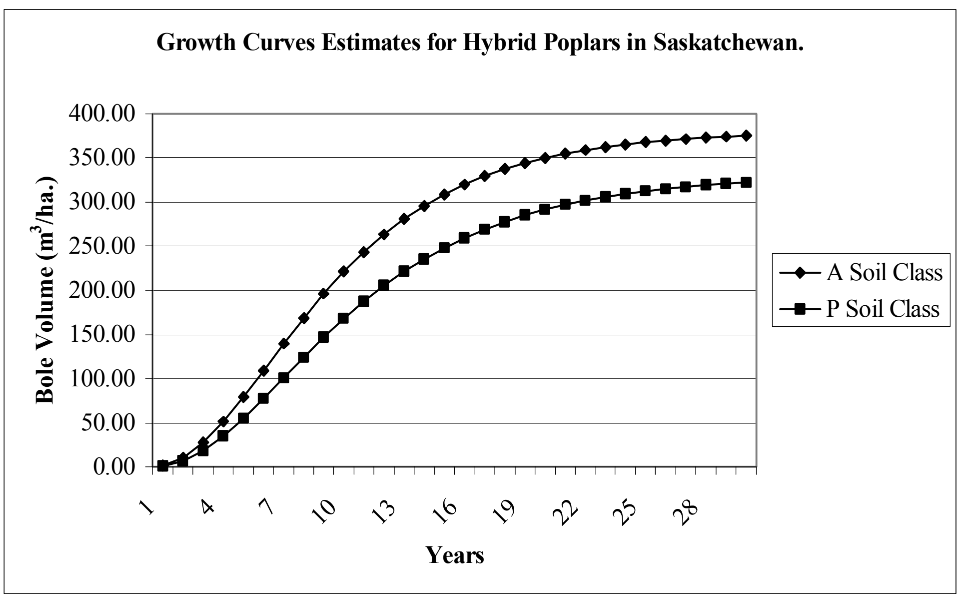

Figure 5. 1: Total growth curves for hybrid poplar trees in A and P Soil Classifications
Source: Author's estimation

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54 This derivative is the annual marginal growth rate of the trees.

5.7 Conclusion

The estimation of the private and social benefits and costs of afforestation was conducted in this chapter. These estimates will be used in the benefit cost framework to determine the economic efficiency of afforestation practices on agricultural land. In addition the growth and carbon sequestration potential for hybrid poplars grown in Saskatchewan were estimated. The optimal rotation length was also determined for the various afforestation practices. The next chapter will provide the results from the benefit cost analysis.

CHAPTER SIX: RESULTS

6.0 Introduction

This chapter presents the results of the benefit cost analysis. The first Section of this chapter (Section 6.1) provides the various scenarios to be tested using the benefit cost framework. The general results of the model are described in Section 6.2. Sections 6.3 and 6.4 provide the benefit cost results of these scenarios for crop and pasture systems respectively. Section 6.5 summarizes the main results for the chapter and Section 6.5 concludes the Chapter and provides the introduction to Chapter Seven.

6.1 Simulation Scenarios

The two main scenarios examined in this thesis were afforestation of annually cultivated land and perennial pastureland. Under each main scenario various simulations were conducted to examine the economic efficiency of afforestation under varying circumstances. These scenarios examined both the social and private perspectives of afforestation, including various carbon payments, inclusion of external benefits and single time period versus infinite rotation lengths. The following Section summarizes these scenarios for both crop and pasture systems.

6.1.1 Simulation Scenarios for Crop and Pasture Systems

The various simulation scenarios, which were examined in this thesis (Table 6.1), were used to evaluate afforestation projects from both the private and public perspective. Potential carbon payments paid to the producer reflect either the private or societal value of carbon (or at least some part of it). In an attempt to avoid double counting it was assumed that the carbon value would only accounted to one of these entities. Finally the afforestation value was assessed for either a single or infinite rotation based on OSB as the end product. The infinite rotation was included to allow for afforestation projects to continue indefinitely and thus the carbon values were adjusted accordingly (Chapter Five, Section 5.6).

Table 6. 1: Simulation scenarios for crop and pasture systems

System	*Scenario*	*Private Benefits & Costs Included*	*Carbon Perspective*	*External Benefits Included*	*# of Rotations*
Crops	1a	Yes	Social	No	1 period
	1b	Yes	Social	Yes	1 period
	2a	Yes	Social	No	Infinite
	2b	Yes	Social	Yes	Infinite
	3a	Yes	Private	No	1 period
	3b	Yes	Private	Yes	1 period
	4a	Yes	Private	No	Infinite
	4b	Yes	Private	Yes	Infinite
Pasture					
	1a	Yes	Private	No	1 period
	1b	Yes	Private	Yes	1 period
	1c	Yes	Social	No	1 period
	1d	Yes	Social	Yes	1 period
	2a	Yes	Private	No	Infinite
	2b	Yes	Private	Yes	Infinite
	2c	Yes	Social	No	Infinite
	2d	Yes	Social	Yes	Infinite

Source: Author's estimation

6.2 General Results

In general, the model examined the economic efficiency of afforestation as a land use decision for a homogenous, profit-maximizing producer in Crop District 5B. The producer attempted to maximize afforestation profits for OSB production subject to price, climatic and yield constraints. The price constraints resulted from the producer being a price taker in both the afforestation input and output markets (refer to Chapter Four, Section 4.3). These constraints played an important role in the economic efficiency of afforestation and will be discussed further as they relate to the results of the various scenarios. The first part of this Section will deal with the private marginal revenues and the subsequent Section will deal with the private marginal costs.

6.2.1 Private Marginal Revenue

This Section graphically depicts the marginal revenue curves for afforestation projects as estimated in this thesis. The producer attempted to maximize profits, and the resulting optimal solution occurred where marginal revenue equaled marginal cost. In a competitive industry the marginal revenue is simply the price. So the optimal output level occurred where the price equaled marginal cost.

The output price constraint producers faced for OSB production resulted in a perfectly elastic private marginal benefit function. This implied that afforestation output levels had no effect on output price. This was a valid assumption given the tenure systems and stumpage fees in Saskatchewan (refer to Chapter Three, Section 3.2). The average and marginal revenue curves were estimated using the following formulas,

$$AR = TR / Output \tag{6.1}$$

$$MR = \Delta TR / \Delta Output \tag{6.2}$$

Where: AR – is the average revenue (\$ m^{-3}),
TR – is the total revenue (\$ m^{-3}),
$Output$ – is the total annual growth (m^3),
MR is the marginal revenue (\$ m^{-3}),
ΔTR – is the annual change in total revenue (\$ m^{-3}) and,
$\Delta Output$ – is the annual change in output (marginal growth) (m^3).

Carbon payments provided an additional revenue source for afforestation projects. As with the price constraints mentioned previously producers in the carbon market were also price takers. This was a result of the carbon market being global in scope with Canada having no impact on prices. Consequently the levels of carbon sequestered through afforestation had no effect on carbon prices.

The yield constraint resulted in upward sloping private average and marginal revenue curves (Figure 6.1) [55]. The total revenue curve was increasing at a decreasing rate and started to level off at a production level of approximately 300 m^3 (Figure 6.1).

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[55] The logarithmic scale was for clarity.

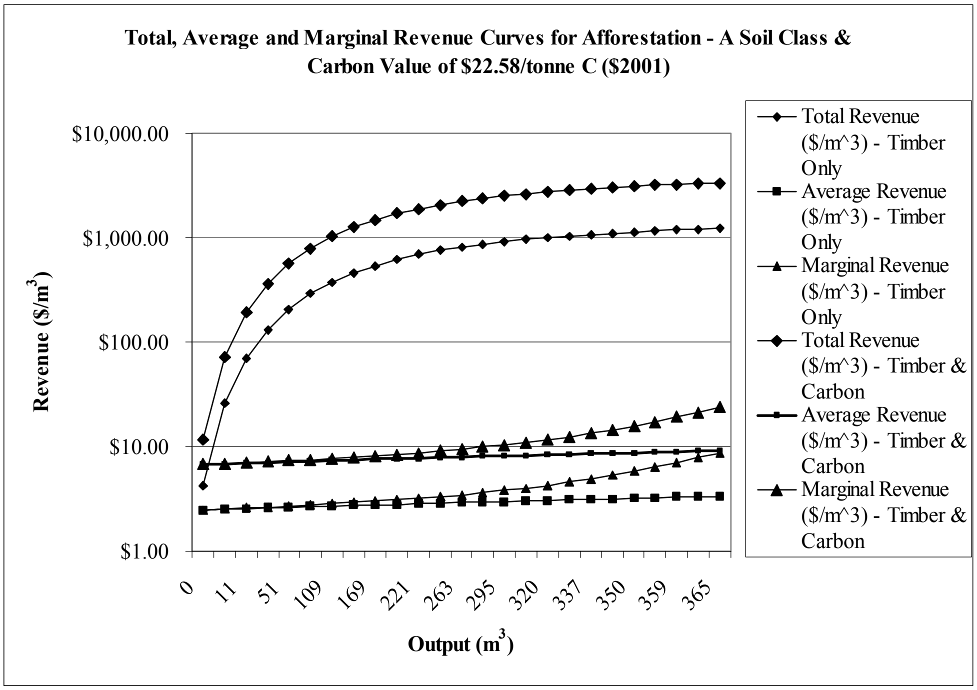

Figure 6. 1: Total, average and marginal revenue curves for afforestation of crop systems and a private carbon payment of $22.58 tonne C^{-1} (A soil class with a single rotation, $2001)

Source: Author's estimation

In the absence of a carbon payment the private marginal revenue curve (Marginal Revenue - Timber) was the product of the timber price and hybrid poplar growth curve estimates (Figure 6.1)[56]. When a single rotation carbon payment was introduced the private marginal revenue curve (Marginal Revenue – Timber & Carbon) was the product of the carbon price and the hybrid poplar carbon sequestration curve estimates (Figure 6.1). In this scenario the private marginal revenue curve was the horizontal sum of the private marginal revenue curves for timber and carbon, respectively for one rotation period. When there was an infinite rotation the private marginal revenue curve was the product of the carbon price and hybrid poplar growth estimates for an infinite rotation (not shown). These various private marginal revenue curves provided the private benefits as a result of afforestation and were used in determining the economic efficiency of afforestation. This analysis was applied to pasture systems (Figure 6.2). The only difference was with respect to the growth functions for each respective system (refer to Chapter Five, Section 5.5).

56 Due to the complexity of the model and the differing harvest years it is impossible to graph the results for the various scenarios. As a result for illustrative purposes a thirty-year rotation with a carbon payment of $22.58/tonne C was used.

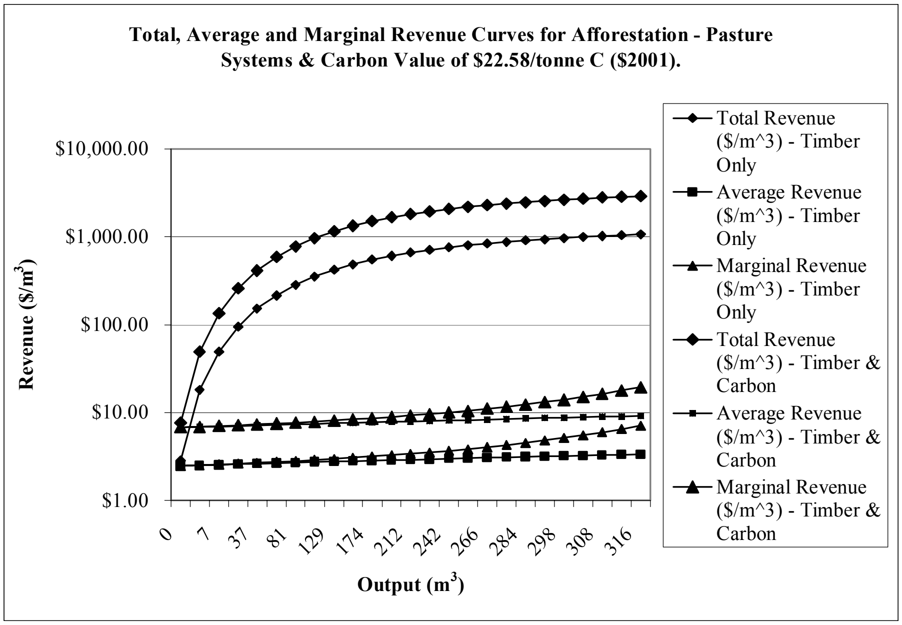

Figure 6. 2: Total, average and marginal revenue curves for afforestation of pasture systems with a private carbon payment of $22.58 tonne C^{-1} (single rotation, $2001)

Source: Author's estimation

6.2.2 Cost Curves

This Section graphically depicts the cost curves for an afforestation project. This allowed for a cost function for afforestation to be developed to help determine the optimal output levels. In this analysis the fixed costs were excluded (refer to Chapter Five, Section 5.3.3) and as a result the total costs were comprised solely of the variable costs. However, the inclusion of only the variable cash costs for afforestation covered only the accounting costs and failed to take into account the opportunity cost of the land. The total costs examined in this research included both the variable and opportunity costs of afforestation.

Cost minimization occurs where the marginal cost curve intersects the average variable cost curve. This occurs when the average variable cost curve is at a minimum and where the marginal cost curve is increasing. The minimum market price necessary for the producer to be indifferent between either adopting an afforestation project or not was thus estimated where costs were minimized.

As mentioned previously producers were assumed to be price takers in the afforestation-input market. However the social or opportunity cost curve (crop systems) of afforestation was upward sloping. This implied that as soil productivity improved there was a higher cost associated with converting agricultural land to afforestation. In other words as a greater area of land was converted to afforestation the quality of the marginal unit of land increased. The total cost curve for afforestation was thus the horizontal sum of the private and opportunity cost curves (Figure 6.3).

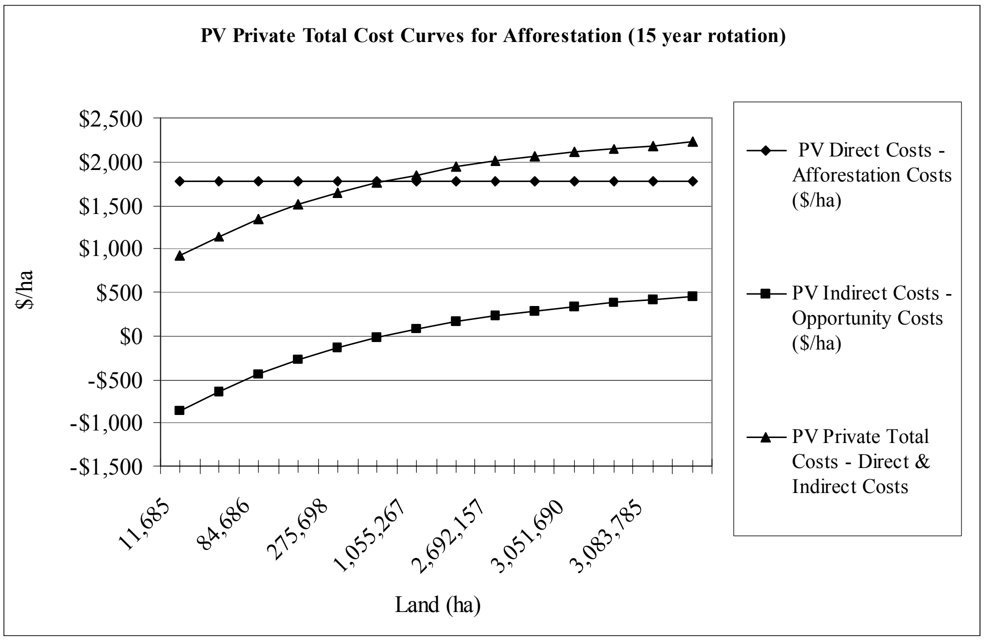

Figure 6. 3: PV total afforestation costs for crop systems

Source: Author's estimation

The opportunity cost curve (crop systems) was initially below the x axis (Figure 6.3) which implied a negative opportunity cost for afforestation. This resulted in the total cost curve to be below the private cost curve for soil classes J through P. This result will be dealt with more comprehensively below.

The private total cost curve for afforestation was the horizontal summation of the average private (establishment and maintenance costs) cost curve, average social cost curve (opportunity cost of crop, or pasture systems) and the marginal cost curve (Figures 6.4 & 6.5). The private marginal cost curve was upward sloping which implied increasing costs for converting agricultural land to afforestation. The following formulas were used in calculating the average variable, average opportunity, average total and marginal cost curves,

$$AVC = {TC}/{Output} \tag{6.3}$$

$$AOC = {OC}/{Output} \tag{6.4}$$

$$ATC = AVC + AOC \tag{6.5}$$

$$MC = {\Delta TC}/{\Delta Output} \tag{6.6}$$

Where: AVC – is the average variable cost (\$ m^{-3}),
TC – is the total cost and is the sum of the direct and opportunity costs(\$ m^{-3}),
$Output$ – is the annual growth (m^3),
AOC – is the average opportunity cost (\$ m^{-3}),
OC – is the opportunity cost (\$ m^{-3}),
ATC – is the average total cost (\$ m^{-3}),
MC – is the marginal cost (\$ m^{-3}),
ΔTC – is the annual change in total costs (\$ m^{-3}) and,
$\Delta Output$ – is the annual growth (marginal growth) (m^3).

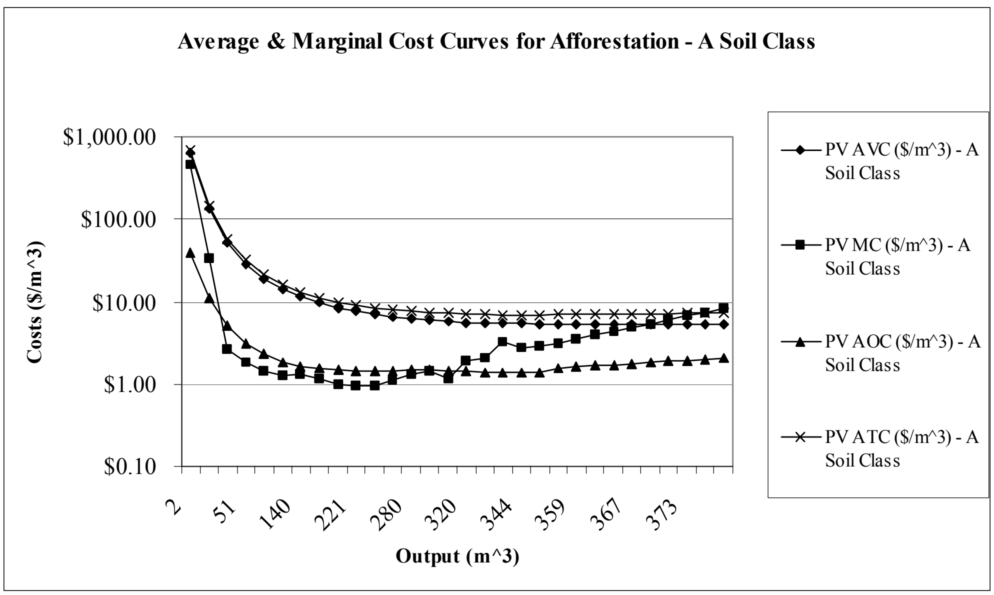

Figure 6. 4: PV of total, average, marginal and opportunity costs curves for afforestation of soil class A

Source: Author's estimation

Figure 6.4 indicates that if the producer is to minimize costs (MC = ATC) on soil class A, the corresponding price and quantity would be \$7.25 m^3 and 373 m^3 ha^{-1}. These values were compared to the growth functions from Chapter Five; Section 5.5 to determine which year corresponded to the estimated output. The rotation length was estimated from the output quantity of 373 m^3 ha^{-1} and occurred at year 28.

