Economic Analysis of Alternative Mechanical Harvesting Systems for Wild Blueberries

by

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ABSTRACT

The purpose of this study was to assess the economic impacts of small box and semi-automatic bin handling technologies for wild blueberries production in Nova Scotia. Wild blueberry mechanical harvesters with similar engineering configuration were evaluated. A first objective involved quantifying and comparing harvest efficiency and harvest rates of the alternative harvesting technologies. In addition, partial budgeting methods were used to evaluate the economics of switching from the small box to the semi-automatic bin handling system. Furthermore, the profitability of wild blueberry production was investigated for the two harvest handling technologies, with and without a Nova Scotia government cost-share program, and for alternative asset ownership scenarios. Semi-automatic bin handling system was 22% more field efficient in 2017 and 29% in 2018, than the small box system. Net change in profit was \$674 ha^{-1} in 2017 and \$176 ha^{-1} in 2018 when switching from the small box to bin handling technology.

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CHAPTER 1: INTRODUCTION

1.1 Background

The wild blueberry (*Vaccinium angustifolium* Ait.) is an important economic crop native to eastern North America (Agriculture and Agri-Food Canada (AAFC) 2016). A wide range of health benefits, including antioxidant (Kay and Holub 2002), anti-inflammatory and anti-aging properties (Beattie et al 2005) make the wild blueberry a unique berry, and have increased global demand, especially in high income industrialized countries (AAFC 2016).

Production of wild blueberries has increased significantly in Atlantic Canada and in the US state of Maine, especially during the last two decades (Yarborough 2012). Canada is the largest producer and exporter of wild blueberries in the world (AAFC 2016), with about 11.1% of Canada's production volume coming from Prince Edward Island, 23% from Nova Scotia, 28% from New Brunswick, and 37% from Quebec (Statistics Canada 2017). Wild blueberry production for Canada as a whole increased by 41.2% from 93,637 in 2015 to 132,235 tonnes in 2016. The increase in wild blueberry production resulted in a decrease in berry farm gate value from $110.5 million in 2015 to $90.7 million in 2016, representing a 17.9% decline (Statistics Canada 2017). Production of wild blueberries in Quebec, Atlantic Canada, and Maine has increased steadily since the 1990's (Figure 1.1). Improved land management, weed and pest management, better pruning techniques, increased pollination services and mechanization have contributed to the increase in wild blueberry production (Strik and Yarborough 2005; Yarborough 2004, 2012).

In 2016, wild blueberry acreage for Canada as a whole was 68,992 ha, with production at 132,235 tonnes (AAFC 2016; Statistics Canada 2017). Wild blueberry area under production has been increasing steadily since the early 1980s, following introduction of commerical mechanical harvesters (Farooque 2015). The increased acreage and production is due to a changing structure of wild blueberry production, from small family-farms to domination of large commercial and corporate farms in recent decades (Grevais et al 2001). Blueberry available consumption per capita in Canada increased from 1.06 kg per person in 2014 to 1.08 kg per person in 2016 (AAFC 2017).

Wild blueberry ranks first in Nova Scotia in terms of hectares, production, value and exports revenue, compared with other horticultural crops in the province (Wild Blueberry Producers Association of Nova Scotia (WBPANS) 2016; Statistics Canada 2017). In 2016, for example, 30,826 tonnes of wild blueberries were produced in Nova Scotia (WBPANS 2016).

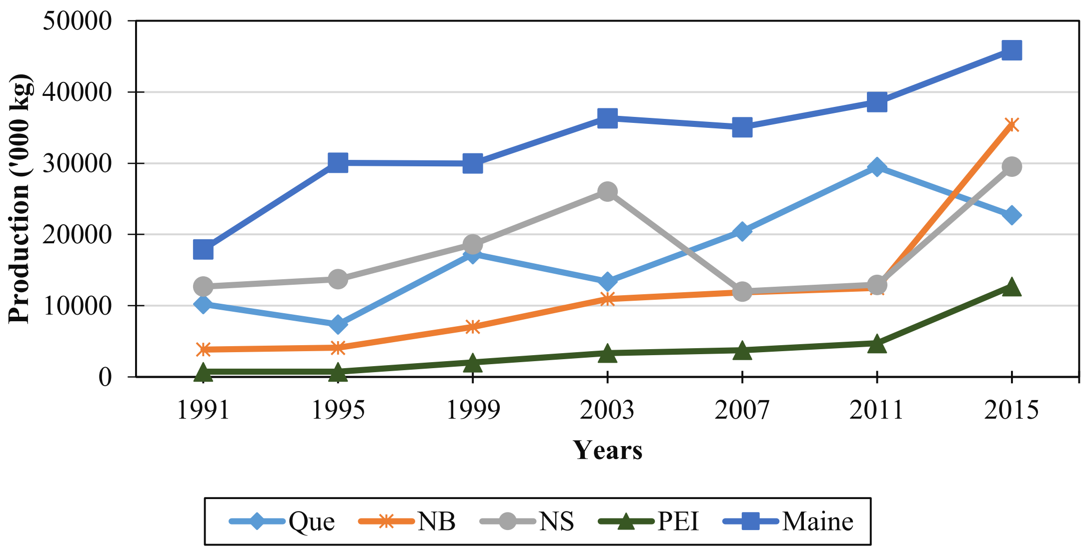

Figure: 1.1: Trends in wild blueberry production for selected Canadian Provinces and US state of Maine (1991-2015).
Data Source: Wild Blueberry Producers Association of Nova Scotia (2016) and Statistics Canada (2017).