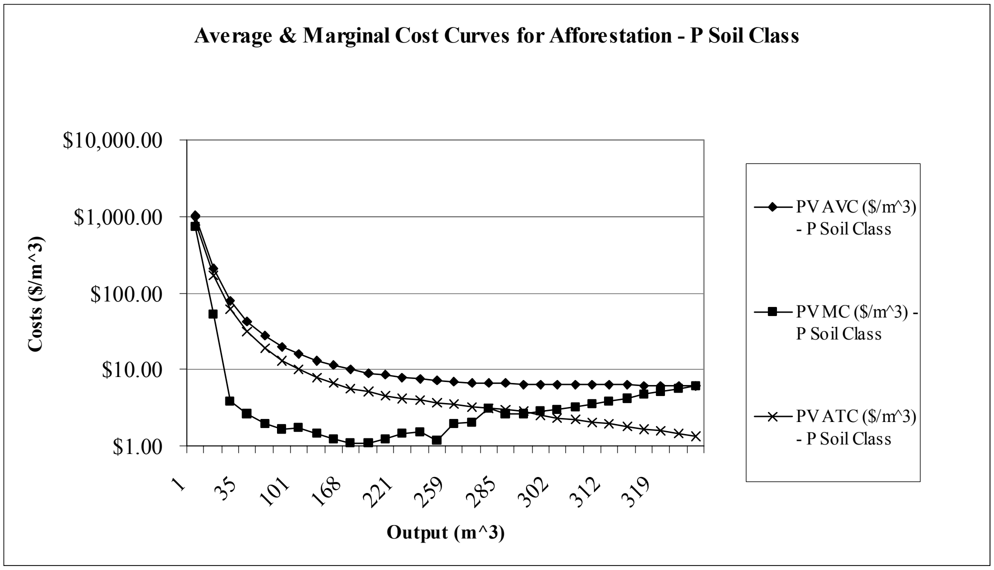

Figure 6. 5: PV of total, average, marginal and opportunity costs curves for afforestation of soil class P[57]

Source: Author's estimation

Cost minimization for soil class P resulted in a price of $3.07 m^3 and quantity of 277 m^3 ha^{-1} (Figure 6.5) in year 18. The main problem with using the above analysis is the *PV* of timber prices never achieves the cost minimization solution. Thus the optimal harvest decision utilized in this model, maximized profits subject to the above constraints and thus equated the optimal harvest decision with the respect to these constraints.

While the above analysis is fairly straightforward the results of the opportunity cost of crop systems becomes a little more complex. As presented in Chapter Five, Section 5.3.3.1 the economic returns from crop systems on soil classes J through P were negative. This result had important consequences for afforestation of these land classes. The assumption was made (Chapter Four, Section 4.1.1) that the next best alternative for these lands was the current land use practices (i.e. either crop or pasture systems). The negative opportunity cost associated with the conversion of poor quality soil classes from crop systems to afforestation was in fact a benefit to afforestation because the average total cost curve (Figure 6.5) lies below the average private cost curve.

57 The AOC was intentionally left off the graph, as the negative values were unable to be graphed using the log scale. The ATC does however include the AOC.

The opportunity cost curve for pasture systems was estimated differently than was done for crop systems. The assumption was made (Chapter Five, Section 5.3.3.2) that the costs, growth and carbon estimates for pasture systems were going to be averages for the physically marginal soil classes (L – P). The total cost curve was the sum of the marginal, average and opportunity cost curves (Figure 6.6).

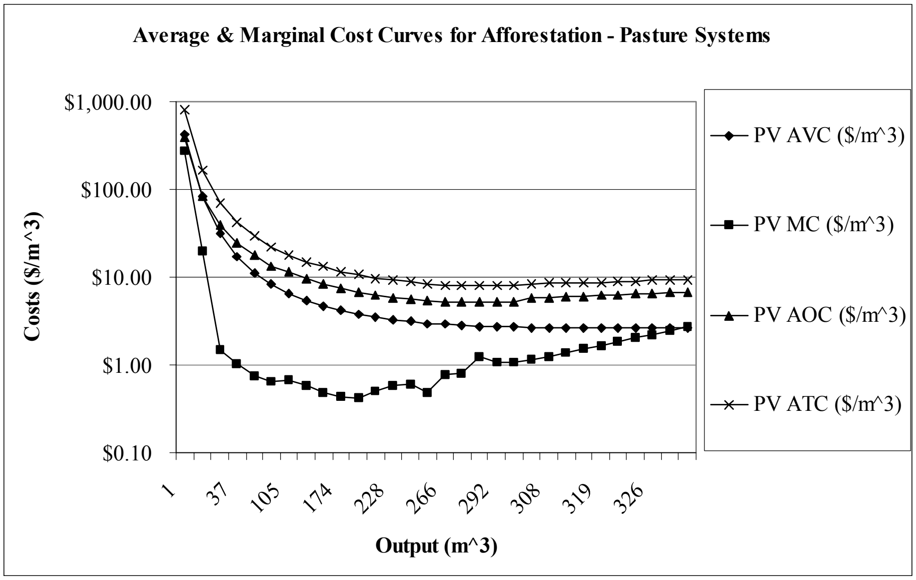

Figure 6. 6: PV total, average, marginal and opportunity cost curves for pasture systems
Source: Author's estimation

The cost minimizing solution for pasture systems extended beyond the timeframe of the model and thus was unable to be estimated using the above analysis.

While the above analysis maybe somewhat ambiguous it is necessary to provide the underlying economic framework so each simulation scenario can be easily interpreted. The various simulation scenarios were conducted for each land classification (crop systems) and thus the results are specific to each land class. Within each simulation scenario there are also differing harvest years. The optimal harvest decision (Chapter Five, Section 5.6) did not explicitly define land quality but due to the estimated marginal growth rates, in which land quality was defined, then indirectly land quality was factored in the optimal harvest year. This combined with the time value of money and the opportunity cost of interest foregone (equations 5.4 and 5.5) resulted in a land-class specific harvest year. The results for each scenario are summarized below with detailed results presented in Appendix H (Tables H.1 – H.14).

6.3 Benefit Cost Ratios for Afforestation of Crop Systems

The results for the afforestation of crop systems are summarized below (Table 6.2 and Table 6.3). The comparison between a social and private benefits and costs under both a single and infinite rotation period are summarized with the three carbon payments. The optimal rotation length (Chapter Five, Section 5.6) under each scenario varied depending on the soil classification. As land productivity decreased the optimal rotation length became longer. In addition land with lower productivity was converted to afforestation first.

The results indicated that with private carbon values the benefit cost ratios exceeded one under only three of the simulation scenarios (Table 6.2);

1. Under a single rotation with a carbon value of \$33.55 tonne C^{-1} and including the external benefits for soil class P,
2. Under an infinite rotation with a carbon value of \$22.58 tonne C^{-1} and including the external benefits for soil class P and,
3. Under an infinite rotation with a carbon value of \$33.55 tonne C^{-1} and including the external benefits for soil classes M, O and P.

With a social carbon value (Table 6.3) the benefit cost ratios exceeded one for three scenarios;

1. Under a single rotation with a carbon value of \$33.55 tonne C^{-1} and including the external benefits for soil class P,
2. Under an infinite rotation with a carbon value of \$22.58 tonne C^{-1} and including the external benefits for soil class P and,
3. Under an infinite rotation with a carbon value of \$33.55 tonne C^{-1} and including the external benefits for soil classes O and P.

The above results imply that social efficiency would be attained if these soil classes were converted to afforestation. This does not indicate however that producers would actually convert the agricultural land to trees as there are many other considerations involved in the decision making process. Some of these issues will be dealt with in the next Chapter.

The inclusion of the external benefits into the analysis provided enough financial incentive for the conversion of a limited amount agricultural land into afforestation. This limited conversion of agricultural land does not mean however that the external benefits as a result of afforestation were insignificant but rather the combination of low stumpage prices and high establishment costs created situations where the external benefits failed to outweigh the private costs. In order for afforestation to be economically efficient the necessary breakeven timber price was estimated under the various carbon price scenarios (Figures 6.7 – Figure 6.9). It can be seen that as more land is converted to afforestation the breakeven price increased. This resulted from the increased opportunity cost of converting more productive land to afforestation. However, the inclusion of the three carbon prices under both a single and infinite rotation caused the breakeven timber price to fall for all the scenarios.

The use of afforestation as a low cost method of carbon sequestration (refer to Chapter Two, Section 2.3) has been greatly investigated with some mixed results (refer to Table 5.11). The cost of carbon sequestration in this analysis was calculated (Table 6.4) and the prices ranged from \$14.57 to \$34.59 tonne C^{-1} for soil classes P and A respectively (\$2001). These prices are significantly higher than the \$2.73 to \$13.64 tonne C^{-1} as estimated by the Federal Government (2002) in the development of a carbon credit trading system.

The estimated breakeven carbon values are significant, as afforestation in this thesis does not provide a low cost method of carbon sequestration. The two main reasons for this are the low stumpage fees for hardwood tress and the high costs of establishing an afforestation project. The negative *NPV* of afforestation for most scenarios in this thesis creates a breakeven carbon price that exceeds the estimated carbon market values from the Federal Government. Unless the actual carbon credit market has carbon values, which are comparable to the estimates in this thesis, or producers can generate higher timber revenues through different end products for the timber then afforestation would not be utilized for carbon sequestration. The idea of different timber markets is discussed further in Chapter Seven.

Table 6. 2: Summary of social afforestation benefit cost ratios of crop systems (private carbon value)

Soil Class	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*O*	*P*
B-C Ratio – Timber Revenue Only	0.122	0.122	0.122	0.121	0.122	0.122	0.124	0.126	0.130	0.151	0.161	0.175	0.217	0.263
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NPV Afforestation ($ ha^{-1})	$(1,797.80)	$(1,773.16)	$(1,749.28)	$(1,720.16)	$(1,684.90)	$(1,639.03)	$(1,585.84)	$(1,518.78)	$(1,440.82)	$(1,347.36)	$(1,228.81)	$(1,086.41)	$(898.76)	$(682.06)
Private Carbon Values – 1 Rotation														
B-C Ratio ($7.75 tonne C^{-1})	0.237	0.237	0.237	0.238	0.239	0.241	0.245	0.251	0.260	0.299	0.318	0.379	0.432	0.527
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NPV Afforestation ($ ha^{-1})	$(1,562.25)	$(1,540.24)	$(1,518.99)	$(1,492.51)	$(1,459.89)	$(1,416.65)	$(1,366.10)	$(1,301.67)	$(1,226.35)	$(1,113.73)	$(998.04)	$(825.78)	$(653.66)	$(438.04)
B-C Ratio ($22.58 tonne C^{-1})	0.377	0.376	0.375	0.376	0.377	0.381	0.386	0.395	0.451	0.471	0.501	0.599	0.679	0.818
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NPV Afforestation ($ ha^{-1})	$(1,276.96)	$(1,260.01)	$(1,243.81)	$(1,222.38)	$(1,194.81)	$(1,156.63)	$(1,111.13)	$(1,051.76)	$(927.44)	$(840.31)	$(730.10)	$(533.90)	$(369.39)	$(170.99)
B-C Ratio ($33.55 tonne C^{-1})	0.480	0.479	0.478	0.478	0.479	0.484	0.490	0.501	0.573	0.598	0.637	0.761	0.863	1.039
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	4731
NPV Afforestation ($ ha^{-1})	$(1,066.07)	$(1,052.86)	$(1,040.39)	$(1,022.70)	$(998.87)	$(964.42)	$(922.66)	$(867.02)	$(721.28)	$(638.20)	$(532.03)	$(318.15)	$(157.91)	$36.22
Private Carbon Values - > 1 Rotation														
B-C Ratio ($7.75 tonne C^{-1})	0.279	0.279	0.278	0.279	0.280	0.283	0.287	0.294	0.303	0.350	0.373	0.444	0.505	0.616
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NPV Afforestation ($ ha^{-1})	$(1,477.43)	$(1,456.93)	$(1,437.18)	$(1,412.20)	$(1,381.08)	$(1,339.35)	$(1,290.30)	$(1,227.38)	$(1,153.56)	$(1,032.44)	$(918.38)	$(739.00)	$(570.43)	$(355.69)
B-C Ratio ($22.58 tonne C^{-1})	0.497	0.496	0.495	0.495	0.497	0.501	0.508	0.520	0.594	0.620	0.660	0.789	0.895	1.077
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	4731
NPV Afforestation ($ ha^{-1})	$(1,029.53)	$(1,016.97)	$(1,005.15)	$(988.10)	$(964.92)	$(931.12)	$(890.00)	$(835.02)	$(685.56)	$(603.19)	$(497.72)	$(280.77)	$(121.27)	$72.12
B-C Ratio ($33.55 tonne C^{-1})	0.659	0.657	0.656	0.655	0.657	0.663	0.672	0.761	0.786	0.820	0.872	1.044	1.183	1.423
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	17716	11839	4731
NPV Afforestation ($ ha^{-1})	$(698.44)	$(691.74)	$(685.79)	$(674.60)	$(657.28)	$(629.35)	$(594.10)	$(424.63)	$(361.89)	$(285.87)	$(186.75)	$57.97	$210.76	$397.43

Source: Author's estimation

* Values in parenthesis are negative values

Table 6. 3: Summary of social afforestation benefit cost ratios of crop systems (social carbon value)

Soil Class	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*O*	*P*
Social Carbon Values – 1 Rotation														
B-C Ratio ($7.75 tonne C^{-1})	0.237	0.237	0.237	0.238	0.239	0.241	0.245	0.251	0.260	0.299	0.318	0.348	0.432	0.527
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NPV Afforestation ($ ha^{-1})	$(1,562.25)	$(1,540.24)	$(1,518.99)	$(1,492.51)	$(1,459.89)	$(1,416.65)	$(1,366.10)	$(1,301.67)	$(1,226.35)	$(1,113.73)	$(998.04)	$(858.49)	$(651.91)	$(438.04)
B-C Ratio ($22.58 tonne C^{-1})	0.377	0.376	0.375	0.376	0.377	0.381	0.386	0.395	0.407	0.471	0.501	0.548	0.678	0.826
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NPV Afforestation ($ ha^{-1})	$(1,276.96)	$(1,260.01)	$(1,243.81)	$(1,222.38)	$(1,194.81)	$(1,156.63)	$(1,111.13)	$(1,051.76)	$(981.49)	$(840.31)	$(730.10)	$(596.02)	$(369.45)	$(161.02)
B-C Ratio ($33.55 tonne C^{-1})	0.480	0.479	0.478	0.478	0.479	0.484	0.490	0.501	0.517	0.598	0.637	0.695	0.860	1.047
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	4731
NPV Afforestation ($ ha^{-1})	$(1,066.07)	$(1,052.86)	$(1,040.39)	$(1,022.70)	$(998.87)	$(964.42)	$(922.66)	$(867.02)	$(800.49)	$(638.20)	$(532.03)	$(402.00)	$(160.64)	$43.77
Social Carbon Values - > 1 Rotation														
B-C Ratio ($7.75 tonne C^{-1}	0.279	0.365	0.366	0.367	0.370	0.375	0.381	0.390	0.402	0.452	0.478	0.553	0.614	0.728
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NPV Afforestation ($ ha^{-1})	$(1,477.43)	$(1,456.93)	$(1,437.18)	$(1,412.20)	$(1,381.08)	$(1,339.35)	$(1,290.30)	$(1,227.38)	$(1,153.56)	$(1,032.44)	$(918.38)	$(780.46)	$(567.94)	$(355.69)
B-C Ratio ($22.58 tonne C^{-1})	0.494	0.493	0.491	0.491	0.493	0.497	0.504	0.515	0.562	0.620	0.660	0.720	0.891	1.086
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	4731
NPV Afforestation ($ ha^{-1})	$(1,037.22)	$(1,024.66)	$(1,012.84)	$(995.79)	$(972.61)	$(938.81)	$(897.69)	$(842.71)	$(725.68)	$(603.19)	$(497.72)	$(368.39)	$(124.47)	$79.25
B-C Ratio ($33.55 tonne C^{-1})	0.659	0.657	0.656	0.655	0.657	0.663	0.672	0.687	0.707	0.820	0.872	0.952	1.177	1.433
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	11839	4731
NPV Afforestation ($ ha^{-1})	$(698.44)	$(691.74)	$(685.79)	$(674.60)	$(657.28)	$(629.35)	$(594.10)	$(544.97)	$(484.95)	$(285.87)	$(186.75)	$(63.77)	$203.35	$400.76

Source: Author’s estimation

* Values in parenthesis are negative values

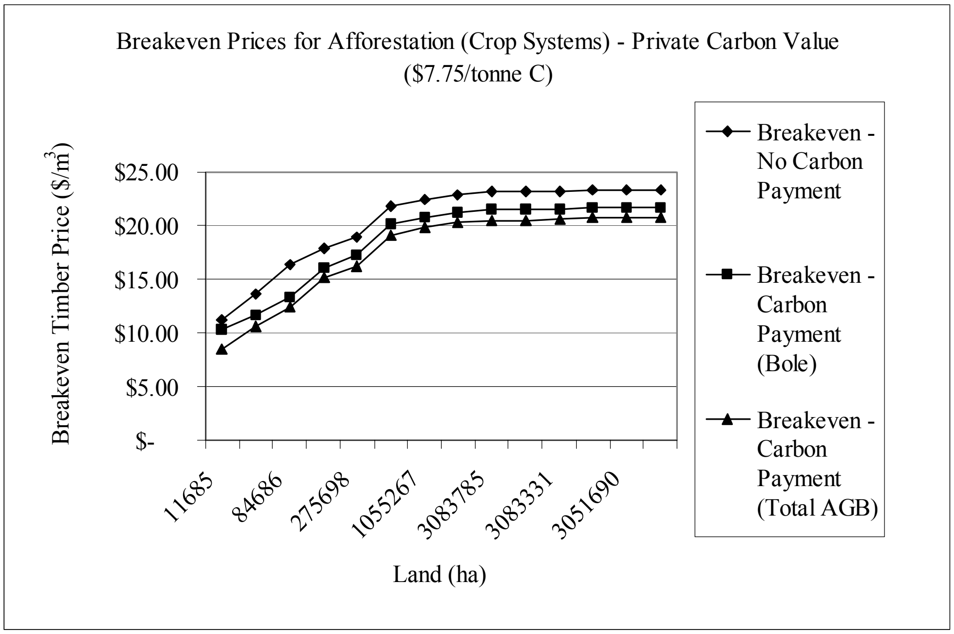

Figure 6. 7: Breakeven timber price for afforestation of crop systems with a carbon value of \$7.75 tonne C^{-1} (\$2001)

Source: Author's estimation

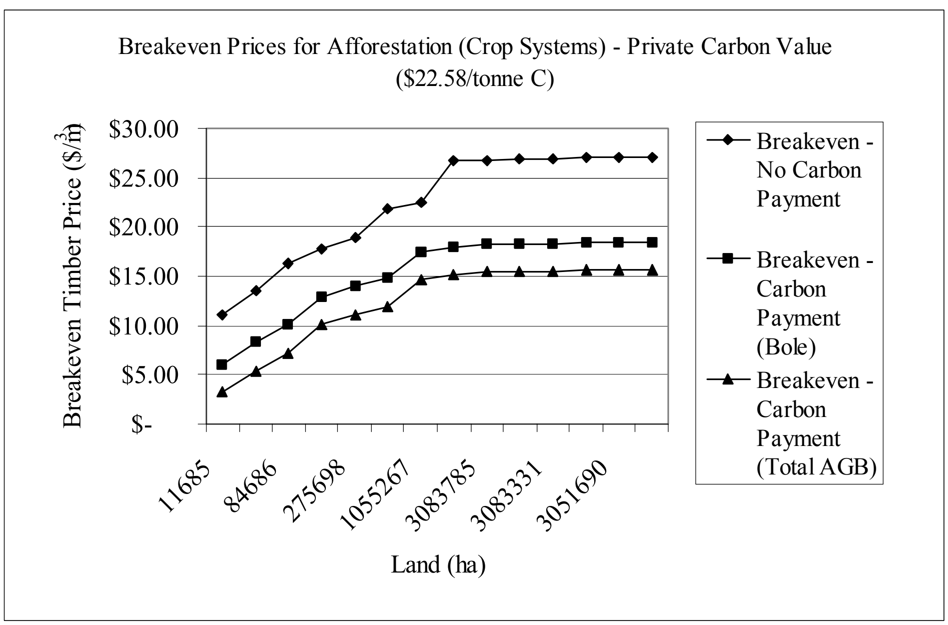

Figure 6. 8: Breakeven timber price for afforestation of crop systems with a carbon value of \$22.58 tonne C^{-1} (\$2001)

Source: Author's estimation

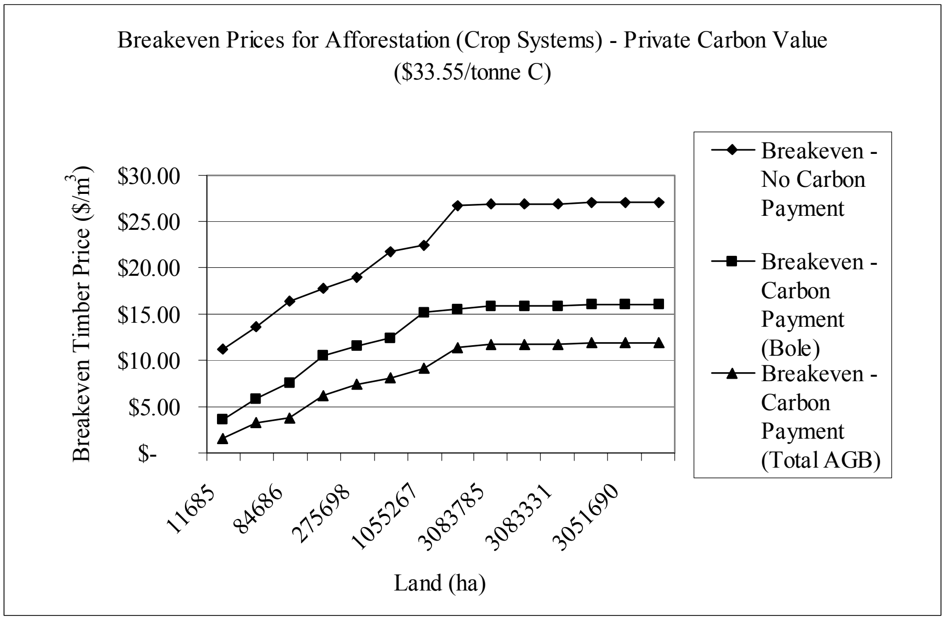

Figure 6. 9: Breakeven timber price for afforestation of crop systems with a carbon value of $33.55 tonne C^{-1} ($2001)

Source: Author's estimation

Table 6. 4: Cost of carbon sequestration for afforestation (OSB end product) of crop systems ($2001)

Soil Class	*Hectares*	*Carbon Price ($* tonne C^{-1}*)*	*Total Bole Carbon Sequestered (MT* yr^{-1}*)*	*Total Above Ground Carbon Sequestered (MT* yr^{-1}*)*
A	0	34.59	-	-
B	184	34.73	0.00	0.00
C	12,810	34.89	0.05	0.08
D	34,804	34.95	0.14	0.21
E	110,755	34.88	0.43	0.67
F	301,917	34.60	1.14	1.79
G	360,791	34.15	1.33	2.09
H	194,990	33.38	0.71	1.11
J	120,625	32.34	0.43	0.67
K	53,355	27.56	0.19	0.29
L	23,977	25.70	0.08	0.13
M	17,716	23.26	0.06	0.09
O	11,839	18.59	0.04	0.06
P	4,731	14.57	0.01	0.02
Total	1,248,496		4.60	5.35

Source: Author's estimation

6.4 Benefit Cost Ratios for Afforestation of Pasture Systems

The results of the benefit cost analysis for pasture systems are summarized below (Tables 6.5 and 6.6). As with crop systems the comparison between social and private benefits and costs for either a single or infinite rotation period is summarized based on the three carbon payments. The land quality for pasture systems was the average of the L through P soil classes so there was no distinction between soil classes.

The results indicate that for any private carbon value the benefit cost ratios never exceed one, even with the inclusion of the external benefits. Thus the *NPV* for afforestation was less than zero and resulted in afforestation being economically inefficient from the private perspective. The main cause of these results was the fact that the profitability of pasture systems was not dependent on soil class and that most pastureland was considered poor quality. The utilization of poor quality land in pasture systems provided a much higher economic return than afforestation. This led to significant positive opportunity costs when considering allocating land to afforestation.

Table 6. 5: Summary of the private and social benefit cost ratios for pasture systems with a private carbon value

	1 Rotation	*1 Rotation*	*> 1 Rotation*	*> 1 Rotation*
	Private Benefits	Social Benefits	Private Benefits	Social Benefits
\$7.75 tonne C^{-1}	0.115	0.152	0.140	0.176
Land Converted	0	0	0	0
NPV Afforestation (\$ ha^{-1})	(\$2,790.81)	(\$2,675.83)	(\$2,713.60)	(\$2,598.61)
\$22.58 tonne C^{-1}	0.198	0.234	0.238	0.274
Land Converted	0	0	0	0
NPV Afforestation (\$ ha^{-1})	(\$2,531.08)	(\$2,416.10)	(\$2,372.31)	(\$2,262.71)
\$33.55 tonne C^{-1}	0.259	0.295	0.365	0.401
Land Converted	0	0	0	0
NPV Afforestation (\$ ha^{-1})	(\$2,339.08)	(\$2,224.10)	(\$2,004.38)	(\$1,889.40)

Source: Author's estimation

Table 6. 6: Summary of the private and social benefit cost ratios for pasture systems with a social carbon value

	1 Rotation	*1 Rotation*	*> 1 Rotation*	*> 1 Rotation*
	Private Benefits	Social Benefits	Private Benefits	Social Benefits
$7.75 tonne C^{-1}	0.064	0.137	0.064	0.157
Land Converted	0	0	0	0
NPV Afforestation ($ ha^{-1})	($2,928.02)	($2,699.93)	($2,928.02)	($2,635.55)
$22.58 tonne C^{-1}	0.064	0.209	0.064	0.269
Land Converted	0	0	0	0
NPV Afforestation ($ ha^{-1})	($2,928.02)	($2,472.76)	($2,928.02)	($2,284.93)
$33.55 tonne C^{-1}	0.064	0.263	0.064	0.352
Land Converted	0	0	0	0
NPV Afforestation ($ ha^{-1})	($2,928.02)	($2,304.83)	($2,928.02)	($2,025.15)

Source: Author's estimation

As with crop systems the inclusion of the external benefits into the analysis did little in providing economic justification for the conversion of pasture systems into afforestation. The low stumpage prices and high establishment costs created a situation where the social benefits failed to outweigh the private costs. The breakeven timber prices were estimated under the various carbon price scenarios (Tables 6.7 and 6.8). The breakeven price decreased with an increase in carbon payments and when the external benefits were included but the prices were significantly higher compared to crop systems. This resulted from the increased opportunity cost of pasture systems and the resulting increased cost of afforestation.

Table 6. 7: Summary of breakeven OSB timber prices for pasture systems with a private carbon value ($2001)

	1 Rotation	*1 Rotation*	*> 1 Rotation*	*> 1 Rotation*
Breakeven Prices	Private Benefits	Social Benefits	Private Benefits	Social Benefits
$7.75 tonne C^{-1}	37.93	36.55	36.95	35.56
$22.58 tonne C^{-1}	34.66	33.28	36.69	35.20
$33.55 tonne C^{-1}	32.24	30.88	28.04	26.65

Source: Author's estimation

Table 6. 8: Summary of breakeven OSB timber prices for pasture systems with a social carbon value ($2001)

	1 Rotation	*1 Rotation*	*> 1 Rotation*	*> 1 Rotation*
Breakeven Prices	Private Benefits	Social Benefits	Private Benefits	Social Benefits
$7.75 tonne C^{-1}	44.39	41.22	44.39	40.26
$22.58 tonne C^{-1}	44.39	38.01	44.39	35.20
$33.55 tonne C^{-1}	44.39	35.61	44.39	31.46

Source: Author's estimation

The cost of carbon sequestration in this analysis has been calculated and the estimated price is $70.05 tonne of C^{-1} ($2001). These prices are significantly higher than the $2.73 to $13.64 tonne C^{-1} as estimated by the Federal Government (2002).

Table 6. 9: Cost of carbon sequestration for afforestation (OSB end product) of pasture systems ($2001)

Hectares	*Carbon Price ($ tonne C^{-1})*	*Total Bole Carbon Sequestered (MT yr^{-1})*	*Total Above Ground Carbon Sequestered (MT yr^{-1})*
80,902	70.05	0.33	0.53

Source: Author's estimation

6.5 Summary

The benefit cost results from the above indicate that only nine scenarios exist where agricultural land would be converted to afforestation based on social economic efficiency (Table 6.10). The agricultural land, which would be converted, is of poor quality (physically marginal) and in the current land use is providing a negative return (refer to Table 5.5). This negative return, or opportunity cost, allows afforestation to be socially economically efficient with respect to cropping activities on these physically marginal lands.

Table 6. 10: Summary of benefit cost ratios > one for crop systems

System	*Scenario*	*Carbon Perspective*	*Carbon Value ($ tonne C^{-1})*	*Soil Class*	*Harvest Year*	*B/C Ratio*	*NPV ($ ha^{-1})*	*Land Converted (ha)*
Crops	3b	Private	33.55	P	13	1.039	36.22	4,731
Crops	4b	Private	22.58	P	13	1.077	72.12	4,731
Crops	4b	Private	33.55	M	13	1.044	57.97	17,716
Crops	4b	Private	33.55	O	13	1.183	210.76	11,839
Crops	4b	Private	33.55	P	13	1.423	397.43	4,731
Crops	1b	Social	33.55	P	14	1.047	43.77	4,731
Crops	2b	Social	22.58	P	14	1.086	79.25	4,731
Crops	2b	Social	33.55	O	14	1.177	203.35	11,839
Crops	2b	Social	33.55	P	14	1.433	400.76	4,731

Source: Author's estimation

Caution should be exercised when interpreting the results of the above analysis. While the benefit cost ratios do exceed one for the simulations identified in Table 6.10 the reality is that the analysis is really providing a relative comparison of the crop and pasture systems to afforestation. The benefit cost ratios and NPV estimates are providing the potential increase (decrease) in returns from converting the land to afforestation. The results show the gain in welfare the producer would receive from converting agricultural land to afforestation. The results are not however providing the net returns from afforestation. The net returns from afforestation would differ significantly, as the opportunity costs would be excluded. The benefit cost methodology used in this thesis allows for comparison of projects by including the opportunity costs. If only the net returns from afforestation were identified then there would be no benchmark for comparing the results to the current land use.

6.6 Conclusion

This chapter provided the various afforestation scenarios, which were estimated in the model. The results were summarized and the economic efficiency of afforestation of agricultural land was determined for each of the scenarios. The next chapter will provide the conclusions, limitation and recommendations for further study.

CHAPTER SEVEN: CONCLUSIONS, STUDY LIMITATIONS AND RECOMMENDATIONS

7.0 Summary of Conclusions

The agricultural problems that are plaguing producers (Chapter One) have resulted in many landowners undertaking initiatives to help maximize their income potential. The initiatives include diversification, including the adoption of alternative cropping practices and production intensification. A production alternative for producers is afforestation. The benefits of afforestation include providing a potentially economically efficient alternative to traditional crop and livestock practices, as well providing a host of environmental and social benefits. The environmental and social benefits include carbon sequestration, biodiversity, hunting and wildlife viewing, providing areas for recreational activities, preservation of native forests and wildlife, as well as improving air, water and soil quality.

Saskatchewan is in an excellent position to take advantage of afforestation with the projected increase in demand for wood products. The main problem with the development of afforestation is that the economics of afforestation in Saskatchewan is not well developed. The main objective of this study was to identify and quantify the private benefits and cost (timber revenue and costs) and social benefits and costs (carbon sequestration, hunting, wildlife viewing and conservation of native forests) of afforestation.

The economic efficiency of afforestation was assessed using a transitional benefit cost framework[58], with an end product of OSB. The analyses looked at the economic efficiency of converting either crop or pasture systems to afforestation. Various scenarios where then examined to determine whether afforestation was efficient from the private or social perspective. These scenarios included various combinations of the private, social and environmental benefits described above.

[58] Refer to Chapter Six, Section 6.5.

The results indicated that from private perspective afforestation, for the purpose of growing OSB material was not economically efficient, even with the inclusion of a carbon payment. The range of private economic efficiencies for crop systems varied greatly depending on the soil class and whether a carbon payment was included. When viewed from the social perspective the conversion of crop systems to afforestation was socially economically efficient under nine of the simulation scenarios. The land, which was converted, was poor quality and considered physically and economically marginal for annual crop production.

In order for afforestation to become economically efficient on a large-scale there are two main factors that must change. Firstly the stumpage fees currently levied in Saskatchewan for tenure rights on crown land are well below the prices necessary to promote afforestation practices. This market failure created by the federal government may be the result of the federal government trying to help maintain the commercial lumber industry in Canada via subsidies. While there is not a direct subsidy being paid to the lumber companies there may be an indirect subsidy. This indirect subsidy could be based on the assumption that the federal government is providing the lumber companies access to crown land below what the competitive market would bear. If afforestation is to be promoted in Saskatchewan the stumpage fee needs to be either based on a competitive equilibrium or some sort of government support is required.

Secondly, the current cost structure of afforestation is substantial, with the majority of these costs occurring early in the rotation, which results in negative net returns per hectare. These high costs for afforestation are largely due to the infancy of the industry in Saskatchewan and Canada and the lack of research and development. Until more research and development are undertaken to help promote the industry the high costs will restrict the applicability of afforestation.

While each of these constraints described above may individually aid in the adoption of afforestation practices more likely a combination of the two would help move the system towards a socially optimal solution. This would help to meet various objectives including those of the lumber companies, private afforestation practices, as well as societies concerns regarding the environment.

7.1 Study Limitations

The main limitation of this study deals with the data obtained for afforestation. The lack of afforestation practices in Saskatchewan and western Canada creates significant uncertainty when estimating the cost structure and growth estimates for hybrid poplars. While cost structure data from the US was obtained for comparison purposes the fact is as more research and development on afforestation practices are undertaken in Canada and the US, new techniques and technologies will be developed. This may significantly reduce the cost structure and increase the economic efficiency of afforestation. The other main data constraint deals with growth estimation for hybrid poplars. While estimates were obtained for western Canada these estimates were adjusted to meet the specific intricacies of the study scope. How the hybrid poplar trees would actually grow in the study area could significantly differ from the estimated values used in this study, thus affecting the overall results.

Another limitation of this study deals with the chosen end product for the hybrid poplars. The end product in this study dealt with OSB due to the predicted market growth for this product but there are a host of other potential end products that could have been investigated. For example longer rotation cycles would have allowed for end products that include dimensional lumber, veneer products and logs. In addition with the construction of ethanol plants in the province, including two that are in relatively close proximity to the study area, provides another potential market for hybrid poplars.

Finally the estimation of the external benefits associated with afforestation has to be dealt with cautiously. The monetary values assigned to the various social benefits were conducted using the benefit transfer method and the reliability of these estimates is largely determined by the initial study from which they were obtained. However the inclusion of these social benefits is critical as to estimate the social value of afforestation.

7.2 Recommendations for Further Research

The lack of research on establishing afforestation plantations on agricultural land in Saskatchewan warrants further research. The only research being conducted on growing hybrid poplars in Saskatchewan has been by the PFRA. Most of the PFRA research deals with shelterbelts and no attempts have been made to grow trees on a large-scale basis. As a result the main recommendation of this study is to further examine afforestation practices.

The limitation of only examining afforestation practices in one area of Saskatchewan limits the applicability of the results. Afforestation studies should be conducted across various geographical regions in Saskatchewan. This would allow for various agronomic characteristics to be explicitly defined to determine the most optimal growth characteristics for hybrid poplars.

This study only focused on OSB as an end product for hybrid poplars. Further research needs to be conducted on various other afforestation enterprises and their economic efficiency. In addition, due to the high establishment costs and based on the market supply and demand the potential exist for staggering the establishment of the trees over a number of years. This would provide two benefits: 1) the cash outlay would not occur all in one year but would be over a number of years. This would not constrain cash flow as significantly and the harvest would occur over a number of years thus providing yearly revenues, 2) this would also have favorable tax implications as revenues would not all accrue in the same year thus creating a potential income tax problem.

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APPENDIX A: CONSUMER PRICE INDEX.

Table A. 1: Consumer Price Index

Year	*Consumer Price Index (1992 = 100)*
1992	100.0
1993	102.4
1994	104.2
1995	106.2
1996	108.4
1997	109.9
1998	111.4
1999	113.0
2000	115.0
2001	116.7

Source: Statistics Canada (2002b)

2001 Value = 19XX value × (2001 CPI ÷ 19XX CPI)

APPENDIX B: GROWTH AND CARBON SEQUESTRATION FUNCTIONS FOR HYBRID POPLARS.

Table B. 1: Estimated average growth functions for hybrid poplar based on soil class (bole m^{-3} ha^{-1})

Year / *Soil Class*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
A	1.70	10.50	27.60	51.38	79.41	109.45	139.69	168.84	196.10	220.99	243.33	263.11	280.42	295.46	308.42
B	1.65	10.21	26.89	50.11	77.54	107.00	136.70	165.41	192.29	216.90	239.02	258.65	275.86	290.84	303.78
C	1.60	9.93	26.17	48.84	75.67	104.54	133.72	161.97	188.49	212.80	234.71	254.18	271.30	286.22	299.14
D	1.55	9.64	25.45	47.56	73.80	102.09	130.74	158.54	184.68	208.71	230.40	249.72	266.74	281.61	294.50
E	1.50	9.35	24.74	46.29	71.93	99.63	127.76	155.10	180.88	204.61	226.09	245.26	262.18	276.99	289.86
F	1.46	9.07	24.02	45.02	70.06	97.18	124.77	151.67	177.07	200.52	221.78	240.80	257.62	272.37	285.22
G	1.41	8.78	23.30	43.75	68.19	94.73	121.79	148.23	173.26	196.42	217.47	236.33	253.06	267.75	280.58
H	1.36	8.50	22.58	42.48	66.32	92.27	118.81	144.79	169.46	192.33	213.16	231.87	248.50	263.13	275.93
J	1.31	8.21	21.87	41.21	64.45	89.82	115.83	141.36	165.65	188.23	208.85	227.41	243.93	258.52	271.29
K	1.26	7.92	21.15	39.94	62.58	87.37	112.84	137.92	161.85	184.14	204.54	222.95	239.37	253.90	266.65
L	1.21	7.64	20.43	38.67	60.71	84.91	109.86	134.49	158.04	180.05	200.23	218.48	234.81	249.28	262.01
M	1.16	7.35	19.72	37.40	58.84	82.46	106.88	131.05	154.24	175.95	195.92	214.02	230.25	244.66	257.37
O	1.12	7.06	19.00	36.13	56.97	80.01	103.90	127.62	150.43	171.86	191.61	209.56	225.69	240.05	252.73
P	1.07	6.78	18.28	34.86	55.10	77.55	100.91	124.18	146.63	167.76	187.30	205.10	221.13	235.43	248.09

Source: Author's estimation

Table B. 2: Estimated average bole carbon sequestration for hybrid poplars based on soil class (tonne C ha^{-1})

Year / *Soil Class*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
A	0.25	1.57	4.13	7.69	11.88	16.37	20.90	25.26	29.34	33.06	36.40	39.36	41.95	44.20	46.14
B	0.25	1.53	4.02	7.50	11.60	16.01	20.45	24.74	28.77	32.45	35.76	38.69	41.27	43.51	45.45
C	0.24	1.49	3.92	7.31	11.32	15.64	20.00	24.23	28.20	31.84	35.11	38.03	40.59	42.82	44.75
D	0.23	1.44	3.81	7.12	11.04	15.27	19.56	23.72	27.63	31.22	34.47	37.36	39.90	42.13	44.06
E	0.23	1.40	3.70	6.93	10.76	14.91	19.11	23.20	27.06	30.61	33.82	36.69	39.22	41.44	43.36
F	0.22	1.36	3.59	6.74	10.48	14.54	18.67	22.69	26.49	30.00	33.18	36.02	38.54	40.75	42.67
G	0.21	1.31	3.49	6.55	10.20	14.17	18.22	22.18	25.92	29.39	32.53	35.36	37.86	40.06	41.97
H	0.20	1.27	3.38	6.36	9.92	13.80	17.77	21.66	25.35	28.77	31.89	34.69	37.17	39.36	41.28
J	0.20	1.23	3.27	6.17	9.64	13.44	17.33	21.15	24.78	28.16	31.24	34.02	36.49	38.67	40.59
K	0.19	1.19	3.16	5.98	9.36	13.07	16.88	20.63	24.21	27.55	30.60	33.35	35.81	37.98	39.89
L	0.18	1.14	3.06	5.78	9.08	12.70	16.44	20.12	23.64	26.93	29.95	32.69	35.13	37.29	39.20
M	0.17	1.10	2.95	5.59	8.80	12.34	15.99	19.61	23.07	26.32	29.31	32.02	34.45	36.60	38.50
O	0.17	1.06	2.84	5.40	8.52	11.97	15.54	19.09	22.50	25.71	28.66	31.35	33.76	35.91	37.81
P	0.16	1.01	2.74	5.21	8.24	11.60	15.10	18.58	21.94	25.10	28.02	30.68	33.08	35.22	37.11

Source: Author’s estimation

Table B. 3: Estimated average total above ground biomass (including bole) carbon sequestration for hybrid poplars based on soil class (tonne C ha^{-1})

Year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
Soil Class															
A	0.07	0.45	1.19	2.22	3.43	4.72	6.03	7.29	8.46	9.54	10.50	11.35	12.10	12.75	13.31
B	0.07	0.44	1.16	2.16	3.35	4.62	5.90	7.14	8.30	9.36	10.31	11.16	11.90	12.55	13.11
C	0.07	0.43	1.13	2.11	3.27	4.51	5.77	6.99	8.13	9.18	10.13	10.97	11.71	12.35	12.91
D	0.07	0.42	1.10	2.05	3.18	4.41	5.64	6.84	7.97	9.01	9.94	10.78	11.51	12.15	12.71
E	0.06	0.40	1.07	2.00	3.10	4.30	5.51	6.69	7.81	8.83	9.76	10.58	11.31	11.95	12.51
F	0.06	0.39	1.04	1.94	3.02	4.19	5.38	6.54	7.64	8.65	9.57	10.39	11.12	11.75	12.31
G	0.06	0.38	1.01	1.89	2.94	4.09	5.26	6.40	7.48	8.48	9.38	10.20	10.92	11.55	12.11
H	0.06	0.37	0.97	1.83	2.86	3.98	5.13	6.25	7.31	8.30	9.20	10.01	10.72	11.36	11.91
J	0.06	0.35	0.94	1.78	2.78	3.88	5.00	6.10	7.15	8.12	9.01	9.81	10.53	11.16	11.71
K	0.05	0.34	0.91	1.72	2.70	3.77	4.87	5.95	6.98	7.95	8.83	9.62	10.33	10.96	11.51
L	0.05	0.33	0.88	1.67	2.62	3.66	4.74	5.80	6.82	7.77	8.64	9.43	10.13	10.76	11.31
M	0.05	0.32	0.85	1.61	2.54	3.56	4.61	5.66	6.66	7.59	8.45	9.24	9.94	10.56	11.11
O	0.05	0.30	0.82	1.56	2.46	3.45	4.48	5.51	6.49	7.42	8.27	9.04	9.74	10.36	10.91
P	0.05	0.29	0.79	1.50	2.38	3.35	4.35	5.36	6.33	7.24	8.08	8.85	9.54	10.16	10.71

Source: Author’s estimation

APPENDIX C: ESTIMATION OF THE RANDOM WALK MODEL.

Forecast of Random Variables

The predictions of future movements in the random variables[59] are conducted using time series analysis on past variations of each specific variable. Traditional econometric models use explanatory variables in a causal framework to predict the relationship with the dependant variable. Pindyck and Rubinfeld (1998) indicate difficulties arise when trying to explain the movement of the dependant variable through the use of a structural model. These complications are a result of model specification errors, data limitations, or lack of predictability power. This can result in the standard errors of the regression model being so large that the coefficients of the explanatory variables are insignificant and the resulting standard errors of the forecast are so large the forecast becomes unacceptable.

The other main issue relative to my estimates is that if a statistically significant regression model can be developed the applicability for forecasting may not be functional. The forecast for the dependant variable relies on the explanatory variables and if these variables are not lagged they themselves must be forecasted. This can create obvious complications, as the standard errors of the forecasted explanatory variables can be so large the forecast error for the dependant variable is too large to accept.

To forecast future values of the random variables a time series model is developed. Pindyck and Rubinfeld (1998) and Kennedy (1998) define a time series model as a sophisticated method of extrapolation. The time series model accounts for past variations in a variable and uses that information to make future predictions. In order to specify a time series model an assumption is made that the economic variable of interest is a random variable whose outcome possibilities can be represented by a probability density function (Griffiths, et al. 1993). In specifying the time series model the key assumption is the value of the random variable only depends on its own past values along with current and past values of random disturbances.

The stochastic (random) time series model used is the random walk process. The basis for this random walk model is each successive change in the dependant variable, y_t, is drawn independently from a probability distribution with a mean of 0. The equation for y_t can be described as follows,

$$y_t = y_{t-1} + \varepsilon_t \tag{C.1}$$

With: $E(\varepsilon_t) = 0$, $E(\varepsilon_t\varepsilon_s) = 0$ for $\forall\ t \neq s$ (no autocorrelation) and $\sigma_t^2 = \sigma_s^2$ for $\forall\ t, s$ (homoskedasticity). These assumptions ensure the error terms comply with the Gauss-Markov theorem to ensure the regression estimates are BLUE (Best Linear Unbiased Estimates). From equation C.1 the assumption can be made that $\varepsilon_t \sim iid\left(0, \sigma_\varepsilon^2\right)$, which states the error terms are identically and independently distributed with a mean 0 and constant variance. The forecast using the random walk process is given by,

$$\hat{y}_{T+l} = \mathrm{E}\left(y_{T+l} \middle| y_T, \ldots, y_1\right) = \mathrm{E}\left(y_{T+l-1} + \varepsilon_{T+l}\right)$$

$$\hat{y}_{T+l} = \mathrm{E}\left(y_T + \varepsilon_{T+l} + \varepsilon_{T+l-1}\right) = y_T \tag{C.2}$$

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59 The random variables include all crop and livestock prices, interest rates, consumer price index and farm input price index. The random variable for timber prices was excluded from this analysis due to data limitations.

Where: l represents the forecast period.

As the forecast period, l, increases the variance of the forecast error will grow. For $l = 1$ the forecast error is,

$$e_1 = y_{T+1} - \hat{y}_{T+1} = y_T + \varepsilon_{T+1} - y_T = \varepsilon_{T+1} \tag{C.3}$$

And the variance for l = 1 is $\mathrm{E}\left(\varepsilon_{T+1}^2\right) = \sigma_\varepsilon^2$. For the forecast period l the variance becomes $l\,\sigma_\varepsilon^2$. The relationship between l and the variance causes the standard error of the forecast error to increase by the $\sqrt{l}$ (Pindyck and Rubinfeld 1998). As the forecast horizon increases the wider the confidence intervals become.

An extension of the random walk process is the random walk with drift process. The drift allows for a trend either upwards or downwards in the series y_t, and thus incorporates the trend in the forecast. The equation for y_t can thus be written as follows,

$$y_t = y_{t-1} + d + \varepsilon_t \tag{C.4}$$

Where d represents the drift and the process will move upwards for $d > 0$ and downwards for $d < 0$. The resulting forecast for period l becomes,

$$\hat{y}_{T+l} = y_T + d \tag{C.5}$$

The standard error of the forecast for period l is written as follows,

$$e_l = y_{T+l} - \hat{y}_{T+l}$$

$$e_l = y_T + d + \varepsilon_{T+l} - y_T - d = \varepsilon_{T+l} \tag{C.6}$$

As with the random walk process the forecast standard error increase by $\sqrt{l}$.

Model Estimation

Farm gate crop and livestock prices were obtained from SAF (2001). The crop prices, excluding peas, are for the period of 1960 – 2000. Pea prices were obtained for the years of 1971 – 2000. Livestock prices, for 500 – 600 lb. calves, were acquired for the period of 1974 – 2000. Nominal interest rates from the Bank of Canada are for the period of 1960 – 2000 (Statistics Canada 2002). The nominal interest rates were converted to real interest rates by adjusting for inflation (Statistics Canada 2002). The consumer price index was obtained for the period of 1992 to 2001 (Statistics Canada 2002b). The farm-input price index for western Canada was acquired from SAF (2001) for the period of 1985 to 2000.

The first step in estimating the random walk model is to apply equations C.1 or C.4 to each of the random variables, as shown in Table C.1. In order to determine the order of the AR process, or lag length, the autocorrelation graph of the random variable was examined and any data point that was significant defined an AR process.

Table C. 1: Summary of equation coefficients and statistics using OLS

Variable	*n*	β_0	β_1	β_2	β_3	*Trend*	R^2	*Jarque-Bera*
Real Interest Rates (1,15)	26		0.466	-0.388		0.111	0.502	0.724
			(3.186)*	(-2.471)*		(3.710)*		
Calf Prices (1)	26	43.964	0.437			0.935	0.587	3.194
		(2.728)*	(2.336)*			(2.181)*		
Wheat Prices (1)	40	2.563	0.454			-0.019	0.449	1.808
		(3.606)*	(3.110)*			(-2.212)*		
Barley Prices (1)	40	0.972	0.583				0.323	0.931
		(3.116)*	(4.428)*					
Oats Price (1)	40	0.549	0.623				0.418	0.380
		(3.086)*	(5.385)*					
Peas Prices (1)	29	3.748	0.389			-0.035	0.406	1.605
		(3.207)*	(2.098)*			(-2.205)*		
Flax Prices (1,2)	39	7.046	0.557	-0.339		-0.074	0.511	1.355
		(4.339)*	(3.474)*	(-2.106)*		(-3.198)*		
Canola Prices (1,4,16)	25	8.230	0.283	-0.281	-0.334		0.409	1.819
		(5.087)*	(1.846)**	(-1.901)**	(-2.811)*			
CPI (1)	15	-5.619	1.034				0.997	0.925
		(-2.440)*	(49.302)*					
Farm CPI (1)	17	15.482	0.410			1.059	0.950	0.492
		(2.200)*	(1.790)**			(2.626)*		

- number in brackets after variable indicates lags
- *t*-statistics are shown in parenthesis, * indicates 5% level of significance, ** indicates 10% level of significance

Source: Author's estimation

A histogram of the residuals from each of the above equations was examined to determine their frequency distribution and to determine if the residuals approximate a normal distribution. Pindyck and Rubinfeld (1998) suggest using a formal test for normality, the Jarque-Bera statistic. The JB statistic is calculated using the following formula,

$$JB = \left[N/6\right]\left[S^2 + (K-3)^2/4\right] \tag{C.7}$$

The JB statistic follows a chi-square distribution with two degrees of freedom. If the JB statistic is greater than the critical value then we reject the null hypothesis of normality. The chi-square critical value with two degrees of freedom is 5.99, at the 5 percent level of significance. The JB statistic indicates all the residuals from the above equations approximate a normal distribution.

The residuals obtained from the estimated regression equations were entered into the computer program @RISK in order to conduct a Monte Carlo simulation. Pindyck and Rubinfeld (1998) indicate the Monte Carlo simulation is conducted by first specifying an equation which yields a probability distribution for the residuals. As previously stated the residuals approximate a normal distribution. The @RISK program enables the residuals to be approximated using a normal distribution $X \sim N(\mu_X, \sigma_X^2)$ and from this a large number of simulations (1000 artificial data points) were estimated. In each simulation the values for the residual are chosen at random from the normal probability distribution. The results from the simulation trace out a probability distribution for the residuals forecasted value. Table C.2 summarizes the results from the Monte Carlo simulation using the @RISK program. This allows for a confidence interval to be defined as the dispersion of the forecast are around their mean value. From each of the 1000 artificial data points generated a random number generator was used to select 20 random values for the residuals. These values were then used to forecast the variable, y_T, which represents each random variable being estimated, using either equation C.2 or C.5, for a fifteen-year time horizon.

Table C. 2: @RISK Monte Carlo simulation statistics

Variable	*Barley Residuals*	*Calf Residuals*	*Canola Residuals*	*Flax Residuals*	*Oats Residuals*	*Peas Residuals*	*Interest Rates*	*Wheat Residuals*	*CPI*	*Farm CPI Residuals*
Minimum	-1.2040	-35.2397	-2.2010	-4.6674	-0.6497	-1.8569	-6.3154	-1.6249	-0.8783	-3.7219
Maximum	1.2940	33.4133	1.9911	3.6971	0.6681	1.7590	5.6321	1.8077	0.8640	3.2328
Mean	0.0001	-0.0019	-0.0003	-0.0010	-0.0000	0.0000	0.0786	0.0001	0.0000	-0.2442
Std Deviation	0.3368	10.7584	0.5845	1.1014	0.2032	0.5613	1.7666	0.5093	0.2691	2.0113
Variance	0.1135	115.7435	0.3416	1.2131	0.0413	0.3150	3.1209	0.2594	0.0724	4.0453
Skewness	0.0117	-0.0045	-0.0141	-0.0359	0.0010	-0.0017	-0.0147	0.0074	0.0017	-0.0001
Kurtosis	3.0887	2.9513	3.0581	3.1414	2.9764	2.9651	3.0004	2.9979	2.9639	1.7999

Source: @RISK Output Simulation

Table C. 3: Estimated random variables

Year	*Wheat Price*	*Barley Price*	*Oats Price*	*Peas Price*	*Flax Price*	*Canola Price*	*Calf Price*	*CPI*	*Farm Input Price Index*	*Interest Rate*
0	$3.43	$2.37	$1.31	$3.35	$5.08	$5.58	$152.81	116.7	100.00	4.44%
1	$4.06	$2.41	$1.50	$3.95	$6.04	$5.39	$144.85	116.9	100.53	4.57%
2	$3.99	$2.75	$1.31	$3.91	$7.64	$5.81	$133.51	116.8	102.71	4.12%
3	$2.75	$3.04	$1.45	$3.92	$7.81	$5.10	$143.15	117.8	106.20	5.69%
4	$2.80	$3.38	$1.28	$3.95	$7.84	$5.23	$148.04	118.6	110.48	5.60%
5	$2.55	$3.62	$1.40	$3.98	$9.04	$5.32	$148.19	119.4	112.59	7.26%
6	$3.04	$3.52	$1.26	$3.49	$8.50	$6.52	$133.75	119.2	115.56	7.51%
7	$2.90	$3.87	$1.30	$4.47	$6.72	$7.06	$144.41	120.2	114.91	5.06%
8	$2.99	$4.26	$1.25	$5.07	$7.22	$6.16	$118.96	120.9	116.00	6.74%
9	$3.71	$4.28	$1.11	$5.50	$7.16	$6.85	$135.43	121.7	114.28	8.41%
10	$3.46	$4.18	$1.33	$5.14	$7.58	$7.49	$122.25	122.3	115.85	9.50%
11	$3.89	$3.87	$1.20	$5.98	$8.02	$8.17	$115.50	123.0	114.96	9.63%
12	$4.24	$4.19	$1.48	$5.39	$7.36	$8.05	$113.56	123.4	119.02	8.50%
13	$4.67	$3.90	$1.63	$5.82	$8.13	$7.36	$123.49	124.3	121.00	7.65%
14	$3.94	$3.96	$1.47	$5.77	$7.23	$6.22	$140.23	125.2	123.47	7.75%
15	$3.54	$3.92	$1.63	$5.72	$7.43	$5.86	$121.15	124.9	123.13	9.84%
16	$3.86	$3.71	$1.79	$5.11	$7.31	$5.05	$119.50	125.7	125.35	6.68%
17	$4.12	$3.26	$1.65	$4.78	$6.88	$5.20	$116.20	125.7	123.63	6.98%
18	$3.80	$2.68	$1.58	$4.91	$6.27	$5.75	$116.95	126.7	123.47	4.85%
19	$4.24	$2.57	$1.81	$4.82	$8.23	$5.31	$120.87	126.3	126.00	6.46%
20	$4.50	$2.86	$1.75	$5.14	$8.00	$5.29	$125.61	127.8	128.85	7.00%

Source: Author's estimation

APPENDIX D: ESTIMATION OF HYBRID POPLAR BREAKEVEN PRICES.

The methodology used in the breakeven analysis will mirror the Parks and Hardie (1995) study. The author's calculate a break-even price for forest products based on discrete land quality classes. The break-even price is as follows (adapted from Parks and Hardie 1995),

$$P = \frac{E(q^*) + \pi^A(q^*)}{v(I)e^{-rt(q^*)}} \tag{D.1}$$

Where: P - is the price of timber (\$ m^{-3}),
E – is the establishment cost (\$ m^{-3}),
π^A – is the opportunity cost of agricultural land,
$v(I)$ – is the growth function (m^3),
e^{-rt} – is the discount factor, and
q^* - represents the discrete land classification.

The left hand side of equation D.1 is the marginal benefit from growing tree, while the right hand side is the average cost per unit of growth (Parks and Hardie 1995). Equation D.1 can be used to show how profit-maximizing producers will allocate discrete classifications of agricultural land with varying qualities to tree production. The landowner will maximize profits by allocating land to trees, when the price of timber, P, exceeds the establishment and opportunity costs for a particular land class. Solving equation D.1 for each land class can be used to develop an estimate of the quantity of land within the study area that will be allocated to afforestation production at a range of market timber prices. The breakeven price increase as the soil quality decreases. This is a result of the lower yielding potential of the increasingly physically marginal land. As the rotation length increases the breakeven price decreases. This is because of the substantial establishment cost for hybrid poplars and as the rotation length increases these costs get amortized over a longer period.

APPENDIX E: *NPV* CALCULATIONS OF CROP AND PASTURE SYSTEMS.

Table E. 1: *NPV* of annual returns for crop systems ($ ha^{-1})

Year / *Soil Class*	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*Avg.*
A	22.19	43.59	51.00	24.16	20.00	21.24	18.78	28.04	28.15	34.83	27.85	31.07	31.37	32.69	17.64	10.63	27.70
B	19.27	40.50	47.85	21.42	17.34	18.81	16.52	25.48	25.93	32.90	26.23	29.55	29.77	31.02	16.23	9.67	25.53
C	16.38	37.46	44.76	18.78	14.77	16.47	14.32	23.00	23.77	31.03	24.66	28.07	28.21	29.39	14.86	8.74	23.42
D	12.96	33.84	41.08	15.64	11.72	13.70	11.70	20.06	21.24	28.82	22.81	26.33	26.36	27.46	13.24	7.64	20.91
E	8.91	29.55	36.74	11.94	8.13	10.44	8.64	16.59	18.23	26.19	20.61	24.25	24.16	25.16	11.31	6.33	17.95
F	3.77	24.12	31.25	7.28	3.58	6.33	4.75	12.17	14.39	22.84	17.81	21.61	21.36	22.25	8.86	4.67	14.19
G	-2.09	17.95	24.99	1.92	-1.65	1.59	0.28	7.09	9.98	19.01	14.61	18.60	18.16	18.92	6.06	2.77	9.89
H	-9.36	10.26	17.16	-4.73	-8.13	-4.30	-5.28	0.83	4.55	14.26	10.64	14.86	14.20	14.80	2.60	0.42	4.55
J	-17.76	1.37	8.15	-12.40	-15.60	-11.07	-11.66	-6.39	-1.71	8.80	6.08	10.55	9.63	10.04	-1.40	-2.29	-1.60
K	-27.44	-8.84	-2.22	-21.24	-24.21	-18.88	-19.04	-14.73	-8.93	2.50	0.81	5.59	4.37	4.56	-6.00	-5.41	-8.70
L	-39.34	-21.41	-14.99	-32.11	-34.81	-28.49	-28.12	-24.98	-17.82	-5.26	-5.67	-0.51	-2.11	-2.18	-11.67	-9.25	-17.42
M	-53.56	-36.41	-30.22	-45.06	-47.45	-39.95	-38.96	-37.24	-28.43	-14.52	-13.42	-7.78	-9.85	-10.23	-18.42	-13.83	-27.83
O	-69.94	-53.69	-47.76	-59.93	-61.95	-53.08	-51.41	-51.30	-40.60	-25.14	-22.30	-16.14	-18.75	-19.48	-26.18	-19.08	-39.79
P	-89.40	-74.21	-68.64	-77.67	-79.25	-68.78	-66.30	-68.02	-55.05	-37.75	-32.86	-26.05	-29.31	-30.45	-35.38	-25.31	-54.03

Source: Author’s estimation

Table E. 2: *NPV* of annual returns for pasture systems (\$ ha^{-1})

Year	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*Average*
Average Costs	245.72	201.89	144.25	154.55	149.61	125.81	70.04	109.23	27.27	57.98	24.22	13.03	4.63	17.41	36.72	6.76	

Source: Author’s estimation

APPENDIX F: ESTIMATION OF THE HABITAT USE UNITS FOR SASKATCHEWAN.

In a study by Neave and Neave (1998) a habitat availability indicator was estimated for the seven main Ecozones within Canada, in which agriculture is practiced. The habitat indicator estimates the share (percent) of habitat use units for various agriculture habitat types at very gross level. The indicator places a value on a habitat type for all uses and does not provide an estimate of the number of species. The species included in the assessment are mammals, birds, reptiles and amphibians. The indicator is estimated based on the agricultural land meeting the needs required for the habitat. The needs are classified into breeding, feeding, cover, staging and winter use. One habitat unit is derived when a species uses a particular habitat type.

The five land classifications used in the Neave and Neave (1998) study correspond to the categories as defined in the 1996 Census (Statistics Canada 1997c). The land classifications are cropland, summerfallow, tame or seeded pasture, natural land for pasture and all other land. Neave and Neave (1998) break down the classification of all other land in the study into various sub-categories. The sub-category of woodlands, which includes, plantations, woodlots with interior[60] and woodlots without interior, will be used in this thesis, along with the cropland, summerfallow and tame or seeded pasture classifications. For the purpose this thesis several assumptions regarding the estimation of the habitat use units will have to be made. The Prairie Ecozone includes the areas of southern Alberta, Saskatchewan and Manitoba, while the Boreal Plains Ecozone includes central and northern Alberta, central Saskatchewan and Manitoba. As a result the habitat use units for farmland evaluated in the Prairie and Boreal Plains Ecozones in the Neave and Neave (1998) study will have to be converted to Saskatchewan only, as to allow for the thesis study area to be isolated.

Secondly, afforestation of agricultural land will displace harvesting of native forests and the values for wildlife viewing and hunting in the native forest will be calculated for the Boreal Plains Ecozone, as approximately 90.5 percent of the Ecozone is covered in forests (Neave and Neave 1998). The habitat use units for the woodlands will be calculated for existing native forests and thus will not take into account any loss of habitat use units from the afforestation of agricultural land, as this will be addressed next. It will also be assumed that one hectare of afforestation will displace approximately one hectare of native forest. This is due to the fact that the average quantity of timber harvested in the native forest is approximately 165 m^3 ha^{-1}[61], while for afforestation the average yield of timber after 13 years is estimated at 189 m^3 ha^{-1}[62].

Thirdly, for Crop District 5B the conversion of agricultural land to afforestation will have an effect on the habitat use units in that region. Neave and Neave (1998) report agricultural lands do have some value as wildlife habitat and thus any land use changes must take into account the existing habitat use units. As a result the net change in the habitat indicator will be calculated for the Prairie Ecozone only as a result of afforestation of agricultural land. The Prairie Ecozone is chosen for Crop District 5B as the intensive agriculture practices in this area are more indicative of the Prairie Ecozone habitat use units as compared to the Boreal Plains Ecozone.

60 Woodlot interior habitat is habitat, which falls within 100m from the edge of the woodlot.

61 Refer to Chapter Three, Section 3.3.

62 Refer to Appendix B.

Finally, the calculation of the option, bequest and existence values will be based on the percentage of the total area for each of the Prairie and Boreal Plains Ecozone as there is no discrimination as to where a habitat use unit is derived. For example a hectare of land conservation in the Prairie Ecozone will be the same as a hectare of land conservation in the Boreal Shield Ecozone. The estimation will include conversion of agricultural land to afforestation, along with the conservation of the existing woodlands.

The habitat use units for the Prairie and Boreal Plains Ecozones estimated in the Neave and Neave (1998) study are not broken down provincially. In addition the evaluation area was for agricultural land as defined in the 1996 Census and is not representative of the entire Ecozone. To estimate the habitat use units for the entire Prairie and Boreal Plains Ecozones in Saskatchewan the dominant land cover for each of the Ecozones was obtained (Wiken, et al. 1996), as well as the total area of each of the Ecozones represents in Saskatchewan (Saskatchewan Interactive 2002b).

Table F. 1: Dominant cover types in the Prairie and Boreal Plains Ecozones

Prairie Ecozone		*Boreal Plains Ecozone*	
Dominant Land Cover[a]	% of Land Cover	Dominant Land Cover[a]	% of Land Cover
Cropland[b]	67.70%	Cropland[b]	6.60%
Pasture[c]	24.80%	Pasture[c]	2.20%
Forests	6.90%	Forests	90.50%
Other	0.60%	Other	0.70%
Total	100.0%	Total	100.0%

[a] Source: Wiken, et al. (1996)

[b] Cropland includes 20.07 percent and 9.54 percent of summerfallow for the Prairie and Boreal Ecozones, respectively

[c] Pasture includes 18.13 percent and 28.39 percent of Tame or Seeded Pasture for the Prairie and Boreal Ecozones, respectively

Table F. 2: Ecozones areas (million ha)

	Farmland Evaluated[a]	*Saskatchewan*	
Ecozones	Area	Area[b]	% area of province
Boreal & Taiga Shields	N/A	23.38	35.86%
Boreal Plains	13.45	17.70	27.15%
Prairie	41.85	24.11	36.98%
Total	55.3	65.19	100.00%

[a] Source: Neave and Neave (1998)

[b] Source: Saskatchewan Interactive (2002b)

The data in Tables F.1 and F.2 was used to calculate the areas each of the dominant land covers represent in the Prairie and Boreal Ecozones within Saskatchewan. The results are summarized in Table F.3.

Table F. 3: Dominant land cover in the Prairie and Boreal Plains Ecozones within Saskatchewan (million ha)

	Prairie Ecozone	*Boreal Plains Ecozone*
Dominant Land Cover	Land Cover	Land Cover
Cropland	13.05	1.06
Summerfallow	3.28	0.11
Tame or Seeded Pasture	1.08	0.11
Natural Land for Pasture	4.90	0.28
Forests	1.66	16.02
Other	0.14	0.12
Total	24.11	17.70

Source: Author's estimation

The habitat use values for the Prairie and Boreal Plains Ecozones in Saskatchewan were estimated from the Neave and Neave (1998) study and are summarized in Tables F.4 and F.5. In order to calculate the values for Saskatchewan the habitat use units from the Neave and Neave (1998) study were converted to a percentage and per hectare basis for each respective habitat type. The assumption was then made, due to data limitations, that each of the Ecozones in Saskatchewan would have the same distribution for the areas of habitat use that were estimated in Table F.3. From the estimated total number of habitat use units the proportion of each habitat type to the total estimated for the Ecozone was calculated.

Table F. 4: Actual and estimated habitat use units for the Prairie Ecozone

Prairie Ecozone	*Total Prairie Ecozone*			*Saskatchewan Prairie Ecozone*		
Habitat Type	Total Number of Habitat Use Units[a]	Area of Habitat (millions of ha).[a]	Habitat Use Units as a % of Area	Estimated Area of Habitat (millions of ha).[b]	Estimated Total Number of Habitat Use Units	Total Use Units per Hectare
Cropland		21.95		13.05		
General Use	88		0.0004%		52	
Spring Wheat	63		0.0003%		37	
Durum Wheat	60		0.0003%		36	
Oats	55		0.0003%		33	
Barley	54		0.0002%		32	
Winter Cover and Corn	64		0.0003%		38	
Canola	10		0.0000%		6	
Other Oilseeds	24		0.0001%		14	
Alfalfa	78		0.0004%		46	
Tame Hay	104		0.0005%		62	
Other Crops	11		0.0001%		7	
Fruits and Vegetables	53		0.0002%		32	
Sub-total	664		0.0030%		395	0.000030
Summerfallow	34	5.51	0.0006%	3.28	20	0.000006
Tame or Seeded Pasture	161	2.25	0.0072%	1.08	78	0.000072
Natural Land for Pasture	727	10.16	0.0072%	4.90	350	0.000072
All other Land		1.99		0.14	166	0.001145
Woodland				1.66		
Plantations	32		0.0016%		27	
Woodlot with interior	409		0.0206%		342	
Woodlot without interior	418		0.0210%		349	
Other	1420		0.0714%		1187	
Sub-total	2279		0.1145%		1905	0.001145
Total	3865	41.86	0.1325%	24.11	2914	0.002470

[a] Source: Neave and Neave (1998)

[b] Source: Table F.3 – Prairie Ecozone

Table F. 5: Actual and estimated habitat use units for the Boreal Plains Ecozone

Boreal Plains Ecozone	*Total Boreal Plains Ecozone*			*Saskatchewan Boreal Plains Ecozone*		
Habitat Type	Total Number of Habitat Use Units[a]	Area of Habitat (millions of ha).[a]	Habitat Use Units as a % of Area	Estimated Area of Habitat (millions of ha).[b]	Estimated Total Number of Habitat Use Units	Proportion of Total Use Units
Cropland		6.54		1.06		
General Use	73		0.0011%		12	0.05%
Spring Wheat	42		0.0006%		7	0.03%
Durum Wheat	38		0.0006%		6	0.03%
Oats	38		0.0006%		6	0.03%
Barley	36		0.0006%		6	0.03%
Winter Cover and Corn	46		0.0007%		7	0.03%
Canola	6		0.0001%		1	0.00%
Other Oilseeds	13		0.0002%		2	0.01%
Alfalfa	41		0.0006%		7	0.03%
Tame Hay	75		0.0011%		12	0.05%
	408		0.0062%		66	0.30%
Summerfallow	22	0.69	0.0032%	0.11	4	0.02%
Tame or Seeded Pasture	106	1.32	0.0080%	0.11	9	0.04%
Natural Land for Pasture	424	3.33	0.0127%	0.28	36	0.16%
All other Land		1.56		0.12	170	0.76%
Woodland				16.02		
Plantations	59		0.0038%		606	2.72%
Woodlot with interior	447		0.0287%		4,590	20.64%
Woodlot without interior	432		0.0277%		4,436	19.95%
Other	1200		0.0769%		12,322	55.41%
	2138		0.1371%		21954	98.72%
Total	3098	13.44	0.1672%	17.70	22237	100.00%

[a] Source: Neave and Neave (1998)

[b] Source: Table F.3 – Boreal Plains Ecozone

APPENDIX G: *PV* OF HYBRID POPLAR COSTS.

Table G. 1: *PV* of annual afforestation costs for crop systems

	** Cost per hectare (2001)*	*Pre-planting*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
Marking Site	7.58	7.58															
Herbicide - Roundup	101.34	101.34															
Herbicide Application	20.25	20.25															
Work Planting Site	81.02	81.02															
Pre-emergent Herbicide - Treflan	50.09	50.09															
Pre-emergent Herbicide Application	40.51	40.51															
Planting material ($ per cutting^{-1})	1.09		341.97														
Plant Trees	129.43		130.12														
Cultivate Tree Rows	112.14		112.73	115.18													
Spray Tree Rows - Glyphosate	128.79		129.47	132.28													
Fall Herbicide - Linuron	56.29		56.59	57.82													
Fertilizer & Application	23.71				25.18	26.20	26.70	27.40	27.25	27.51	27.10	27.47	27.26	28.22	28.69	29.28	29.20
Insect & Disease Control	23.71				25.18	26.20	26.70	27.40	27.25	27.51	27.10	27.47	27.26	28.22	28.69	29.28	29.20
Misc. Expenses		15.04	38.54	15.26	2.52	2.62	2.67	2.74	2.72	2.75	2.71	2.75	2.73	2.82	2.87	2.93	2.92
Total Annual Costs		315.84	809.43	320.54	52.88	55.01	56.06	57.54	57.22	57.76	56.90	57.69	57.24	59.27	60.25	61.48	61.31
Total Establishment Costs																	
Cash Flow		315.84	809.43	320.54	52.88	55.01	56.06	57.54	57.22	57.76	56.90	57.69	57.24	59.27	60.25	61.48	61.31
NPV ($ per ha)		315.84	774.08	295.69	44.79	44.23	39.49	37.25	40.51	34.27	27.50	23.28	20.82	22.27	23.11	21.62	15.00

[a] Source: PFRA (2002)
[b] Source: Author's estimation
[c] Misc. expenses are calculated as 5% of total expenses for the year

APPENDIX H: BENEFIT COST RESULTS.

Table H. 1: Crop systems: Scenarios 1a & 1b - Carbon value of $7.74 tonne C^{-1}

Soil Class	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*O*	*P*
Harvest Year	11	11	11	11	11	11	11	11	11	12	12	12	14	14
PV Timber Price ($ m^{-3})	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.08	1.08	1.08	1.03	1.03
***PV* Private Benefits ($ ha^{-1})**														
Timber Revenue	250.84	246.40	241.95	237.51	233.07	228.62	224.18	219.74	215.29	240.40	235.59	230.78	248.36	243.58
PV Total Private Benefits ($ ha^{-1})	***250.84***	***246.40***	***241.95***	***237.51***	***233.07***	***228.62***	***224.18***	***219.74***	***215.29***	***240.40***	***235.59***	***230.78***	***248.36***	***243.58***
***PV* Private Costs ($ ha^{-1})**														
Afforestation Costs	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1720.02	1720.02	1720.02	1764.75	1764.75
Opportunity Cost of Crop Systems	350.89	321.80	293.47	259.91	220.21	169.90	112.26	40.76	-41.64	-132.27	-255.62	-402.84	-617.64	-839.12
PV Total Private Costs ($ ha^{-1})	*2048.64*	*2019.56*	*1991.23*	*1957.66*	*1917.97*	*1867.65*	*1810.02*	*1738.52*	*1656.11*	*1587.75*	*1464.40*	*1317.19*	*1147.11*	*925.64*
***PV* Social Benefits ($ ha^{-1})**														
Carbon Value	148.80	146.16	143.52	140.89	138.25	135.62	132.98	130.35	127.71	142.60	139.75	136.89	147.32	144.49
Wildlife Viewing	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	17.26	17.26	17.26	18.87	18.87
Hunting	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.81	14.81	14.81	16.19	16.19
Conservation	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	58.95	58.95	58.95	64.46	64.46
PV Total Social Benefits ($ ha^{-1})	***235.56***	***232.92***	***230.28***	***227.65***	***225.01***	***222.38***	***219.74***	***217.11***	***214.47***	***233.63***	***230.77***	***227.92***	***246.85***	***244.01***
***PV* Total Social Benefits ($ ha^{-1})**	**486.40**	**479.32**	**472.24**	**465.16**	**458.08**	**451.00**	**443.92**	**436.84**	**429.76**	**474.03**	**466.36**	**458.70**	**495.20**	**487.59**
***PV* Total Social Costs ($ ha^{-1})**	**2048.64**	**2019.56**	**1991.23**	**1957.66**	**1917.97**	**1867.65**	**1810.02**	**1738.52**	**1656.11**	**1587.75**	**1464.40**	**1317.19**	**1147.11**	**925.64**
Private B/C Ratio	**0.122**	**0.122**	**0.122**	**0.121**	**0.122**	**0.122**	**0.124**	**0.126**	**0.130**	**0.151**	**0.161**	**0.175**	**0.217**	**0.263**
NPV Breakeven Timber Price ($ m^{-3})	8.42	8.45	8.48	8.50	8.48	8.42	8.32	8.16	7.93	7.12	6.70	6.15	4.78	3.93
Land Converted (ha)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Social B/C Ratio	**0.237**	**0.237**	**0.237**	**0.238**	**0.239**	**0.241**	**0.245**	**0.251**	**0.260**	**0.299**	**0.318**	**0.348**	**0.432**	**0.527**
NPV Breakeven Timber Price ($ m^{-3})	7.99	8.03	8.07	8.09	8.08	8.02	7.92	7.14	6.90	6.60	6.17	5.09	4.40	3.53
Land Converted (ha)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: Author's estimation

Explanatory Notes for Table H.1:

1. One rotation period is assumed under this scenario and once harvest occurs the land use will be based on the highest returns from the various potential enterprises.
2. Harvest Year – Harvest year is calculated from equation 5.4 and reflects the optimal rotation length for a stand of timber (refer to Chapter Five, Section 5.6).
3. *PV* Timber Price – The *PV* timber price is the discounted timber price for the appropriate harvest year.
4. Timber Revenue – Timber revenues are based on the *PV* price of standing timber and yield estimates from growth functions in Chapter Five, Section 5.5 based on the harvest year. Refer to Appendix B for average annual growth rates based on soil classification.
5. Afforestation Costs – The *PV* of afforestation costs are calculated for each soil class depending on the appropriate harvest year (refer to Appendix G for annual *PV* of afforestation costs).
6. Opportunity Cost of Crop Systems – The sum of the *NPV* of returns from crop systems for each soil class and harvest year are calculated as this is the opportunity cost of land in this scenario. Refer to Appendix E for the *NPV* of the average annual returns for crop systems based on soil classification.
7. *PV* Total Private Costs – This is the sum of the afforestation costs and opportunity costs of crop systems.
8. Carbon Value – The social carbon value in this scenario is \$7.74 tonne C^{-1} and is viewed as an social benefit of afforestation, which accrues to all of society. The assumption in note one implies the carbon value is calculated from the bole component of the tree only as after harvest the land may not be retained to afforestation (refer to Chapter Five, Section 5.5 and Appendix B). The producer in this scenario receives no monetary compensation for carbon sequestered in the trees.
9. Wildlife Viewing – This value is the sum of the *PV* of wildlife viewing values based on the appropriate harvest year. The value is independent of soil classification as there is no distinction between soil classes in regards to habitat use (refer to Section 5.4.1 and Appendix F).
10. Hunting – This value is the sum of the *PV* of hunting values based on the appropriate harvest year (refer to note six).
11. Conservation – This value is the sum of the *PV* of conservation values based on harvest year (refer to note six).
12. *PV* Total Social Benefits – This is the sum of the *PV* Total Private Benefits and *PV* Total Social Benefits.
13. *PV* Total Social Cost – This is the same as *PV* Total Private Costs as it was assumed there were no social costs resulting from afforestation (refer to Chapter Four, Section 4.3)
14. Private B/C Ratio – This is the ratio of *PV* Total Private Benefits to *PV* Total Private Costs.

15. *NPV* Breakeven Timber Price – This is the required timber price required to have a private B/C Ratio greater than one (refer to Appendix D for breakeven analysis).
16. Land Converted – This is the amount of land that potentially would be converted from the private perspective (private B/C ratio).
17. Social B/C Ratio – This is the ratio of *PV* Total Social Benefits to *PV* Total Social Costs.
18. *NPV* Breakeven Timber Price – This is the required timber to have a social B/C ratio greater than one.
19. Land Converted – This is the amount of land should be converted from the social perspective (social B/C ratio).

<u>Explanatory Notes for Table H.2 and Table H.3</u>:

1. All the explanatory notes for Table H.1 remain the same except for the notes below.
2. Carbon Value (Table H.2) – The carbon value under this scenario is \$22.58 tonne C^{-1}.
3. Carbon Value (Table H.3) – The carbon value under this scenario is \$33.55 tonne C^{-1}.

Table H. 2: Crop systems: Scenarios 1a & 1b - Carbon value of $22.58 tonne C^{-1}

Soil Class	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*O*	*P*
Harvest Year	11	11	11	11	11	11	11	11	11	12	12	12	14	14
PV Timber Price ($ m^{-3})	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.08	1.08	1.08	1.03	1.03
***PV* Private Benefits ($ ha^{-1})**														
Timber Revenue	250.84	246.40	241.95	237.51	233.07	228.62	224.18	219.74	215.29	240.40	235.59	230.78	248.36	243.58
PV Total Private Benefits ($ ha^{-1})	***250.84***	***246.40***	***241.95***	***237.51***	***233.07***	***228.62***	***224.18***	***219.74***	***215.29***	***240.40***	***235.59***	***230.78***	***248.36***	***243.58***
***PV* Private Costs ($ ha^{-1})**														
Afforestation Costs	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1720.02	1720.02	1720.02	1764.75	1764.75
Opportunity Cost of Crop Systems	350.89	321.80	293.47	259.91	220.21	169.90	112.26	40.76	-41.64	-132.27	-255.62	-402.84	-617.64	-839.12
PV Total Private Costs ($ ha^{-1})	***2048.64***	***2019.56***	***1991.23***	***1957.66***	***1917.97***	***1867.65***	***1810.02***	***1738.52***	***1656.11***	***1587.75***	***1464.40***	***1317.19***	***1147.11***	***925.64***
***PV* Social Benefits ($ ha^{-1})**														
Carbon Value	434.08	426.39	418.70	411.01	403.32	395.64	387.95	380.26	372.57	416.01	407.69	399.36	429.79	421.52
Wildlife Viewing	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	17.26	17.26	17.26	18.87	18.87
Hunting	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.81	14.81	14.81	16.19	16.19
Conservation	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	58.95	58.95	58.95	64.46	64.46
PV Total Social Benefits ($ ha^{-1})	***520.84***	***513.15***	***505.46***	***497.77***	***490.09***	***482.40***	***474.71***	***467.02***	***459.33***	***507.04***	***498.71***	***490.39***	***529.31***	***521.04***
***PV* Total Social Benefits ($ ha^{-1})**	**771.68**	**759.55**	**747.42**	**735.28**	**723.15**	**711.02**	**698.89**	**686.75**	**674.62**	**747.44**	**734.30**	**721.16**	**777.67**	**764.62**
***PV* Total Social Costs ($ ha^{-1})**	**2048.64**	**2019.56**	**1991.23**	**1957.66**	**1917.97**	**1867.65**	**1810.02**	**1738.52**	**1656.11**	**1587.75**	**1464.40**	**1317.19**	**1147.11**	**925.64**
Private B/C Ratio	**0.122**	**0.122**	**0.122**	**0.121**	**0.122**	**0.122**	**0.124**	**0.126**	**0.130**	**0.151**	**0.161**	**0.175**	**0.217**	**0.263**
NPV Breakeven Timber Price ($ m^{-3})	8.42	8.45	8.48	8.50	8.48	8.42	8.32	8.16	7.93	7.12	6.70	6.15	4.78	3.93
Land Converted (ha)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Social B/C Ratio	**0.377**	**0.376**	**0.375**	**0.376**	**0.377**	**0.381**	**0.386**	**0.395**	**0.407**	**0.471**	**0.501**	**0.548**	**0.678**	**0.826**
NPV Breakeven Timber Price ($ m^{-3})	6.71	6.74	6.78	6.80	6.80	6.74	6.64	5.96	5.73	5.42	5.00	3.86	3.18	2.31
Land Converted (ha)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: Author's estimation

Table H. 3: Crop systems: Scenarios 1a & 1b - Carbon value of $33.55 tonne C^{-1}

Soil Class	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*O*	*P*
Harvest Year	11	11	11	11	11	11	11	11	11	12	12	12	14	14
PV Timber Price ($ m^{-3})	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.08	1.08	1.08	1.03	1.03
***PV* Private Benefits ($ ha^{-1})**														
Timber Revenue	250.84	246.40	241.95	237.51	233.07	228.62	224.18	219.74	215.29	240.40	235.59	230.78	248.36	243.58
PV Total Private Benefits ($ ha^{-1})	***250.84***	***246.40***	***241.95***	***237.51***	***233.07***	***228.62***	***224.18***	***219.74***	***215.29***	***240.40***	***235.59***	***230.78***	***248.36***	***243.58***
***PV* Private Costs ($ ha^{-1})**														
Afforestation Costs	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1720.02	1720.02	1720.02	1764.75	1764.75
Opportunity Cost of Crop Systems	350.89	321.80	293.47	259.91	220.21	169.90	112.26	40.76	-41.64	-132.27	-255.62	-402.84	-617.64	-839.12
PV Total Private Costs ($ ha^{-1})	***2048.64***	***2019.56***	***1991.23***	***1957.66***	***1917.97***	***1867.65***	***1810.02***	***1738.52***	***1656.11***	***1587.75***	***1464.40***	***1317.19***	***1147.11***	***925.64***
***PV* Social Benefits ($ ha^{-1})**														
Carbon Value	644.97	633.55	622.12	610.70	599.27	587.85	576.42	565.00	553.57	618.13	605.75	593.38	638.59	626.30
Wildlife Viewing	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	17.26	17.26	17.26	18.87	18.87
Hunting	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.81	14.81	14.81	16.19	16.19
Conservation	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	58.95	58.95	58.95	64.46	64.46
PV Total Social Benefits ($ ha^{-1})	***731.73***	***720.31***	***708.88***	***697.46***	***686.03***	***674.61***	***663.18***	***651.76***	***640.33***	***709.15***	***696.78***	***684.41***	***738.11***	***725.83***
***PV* Total Social Benefits ($ ha^{-1})**	**982.57**	**966.70**	**950.83**	**934.97**	**919.10**	**903.23**	**887.36**	**871.49**	**855.63**	**949.55**	**932.37**	**915.18**	**986.47**	**969.41**
***PV* Total Social Costs ($ ha^{-1})**	**2048.64**	**2019.56**	**1991.23**	**1957.66**	**1917.97**	**1867.65**	**1810.02**	**1738.52**	**1656.11**	**1587.75**	**1464.40**	**1317.19**	**1147.11**	**925.64**
Private B/C Ratio	**0.122**	**0.122**	**0.122**	**0.121**	**0.122**	**0.122**	**0.124**	**0.126**	**0.130**	**0.151**	**0.161**	**0.175**	**0.217**	**0.263**
NPV Breakeven Timber Price ($ m^{-3})	8.42	8.45	8.48	8.50	8.48	8.42	8.32	8.16	7.93	7.12	6.70	6.15	4.78	3.93
Land Converted (ha)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Social B/C Ratio	**0.480**	**0.479**	**0.478**	**0.478**	**0.479**	**0.484**	**0.490**	**0.501**	**0.517**	**0.598**	**0.637**	**0.695**	**0.860**	**1.047**
NPV Breakeven Timber Price ($ m^{-3})	5.76	5.79	5.84	5.85	5.85	5.79	5.69	5.10	4.86	4.56	4.13	2.96	2.27	1.40
Land Converted (ha)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4730.77

Source: Author's estimation

Table H. 4: Crop systems: Scenarios 2a & 2b - Carbon value of $7.74 tonne C^{-1}

Soil Class	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*O*	*P*
Harvest Year	11	11	11	11	11	11	11	11	11	12	12	12	14	14
PV Timber Price ($ m^{-3})	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.08	1.08	1.08	1.03	1.03
***PV* Private Benefits ($ ha^{-1})**														
Timber Revenue	250.84	246.40	241.95	237.51	233.07	228.62	224.18	219.74	215.29	240.40	235.59	230.78	248.36	243.58
PV Total Private Benefits ($ ha^{-1})	***250.84***	***246.40***	***241.95***	***237.51***	***233.07***	***228.62***	***224.18***	***219.74***	***215.29***	***240.40***	***235.59***	***230.78***	***248.36***	***243.58***
***PV* Private Costs ($ ha^{-1})**														
Afforestation Costs	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1720.02	1720.02	1720.02	1764.75	1764.75
Opportunity Cost of Crop Systems	350.89	321.80	293.47	259.91	220.21	169.90	112.26	40.76	-41.64	-132.27	-255.62	-402.84	-617.64	-839.12
PV Total Private Costs ($ ha^{-1})	***2048.64***	***2019.56***	***1991.23***	***1957.66***	***1917.97***	***1867.65***	***1810.02***	***1738.52***	***1656.11***	***1587.75***	***1464.40***	***1317.19***	***1147.11***	***925.64***
***PV* Social Benefits ($ ha^{-1})**														
Carbon Value	233.61	229.47	225.33	221.19	217.06	212.92	208.78	204.64	200.50	223.89	219.40	214.92	231.30	226.85
Wildlife Viewing	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	17.26	17.26	17.26	18.87	18.87
Hunting	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.81	14.81	14.81	16.19	16.19
Conservation	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	58.95	58.95	58.95	64.46	64.46
PV Total Social Benefits ($ ha^{-1})	***320.37***	***316.23***	***312.09***	***307.95***	***303.82***	***299.68***	***295.54***	***291.40***	***287.26***	***314.91***	***310.43***	***305.95***	***330.82***	***326.37***
***PV* Total Social Benefits ($ ha^{-1})**	**571.21**	**562.63**	**554.05**	**545.46**	**536.88**	**528.30**	**519.72**	**511.14**	**502.56**	**555.31**	**546.02**	**536.72**	**579.18**	**569.95**
***PV* Total Social Costs ($ ha^{-1})**	**2048.64**	**2019.56**	**1991.23**	**1957.66**	**1917.97**	**1867.65**	**1810.02**	**1738.52**	**1656.11**	**1587.75**	**1464.40**	**1317.19**	**1147.11**	**925.64**
Private B/C Ratio	**0.122**	**0.122**	**0.122**	**0.121**	**0.122**	**0.122**	**0.124**	**0.126**	**0.130**	**0.151**	**0.161**	**0.175**	**0.217**	**0.263**
NPV Breakeven Timber Price ($ m^{-3})	8.42	8.45	8.48	8.50	8.48	8.42	8.32	8.16	7.93	7.12	6.70	6.15	4.78	3.93
Land Converted (ha)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Social B/C Ratio	**0.279**	**0.279**	**0.278**	**0.279**	**0.280**	**0.283**	**0.287**	**0.294**	**0.303**	**0.350**	**0.373**	**0.407**	**0.505**	**0.616**
NPV Breakeven Timber Price ($ m^{-3})	7.61	7.65	7.69	7.71	7.70	7.64	7.54	6.79	6.55	6.25	5.82	4.72	4.04	3.17
Land Converted (ha)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: Author's estimation

Explanatory Notes for Table H.4, Table H.5 and Table H.6:

1. All explanatory notes from Table H.1 remain the same with the exceptions noted below.
2. For these three scenarios more than one rotation period is assumed which implies the producer would replant the land to trees once harvest occurs. This has significant implications for the carbon values under each of the scenarios as an infinite rotation length is assumed. The carbon value will be based on the total above ground biomass (including the bole) as this will result in an infinite net increase in carbon sequestered (refer to Chapter Five, Section 5.5 and Appendix B).
3. Carbon Value (Table H.4) – The value of carbon is \$7.75 tonne C^{-1}.
4. Carbon Value (Table H.5) – The value of carbon is \$22.58 tonne C^{-1}.
5. Carbon Value (Table H.6) – The value of carbon is \$33.55 tonne C^{-1}.

Table H. 5: Crop systems: Scenarios 2a & 2b - Carbon value of $22.58 tonne C^{-1}

Soil Class	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*O*	*P*
Harvest Year	11	11	11	11	11	11	11	11	11	12	12	12	14	14
PV Timber Price ($ m^{-3})	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.08	1.08	1.08	1.03	1.03
***PV* Private Benefits ($ ha^{-1})**														
Timber Revenue	250.84	246.40	241.95	237.51	233.07	228.62	224.18	219.74	215.29	240.40	235.59	230.78	248.36	243.58
PV Total Private Benefits ($ ha^{-1})	***250.84***	***246.40***	***241.95***	***237.51***	***233.07***	***228.62***	***224.18***	***219.74***	***215.29***	***240.40***	***235.59***	***230.78***	***248.36***	***243.58***
***PV* Private Costs ($ ha^{-1})**														
Afforestation Costs	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1720.02	1720.02	1720.02	1764.75	1764.75
Opportunity Cost of Crop Systems	350.89	321.80	293.47	259.91	220.21	169.90	112.26	40.76	-41.64	-132.27	-255.62	-402.84	-617.64	-839.12
PV Total Private Costs ($ ha^{-1})	***2048.64***	***2019.56***	***1991.23***	***1957.66***	***1917.97***	***1867.65***	***1810.02***	***1738.52***	***1656.11***	***1587.75***	***1464.40***	***1317.19***	***1147.11***	***925.64***
***PV* Social Benefits ($ ha^{-1})**														
Carbon Value	673.82	661.75	649.67	637.60	625.53	613.46	601.39	589.31	628.38	653.14	640.07	627.00	674.76	661.78
Wildlife Viewing	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	17.26	17.26	17.26	18.87	18.87
Hunting	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.81	14.81	14.81	16.19	16.19
Conservation	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	58.95	58.95	58.95	64.46	64.46
PV Total Social Benefits ($ ha^{-1})	***760.58***	***748.51***	***736.44***	***724.36***	***712.29***	***700.22***	***688.15***	***676.08***	***715.14***	***744.17***	***731.10***	***718.02***	***774.29***	***761.31***
***PV* Total Social Benefits ($ ha^{-1})**	**1011.42**	**994.90**	**978.39**	**961.87**	**945.36**	**928.84**	**912.33**	**895.81**	**930.43**	**984.57**	**966.68**	**948.80**	**1022.65**	**1004.89**
***PV* Total Social Costs ($ ha^{-1})**	**2048.64**	**2019.56**	**1991.23**	**1957.66**	**1917.97**	**1867.65**	**1810.02**	**1738.52**	**1656.11**	**1587.75**	**1464.40**	**1317.19**	**1147.11**	**925.64**
Private B/C Ratio	**0.122**	**0.122**	**0.122**	**0.121**	**0.122**	**0.122**	**0.124**	**0.126**	**0.130**	**0.151**	**0.161**	**0.175**	**0.217**	**0.263**
NPV Breakeven Timber Price ($ m^{-3})	8.42	8.45	8.48	8.50	8.48	8.42	8.32	8.16	7.93	7.12	6.70	6.15	4.78	3.93
Land Converted (ha)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Social B/C Ratio	**0.494**	**0.493**	**0.491**	**0.491**	**0.493**	**0.497**	**0.504**	**0.515**	**0.562**	**0.620**	**0.660**	**0.720**	**0.891**	**1.086**
NPV Breakeven Timber Price ($ m^{-3})	5.59	5.63	5.67	5.69	5.68	5.62	5.53	4.95	4.71	4.41	3.98	2.80	2.11	1.24
Land Converted (ha)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4730.77

Source: Author's estimation

Table H. 6: Crop systems: Scenarios 2a & 2b - Carbon value of $33.55 tonne C^{-1}

Soil Class	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*O*	*P*
Harvest Year	11	11	11	11	11	11	11	11	11	12	12	12	14	14
PV Timber Price ($ m^{-3})	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.08	1.08	1.08	1.03	1.03
***PV* Private Benefits ($ ha^{-1})**														
Timber Revenue	250.84	246.40	241.95	237.51	233.07	228.62	224.18	219.74	215.29	240.40	235.59	230.78	248.36	243.58
PV Total Private Benefits ($ ha^{-1})	***250.84***	***246.40***	***241.95***	***237.51***	***233.07***	***228.62***	***224.18***	***219.74***	***215.29***	***240.40***	***235.59***	***230.78***	***248.36***	***243.58***
***PV* Private Costs ($ ha^{-1})**														
Afforestation Costs	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1720.02	1720.02	1720.02	1764.75	1764.75
Opportunity Cost of Crop Systems	350.89	321.80	293.47	259.91	220.21	169.90	112.26	40.76	-41.64	-132.27	-255.62	-402.84	-617.64	-839.12
PV Total Private Costs ($ ha^{-1})	***2048.64***	***2019.56***	***1991.23***	***1957.66***	***1917.97***	***1867.65***	***1810.02***	***1738.52***	***1656.11***	***1587.75***	***1464.40***	***1317.19***	***1147.11***	***925.64***
***PV* Social Benefits ($ ha^{-1})**														
Carbon Value	1012.60	994.67	976.73	958.79	940.86	922.92	904.98	887.05	869.11	970.46	951.03	931.61	1002.58	983.30
Wildlife Viewing	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	17.26	17.26	17.26	18.87	18.87
Hunting	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.81	14.81	14.81	16.19	16.19
Conservation	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	58.95	58.95	58.95	64.46	64.46
PV Total Social Benefits ($ ha^{-1})	***1099.36***	***1081.43***	***1063.49***	***1045.55***	***1027.62***	***1009.68***	***991.74***	***973.81***	***955.87***	***1061.48***	***1042.06***	***1022.64***	***1102.11***	***1082.82***
***PV* Total Social Benefits ($ ha^{-1})**	**1350.20**	**1327.82**	**1305.44**	**1283.06**	**1260.68**	**1238.30**	**1215.92**	**1193.54**	**1171.16**	**1301.88**	**1277.65**	**1253.41**	**1350.46**	**1326.40**
***PV* Total Social Costs ($ ha^{-1})**	**2048.64**	**2019.56**	**1991.23**	**1957.66**	**1917.97**	**1867.65**	**1810.02**	**1738.52**	**1656.11**	**1587.75**	**1464.40**	**1317.19**	**1147.11**	**925.64**
Private B/C Ratio	**0.122**	**0.122**	**0.122**	**0.121**	**0.122**	**0.122**	**0.124**	**0.126**	**0.130**	**0.151**	**0.161**	**0.175**	**0.217**	**0.263**
NPV Breakeven Timber Price ($ m^{-3})	8.42	8.45	8.48	8.50	8.48	8.42	8.32	8.16	7.93	7.12	6.70	6.15	4.78	3.93
Land Converted (ha)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Social B/C Ratio	**0.659**	**0.657**	**0.656**	**0.655**	**0.657**	**0.663**	**0.672**	**0.687**	**0.707**	**0.820**	**0.872**	**0.952**	**1.177**	**1.433**
NPV Breakeven Timber Price ($ m^{-3})	4.10	4.14	4.18	4.20	4.19	4.13	4.04	3.59	3.35	3.05	2.62	1.38	0.69	-0.18
Land Converted (ha)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11838.87	4730.77

Source: Author’s estimation

Table H. 7: Crop systems: Scenarios 3a & 3b - Carbon value of $7.75 tonne C^{-1}

Soil Class	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*O*	*P*
Harvest Year	11	11	11	11	11	11	11	11	11	12	12	13	13	14
PV Timber Price ($ m^{-3})	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.08	1.08	1.11	1.11	1.03
***PV* Private Benefits ($ ha^{-1})**														
Timber Revenue	250.84	246.40	241.95	237.51	233.07	228.62	224.18	219.74	215.29	240.40	235.59	256.63	251.55	243.58
PV Total Private Benefits ($ ha^{-1})	148.80	146.16	143.52	140.89	138.25	135.62	132.98	130.35	127.71	142.60	139.75	152.23	149.21	144.49
	399.63	***392.56***	***385.48***	***378.40***	***371.32***	***364.24***	***357.16***	***350.08***	***343.00***	***383.00***	***375.34***	***408.86***	***400.76***	***388.07***
***PV* Private Costs ($ ha^{-1})**														
Afforestation Costs														
Opportunity Cost of Crop Systems	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1720.02	1720.02	1743.13	1743.13	1764.75
PV Total Private Costs ($ ha^{-1})	350.89	321.80	293.47	259.91	220.21	169.90	112.26	40.76	-41.64	-132.27	-255.62	-413.06	-591.46	-839.12
	2048.64	***2019.56***	***1991.23***	***1957.66***	***1917.97***	***1867.65***	***1810.02***	***1738.52***	***1656.11***	***1587.75***	***1464.40***	***1330.07***	***1151.67***	***925.64***
***PV* Social Benefits ($ ha^{-1})**														
Carbon Value														
Wildlife Viewing	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	17.26	17.26	18.10	17.26	18.87
Hunting	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.81	14.81	15.53	15.53	16.19
Conservation	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	58.95	58.95	61.81	64.46	64.46
PV Total Social Benefits ($ ha^{-1})	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***91.03***	***91.03***	***95.43***	***97.25***	***99.53***
***PV* Total Social Benefits ($ ha^{-1})**	**486.40**	**479.32**	**472.24**	**465.16**	**458.08**	**451.00**	**443.92**	**436.84**	**429.76**	**474.03**	**466.36**	**504.29**	**498.01**	**487.59**
***PV* Total Social Costs ($ ha^{-1})**	**2048.64**	**2019.56**	**1991.23**	**1957.66**	**1917.97**	**1867.65**	**1810.02**	**1738.52**	**1656.11**	**1587.75**	**1464.40**	**1330.07**	**1151.67**	**925.64**
Private B/C Ratio	**0.195**	**0.194**	**0.194**	**0.193**	**0.194**	**0.195**	**0.197**	**0.201**	**0.207**	**0.241**	**0.256**	**0.307**	**0.348**	**0.419**
NPV Breakeven Timber Price ($ m^{-3})	7.81	7.84	7.87	7.89	7.87	7.81	7.71	7.54	7.32	6.48	6.06	5.12	4.44	3.63
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Social B/C Ratio	**0.237**	**0.237**	**0.237**	**0.238**	**0.239**	**0.241**	**0.245**	**0.251**	**0.260**	**0.299**	**0.318**	**0.379**	**0.432**	**0.527**
NPV Breakeven Timber Price ($ m^{-3})	7.45	7.47	7.50	7.51	7.49	7.42	7.31	7.14	6.90	6.07	5.65	4.70	4.02	2.90
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Author's estimation

Explanatory Notes for Table H.7, Table H.8 and Table H.9:

1. All the notes from Table H.1 remain the same with the following exceptions.
2. In these three scenarios the value of carbon will be from the private perspective. The producers will receive compensation for carbon sequestered in the bole and consequently there will be no additional benefit from society for the carbon sequestered.
3. Harvest Year – The harvest year under each of these scenarios incorporates the bole carbon payment in determination of the optimal rotation length. Equation 5.5 is used to determine the optimal rotation length with the carbon payment to producers (refer Chapter Five, Section 5.6).
4. Carbon Payment – The *PV* of the carbon payment is determined by multiplying the *PV* of carbon under each of the three prices by the carbon sequestered in the bole (refer to Appendix B).
5. *NPV* Breakeven Timber Price – The breakeven analysis for timber prices under the private B/C analysis is the breakeven timber price given that the carbon payment is made to producers.

Explanatory Notes for Table H.10, Table H.11 and Table H.12:

1. All the notes from Table H.1 remain the same with the following exceptions.
2. For these three scenarios more than one rotation period is assumed which implies the producer would replant the land to trees once harvest occurs. This has significant implications for the carbon values under each of the scenarios as an infinite rotation length is assumed. The carbon value will be based on the total above ground biomass (including the bole) as this will result in an infinite net increase in carbon sequestered (refer to Chapter Five, Section 5.5 and Appendix B).
3. In these three scenarios the value of carbon will be from the private perspective. The producers will receive compensation for the carbon sequestered in the total above ground biomass (including the bole) and consequently there will be no additional benefit from society for the carbon sequestered.
4. Harvest Year – The harvest year under each of these scenarios incorporates the total above ground biomass carbon payment in determination of the optimal rotation length. Equation 5.5 is used to determine the optimal rotation length with the carbon payment to producers (refer Chapter Five, Section 5.6).
5. Carbon Payment – The *PV* of the carbon payment is determined by multiplying the *PV* of carbon under each of the three prices by the carbon sequestered in the total above ground biomass (refer to Appendix B).

Table H. 8: Crop systems: Scenarios 3a & 3b - Carbon value of \$22.58 tonne C^{-1}

Soil Class	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*O*	*P*
Harvest Year	11	11	11	11	11	11	11	11	12	12	12	13	13	13
PV Timber Price (\$ m^{-3})	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.08	1.08	1.08	1.11	1.11	1.11
***PV* Private Benefits (\$ ha^{-1})**														
Timber Revenue	250.84	246.40	241.95	237.51	233.07	228.62	224.18	219.74	245.21	240.40	235.59	256.63	251.55	246.46
PV Total Private Benefits (\$ ha^{-1})	434.08	426.39	418.70	411.01	403.32	395.64	387.95	380.26	424.34	416.01	407.69	444.10	435.30	426.51
	684.92	***672.79***	***660.66***	***648.52***	***636.39***	***624.26***	***612.13***	***599.99***	***669.55***	***656.41***	***643.28***	***700.73***	***686.85***	***672.97***
***PV* Private Costs (\$ ha^{-1})**														
Afforestation Costs														
Opportunity Cost of Crop Systems	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1720.02	1720.02	1720.02	1743.13	1743.13	1743.13
PV Total Private Costs (\$ ha^{-1})	350.89	321.80	293.47	259.91	220.21	169.90	112.26	40.76	-32.01	-132.27	-255.62	-413.06	-591.46	-803.74
	2048.64	***2019.56***	***1991.23***	***1957.66***	***1917.97***	***1867.65***	***1810.02***	***1738.52***	***1688.01***	***1587.75***	***1464.40***	***1330.07***	***1151.67***	***939.39***
***PV* Social Benefits (\$ ha^{-1})**														
Carbon Value														
Wildlife Viewing	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	17.26	17.26	17.26	18.10	18.10	18.10
Hunting	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.81	14.81	14.81	15.53	15.53	15.53
Conservation	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	58.95	58.95	58.95	61.81	61.81	61.81
PV Total Social Benefits (\$ ha^{-1})	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***91.03***	***91.03***	***91.03***	***95.43***	***95.43***	***95.43***
***PV* Total Social Benefits (\$ ha^{-1})**	**771.68**	**759.55**	**747.42**	**735.28**	**723.15**	**711.02**	**698.89**	**686.75**	**760.58**	**747.44**	**734.30**	**796.16**	**782.28**	**768.40**
***PV* Total Social Costs (\$ ha^{-1})**	**2048.64**	**2019.56**	**1991.23**	**1957.66**	**1917.97**	**1867.65**	**1810.02**	**1738.52**	**1688.01**	**1587.75**	**1464.40**	**1330.07**	**1151.67**	**939.39**
Private B/C Ratio	**0.334**	**0.333**	**0.332**	**0.331**	**0.332**	**0.334**	**0.338**	**0.345**	**0.397**	**0.413**	**0.439**	**0.527**	**0.596**	**0.716**
NPV Breakeven Timber Price (\$ m^{-3})	6.64	6.67	6.70	6.71	6.70	6.64	6.54	6.37	5.56	5.26	4.84	3.85	3.17	2.32
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Social B/C Ratio	**0.377**	**0.376**	**0.375**	**0.376**	**0.377**	**0.381**	**0.386**	**0.395**	**0.451**	**0.471**	**0.501**	**0.599**	**0.679**	**0.818**
NPV Breakeven Timber Price (\$ m^{-3})	6.28	6.30	6.33	6.34	6.32	6.25	6.14	5.96	5.16	4.85	4.42	3.43	2.75	1.89
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Author's estimation

Table H. 9: Crop systems: Scenarios 3a & 3b - Carbon value of \$33.55 tonne C^{-1}

Soil Class	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*O*	*P*
Harvest Year	11	11	11	11	11	11	11	11	12	12	12	13	13	13
PV Timber Price (\$ m^{-3})	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.08	1.08	1.08	1.11	1.11	1.11
***PV* Private Benefits (\$ ha^{-1})**														
Timber Revenue	250.84	246.40	241.95	237.51	233.07	228.62	224.18	219.74	245.21	240.40	235.59	256.63	251.55	246.46
PV Total Private Benefits (\$ ha^{-1})	644.97	633.55	622.12	610.70	599.27	587.85	576.42	565.00	630.50	618.13	605.75	659.86	646.79	633.71
	895.81	***879.94***	***864.07***	***848.21***	***832.34***	***816.47***	***800.60***	***784.73***	***875.71***	***858.53***	***841.34***	***916.49***	***898.33***	***880.17***
***PV* Private Costs (\$ ha^{-1})**														
Afforestation Costs														
Opportunity Cost of Crop Systems	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1720.02	1720.02	1720.02	1743.13	1743.13	1743.13
PV Total Private Costs (\$ ha^{-1})	350.89	321.80	293.47	259.91	220.21	169.90	112.26	40.76	-32.01	-132.27	-255.62	-413.06	-591.46	-803.74
	2048.64	***2019.56***	***1991.23***	***1957.66***	***1917.97***	***1867.65***	***1810.02***	***1738.52***	***1688.01***	***1587.75***	***1464.40***	***1330.07***	***1151.67***	***939.39***
***PV* Social Benefits (\$ ha^{-1})**														
Carbon Value														
Wildlife Viewing	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	17.26	17.26	17.26	18.10	18.10	18.10
Hunting	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.81	14.81	14.81	15.53	15.53	15.53
Conservation	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	58.95	58.95	58.95	61.81	61.81	61.81
PV Total Social Benefits (\$ ha^{-1})	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***91.03***	***91.03***	***91.03***	***95.43***	***95.43***	***95.43***
***PV* Total Social Benefits (\$ ha^{-1})**	**982.57**	**966.70**	**950.83**	**934.97**	**919.10**	**903.23**	**887.36**	**871.49**	**966.73**	**949.55**	**932.37**	**1011.92**	**993.76**	**975.61**
***PV* Total Social Costs (\$ ha^{-1})**	**2048.64**	**2019.56**	**1991.23**	**1957.66**	**1917.97**	**1867.65**	**1810.02**	**1738.52**	**1688.01**	**1587.75**	**1464.40**	**1330.07**	**1151.67**	**939.39**
Private B/C Ratio	**0.437**	**0.436**	**0.434**	**0.433**	**0.434**	**0.437**	**0.442**	**0.451**	**0.519**	**0.541**	**0.575**	**0.689**	**0.780**	**0.937**
NPV Breakeven Timber Price (\$ m^{-3})	5.77	5.80	5.83	5.85	5.83	5.77	5.67	5.51	4.65	4.35	3.93	2.91	2.24	1.38
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Social B/C Ratio	**0.480**	**0.479**	**0.478**	**0.478**	**0.479**	**0.484**	**0.490**	**0.501**	**0.573**	**0.598**	**0.637**	**0.761**	**0.863**	**1.039**
NPV Breakeven Timber Price (\$ m^{-3})	5.41	5.44	5.46	5.47	5.45	5.38	5.27	5.10	4.25	3.94	3.51	2.50	1.81	0.95
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	4730.77

Source: Author's estimation

Table H. 10: Crop systems: Scenarios 4a & 4b - Carbon value of $7.75 tonne C^{-1}

Soil Class	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*O*	*P*
Harvest Year	11	11	11	11	11	11	11	11	11	12	12	13	13	14
PV Timber Price ($ m^{-3})	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.08	1.08	1.11	1.11	1.03
***PV* Private Benefits ($ ha^{-1})**														
Timber Revenue	250.84	246.40	241.95	237.51	233.07	228.62	224.18	219.74	215.29	240.40	235.59	256.63	251.55	243.58
PV Total Private Benefits ($ ha^{-1})	233.61	229.47	225.33	221.19	217.06	212.92	208.78	204.64	200.50	223.89	219.40	239.00	234.27	226.85
	484.45	***475.87***	***467.28***	***458.70***	***450.12***	***441.54***	***432.96***	***424.38***	***415.80***	***464.28***	***454.99***	***495.63***	***485.81***	***470.43***
***PV* Private Costs ($ ha^{-1})**														
Afforestation Costs														
Opportunity Cost of Crop Systems	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1720.02	1720.02	1743.13	1743.13	1764.75
PV Total Private Costs ($ ha^{-1})	350.89	321.80	293.47	259.91	220.21	169.90	112.26	40.76	-41.64	-132.27	-255.62	-413.06	-591.46	-839.12
	2048.64	***2019.56***	***1991.23***	***1957.66***	***1917.97***	***1867.65***	***1810.02***	***1738.52***	***1656.11***	***1587.75***	***1464.40***	***1330.07***	***1151.67***	***925.64***
***PV* Social Benefits ($ ha^{-1})**														
Carbon Value														
Wildlife Viewing	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	17.26	17.26	18.10	18.10	18.87
Hunting	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.81	14.81	15.53	15.53	16.19
Conservation	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	58.95	58.95	61.81	61.81	64.46
PV Total Social Benefits ($ ha^{-1})	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***91.03***	***91.03***	***95.43***	***95.43***	***99.53***
***PV* Total Social Benefits ($ ha^{-1})**	**571.21**	**562.63**	**554.05**	**545.46**	**536.88**	**528.30**	**519.72**	**511.14**	**502.56**	**555.31**	**546.02**	**591.06**	**581.24**	**569.95**
***PV* Total Social Costs ($ ha^{-1})**	**2048.64**	**2019.56**	**1991.23**	**1957.66**	**1917.97**	**1867.65**	**1810.02**	**1738.52**	**1656.11**	**1587.75**	**1464.40**	**1330.07**	**1151.67**	**925.64**
Private B/C Ratio	**0.236**	**0.236**	**0.235**	**0.234**	**0.235**	**0.236**	**0.239**	**0.244**	**0.251**	**0.292**	**0.311**	**0.373**	**0.422**	**0.508**
NPV Breakeven Timber Price ($ m^{-3})	7.46	7.49	7.52	7.54	7.52	7.46	7.36	7.20	6.97	6.12	5.70	4.74	4.06	2.97
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Social B/C Ratio	**0.279**	**0.279**	**0.278**	**0.279**	**0.280**	**0.283**	**0.287**	**0.294**	**0.303**	**0.350**	**0.373**	**0.444**	**0.505**	**0.616**
NPV Breakeven Timber Price ($ m^{-3})	7.10	7.13	7.15	7.16	7.14	7.07	6.96	6.79	6.55	5.71	5.28	4.32	3.64	2.55
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Author's estimation

Table H. 11: Crop systems: Scenarios 4a & 4b - Carbon value of \$22.58 tonne C^{-1}

Soil Class	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*O*	*P*
Harvest Year	11	11	11	11	11	11	11	11	12	12	12	13	13	13
PV Timber Price (\$ m^{-3})	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.08	1.08	1.08	1.11	1.11	1.11
***PV* Private Benefits (\$ ha^{-1})**														
Timber Revenue	250.84	246.40	241.95	237.51	233.07	228.62	224.18	219.74	245.21	240.40	235.59	256.63	251.55	246.46
PV Total Private Benefits (\$ ha^{-1})	681.51	669.44	657.36	645.29	633.22	621.15	609.08	597.00	666.22	653.14	640.07	697.24	683.43	669.61
	932.35	***915.83***	***899.32***	***882.80***	***866.29***	***849.77***	***833.26***	***816.74***	***911.43***	***893.54***	***875.66***	***953.87***	***934.97***	***916.07***
***PV* Private Costs (\$ ha^{-1})**														
Afforestation Costs														
Opportunity Cost of Crop Systems	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1720.02	1720.02	1720.02	1743.13	1743.13	1743.13
PV Total Private Costs (\$ ha^{-1})	350.89	321.80	293.47	259.91	220.21	169.90	112.26	40.76	-32.01	-132.27	-255.62	-413.06	-591.46	-803.74
	2048.64	***2019.56***	***1991.23***	***1957.66***	***1917.97***	***1867.65***	***1810.02***	***1738.52***	***1688.01***	***1587.75***	***1464.40***	***1330.07***	***1151.67***	***939.39***
***PV* Social Benefits (\$ ha^{-1})**														
Carbon Value														
Wildlife Viewing	16.45	16.45	16.45	16.45	16.45	16.45	16.45	16.45	17.26	17.26	17.26	18.10	18.10	18.10
Hunting	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.81	14.81	14.81	15.53	15.53	15.53
Conservation	56.19	56.19	56.19	56.19	56.19	56.19	56.19	56.19	58.95	58.95	58.95	61.81	61.81	61.81
PV Total Social Benefits (\$ ha^{-1})	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***91.03***	***91.03***	***91.03***	***95.43***	***95.43***	***95.43***
***PV* Total Social Benefits (\$ ha^{-1})**	**1019.11**	**1002.59**	**986.08**	**969.56**	**953.05**	**936.53**	**920.02**	**903.50**	**1002.45**	**984.57**	**966.68**	**1049.30**	**1030.40**	**1011.51**
***PV* Total Social Costs (\$ ha^{-1})**	**2048.64**	**2019.56**	**1991.23**	**1957.66**	**1917.97**	**1867.65**	**1810.02**	**1738.52**	**1688.01**	**1587.75**	**1464.40**	**1330.07**	**1151.67**	**939.39**
Private B/C Ratio	**0.455**	**0.453**	**0.452**	**0.451**	**0.452**	**0.455**	**0.460**	**0.470**	**0.540**	**0.563**	**0.598**	**0.717**	**0.812**	**0.975**
NPV Breakeven Timber Price (\$ m^{-3})	5.62	5.65	5.68	5.70	5.68	5.62	5.52	5.36	4.49	4.19	3.77	2.75	2.07	1.22
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Social B/C Ratio	**0.497**	**0.496**	**0.495**	**0.495**	**0.497**	**0.501**	**0.508**	**0.520**	**0.594**	**0.620**	**0.660**	**0.789**	**0.895**	**1.077**
NPV Breakeven Timber Price (\$ m^{-3})	5.26	5.29	5.31	5.32	5.30	5.23	5.12	4.95	4.09	3.78	3.36	2.33	1.65	0.79
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	4731

Source: Author's estimation

Table H. 12: Crop systems: Scenarios 4a & 4b - Carbon value of $33.55 tonne C^{-1}

Soil Class	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*O*	*P*
Harvest Year	11	11	11	11	11	11	11	12	12	12	12	13	13	13
PV Timber Price ($ m^{-3})	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.08	1.08	1.08	1.08	1.11	1.11	1.11
***PV* Private Benefits ($ ha^{-1})**														
Timber Revenue	250.84	246.40	241.95	237.51	233.07	228.62	224.18	250.02	245.21	240.40	235.59	256.63	251.55	246.46
PV Total Private Benefits ($ ha^{-1})	1012.60	994.67	976.73	958.79	940.86	922.92	904.98	1009.31	989.88	970.46	951.03	1035.98	1015.45	994.93
	1263.44	***1241.06***	***1218.68***	***1196.30***	***1173.92***	***1151.54***	***1129.16***	***1259.33***	***1235.09***	***1210.86***	***1186.62***	***1292.61***	***1267.00***	***1241.39***
***PV* Private Costs ($ ha^{-1})**														
Afforestation Costs														
Opportunity Cost of Crop Systems	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1697.76	1720.02	1720.02	1720.02	1720.02	1743.13	1743.13	1743.13
PV Total Private Costs ($ ha^{-1})	350.89	321.80	293.47	259.91	220.21	169.90	112.26	54.96	-32.01	-132.27	-255.62	-413.06	-591.46	-803.74
	2048.64	***2019.56***	***1991.23***	***1957.66***	***1917.97***	***1867.65***	***1810.02***	***1774.98***	***1688.01***	***1587.75***	***1464.40***	***1330.07***	***1151.67***	***939.39***
***PV* Social Benefits ($ ha^{-1})**														
Carbon Value														
Wildlife Viewing	16.45	16.45	16.45	16.45	16.45	16.45	16.45	17.26	17.26	17.26	17.26	18.10	18.10	18.10
Hunting	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.81	14.81	14.81	14.81	15.53	15.53	15.53
Conservation	56.19	56.19	56.19	56.19	56.19	56.19	56.19	58.95	58.95	58.95	58.95	61.81	61.81	61.81
PV Total Social Benefits ($ ha^{-1})	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***86.76***	***91.03***	***91.03***	***91.03***	***91.03***	***95.43***	***95.43***	***95.43***
***PV* Total Social Benefits ($ ha^{-1})**	**1350.20**	**1327.82**	**1305.44**	**1283.06**	**1260.68**	**1238.30**	**1215.92**	**1350.35**	**1326.12**	**1301.88**	**1277.65**	**1388.04**	**1362.43**	**1336.83**
***PV* Total Social Costs ($ ha^{-1})**	**2048.64**	**2019.56**	**1991.23**	**1957.66**	**1917.97**	**1867.65**	**1810.02**	**1774.98**	**1688.01**	**1587.75**	**1464.40**	**1330.07**	**1151.67**	**939.39**
Private B/C Ratio	**0.617**	**0.615**	**0.612**	**0.611**	**0.612**	**0.617**	**0.624**	**0.709**	**0.732**	**0.763**	**0.810**	**0.972**	**1.100**	**1.321**
NPV Breakeven Timber Price ($ m^{-3})	4.26	4.29	4.32	4.34	4.32	4.26	4.16	3.30	3.07	2.77	2.35	1.28	1.47	0.59
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	0	11839	4731
Social B/C Ratio	**0.659**	**0.657**	**0.656**	**0.655**	**0.657**	**0.663**	**0.672**	**0.761**	**0.786**	**0.820**	**0.872**	**1.044**	**1.183**	**1.423**
NPV Breakeven Timber Price ($ m^{-3})	3.90	3.92	3.95	3.96	3.94	3.87	3.76	2.91	2.67	2.36	1.93	0.86	0.18	-0.68
Land Converted (ha)	0	0	0	0	0	0	0	0	0	0	0	17716	11839	4731

Source: Author's estimation

Table H. 13: Pasture systems – Scenario 1a, 1b, 1c & 1d

	Social Carbon Value			*Private Carbon Value*		
Carbon Value	\$7.74 tonne C^{-1}	\$22.58 tonne C^{-1}	\$33.55 tonne C^{-1}	\$7.74 tonne C^{-1}	\$22.58 tonne C^{-1}	\$33.55 tonne C^{-1}
Harvest Year	11	11	11	12	12	12
PV Timber Price (\$ m^{-3})	1.03	1.03	1.03	1.08	1.08	1.08
PV Private Benefits (\$ ha^{-1})						
Timber Revenue	199.74	199.74	199.74	228.37	228.37	228.37
PV Total Private Benefits (\$ ha^{-1})	0.00	0.00	0.00	135.47	395.20	587.20
	199.74	199.74	199.74	363.84	623.57	815.57
PV Private Costs (\$ ha^{-1})						
Afforestation Costs						
Opportunity Cost of Crop Systems	1804.14	1804.14	1804.14	1826.41	1826.41	1826.41
PV Total Private Costs (\$ ha^{-1})	1323.62	1323.62	1323.62	1328.24	1328.24	1328.24
	3127.76	3127.76	3127.76	3154.65	3154.65	3154.65
PV Social Benefits (\$ ha^{-1})						
Carbon Value						
Wildlife Viewing	118.48	345.66	513.59	0.00	0.00	0.00
Hunting	28.77	28.77	28.77	30.18	30.18	30.18
Conservation	24.63	24.63	24.63	25.85	25.85	25.85
PV Total Social Benefits (\$ ha^{-1})	56.19	56.19	56.19	58.95	58.95	58.95
	228.08	455.25	623.18	114.98	114.98	114.98
PV Total Social Benefits (\$ ha^{-1})						
	427.82	654.99	822.92	478.82	738.55	930.55
PV Total Social Costs (\$ ha^{-1})						
	3127.76	3127.76	3127.76	3154.65	3154.65	3154.65
Private B/C Ratio						
NPV Breakeven Timber Price (\$ m^{-3})	0.064	0.064	0.064	0.115	0.198	0.259
Land Converted (ha)	16.14	16.14	16.14	14.26	13.03	12.12
	0.0	0.0	0.0	0.0	0.0	0.0
Social B/C Ratio						
NPV Breakeven Timber Price (\$ m^{-3})	0.137	0.209	0.263	0.152	0.234	0.295
Land Converted (ha)	14.99	13.82	12.95	13.74	12.51	11.61
Land Converted (ha)	0.0	0.0	0.0	0.0	0.0	0.0

Source: Author’s estimation

Explanatory Notes for Table H.13:

1. One rotation period is assumed under this scenario and once harvest occurs the land use will be based on the highest returns from the various potential enterprises.
2. It is assumed that the land classification for pastures is physically marginal and as a result the assumption is made that the land will have the same characteristics as the average for L, M, O and P soil classifications (refer to Chapter Five, Section 5.3.3.2).
3. Carbon Values – Table H.13 includes both the social carbon values and private carbon values. When the social carbon values are included the private carbon values are excluded and vise versa.
4. Harvest Year – The harvest year is calculated as the optimal rotation length, when either there is no carbon payment to producers and when there is a payment made.
5. Timber Revenue – Timber revenues are based on the *PV* price of standing timber and yield estimates from growth functions in Chapter Five, Section 5.5 based on the harvest year (refer to Appendix B for growth estimates).
6. Carbon Payment – The *PV* of the carbon payment is determined by multiplying the *PV* of carbon under each of the three prices by the carbon sequestered in the bole (refer to Appendix B for carbon sequestration estimates).
7. Afforestation Costs – The *PV* of afforestation costs are calculated for pasture systems depending on the appropriate harvest year. The afforestation costs for pasture systems differ from crop systems and the values are adjusted accordingly (refer to Chapter Five, Section 5.3.2.2 and Appendix G for annual *PV* of afforestation costs).
8. Opportunity Cost of Pasture Systems – The sum of the *NPV* of returns from pasture based on the harvest year are calculated as this is the opportunity cost of land in this scenario (refer to Appendix E for the *NPV* of the average annual returns for pasture systems).
9. *PV* Total Private Costs – This is the sum of the afforestation costs and opportunity costs of crop systems.
10. Carbon Value – The three social carbon values are used in this scenario. The assumption in note one implies the carbon value is calculated from the bole component of the tree only as after harvest the land may not be retained to afforestation (refer to Chapter Five, Section 5.5 and Appendix B).
11. Wildlife Viewing – This value is the sum of the *PV* of wildlife viewing values based on the appropriate harvest year (refer to Chapter Five, Section 5.4.1 and Appendix F).
12. Hunting – This value is the sum of the *PV* of hunting values based on the appropriate harvest year (refer to note 11).
13. Conservation – This value is the sum of the *PV* of conservation values based on harvest year (refer to note 11).
14. *PV* Total Social Benefits – This is the sum of the *PV* Total Private Benefits and *PV* Total Social Benefits.
15. *PV* Total Social Cost – This is the same as *PV* Total Private Costs as it was assumed there were no social costs resulting from afforestation (refer to Chapter Four, Section 4.3).

16. Private B/C Ratio – This is the ratio of *PV* Total Private Benefits to *PV* Total Private Costs.
17. *NPV* Breakeven Timber Price – This is the required timber price required to have a private B/C Ratio greater than one (refer to Appendix D for breakeven analysis).
18. Land Converted – This is the amount of land that potentially would be converted from the private perspective (private B/C ratio).
19. Social B/C Ratio – This is the ratio of *PV* Total Social Benefits to *PV* Total Social Costs.
20. *NPV* Breakeven Timber Price – This is the required timber to have a social B/C ratio greater than one.
21. Land Converted – This is the amount of land should be converted from the social perspective (social B/C ratio).

Explanatory Notes for Table H.14:

1. All the notes from Table H.13 hold with the exception of that under this scenario after harvest the trees will be replanted and there will be an infinite rotation.
2. The social and private carbon values will thus be based on the total above ground biomass (including the bole).

Table H. 14: Pasture systems – Scenario 2a, 2b, 2c & 2d

	Social Carbon Values			*Private Carbon Values*		
Carbon Value	*$7.74* tonne C-1	*$22.58* tonne C-1	*$33.55* tonne C-1	*$7.74* tonne C-1	*$22.58* tonne C-1	*$33.55* tonne C-1
Harvest Year	11	11	11	12	11	12
PV Timber Price ($ m^{-3})	1.03	1.03	1.03	1.08	1.03	1.08
***PV* Private Benefits ($ ha^{-1})**						
Timber Revenue	199.74	199.74	199.74	228.37	199.74	228.37
PV Total Private Benefits ($ ha^{-1})	0.00	0.00	0.00	212.68	542.68	921.90
	199.74	199.74	199.74	441.05	742.42	1150.27
***PV* Private Costs ($ ha^{-1})**						
Afforestation Costs						
Opportunity Cost of Crop Systems	1804.14	1804.14	1804.14	1826.41	1804.14	1826.41
PV Total Private Costs ($ ha^{-1})	1323.62	1323.62	1323.62	1328.24	1310.58	1328.24
	3127.76	3127.76	3127.76	3154.65	3114.73	3154.65
***PV* Social Benefits ($ ha^{-1})**						
Carbon Value						
Wildlife Viewing	182.87	533.48	792.67	0.00	0.00	0.00
Hunting	28.77	28.77	28.77	30.18	28.77	30.18
Conservation	24.63	24.63	24.63	25.85	24.63	25.85
PV Total Social Benefits ($ ha^{-1})	56.19	56.19	56.19	58.95	56.19	58.95
	292.47	643.08	902.26	114.98	109.60	114.98
***PV* Total Social Benefits ($ ha^{-1})**						
	492.21	842.82	1102.00	556.04	852.02	1265.25
***PV* Total Social Costs ($ ha^{-1})**						
	3127.76	3127.76	3127.76	3154.65	3114.73	3154.65
Private B/C Ratio						
NPV Breakeven Timber Price ($ m^{-3})	0.064	0.064	0.064	0.140	0.238	0.365
Land Converted (ha)	16.14	16.14	16.14	13.89	13.34	10.54
	0	0	0	0	0	0
Social B/C Ratio						
NPV Breakeven Timber Price ($ m^{-3})	0.157	0.269	0.352	0.176	0.274	0.401
Land Converted (ha)	14.64	12.80	11.44	13.37	12.80	10.02
Land Converted (ha)	0	0	0	0	0	0

Source: Author's estimation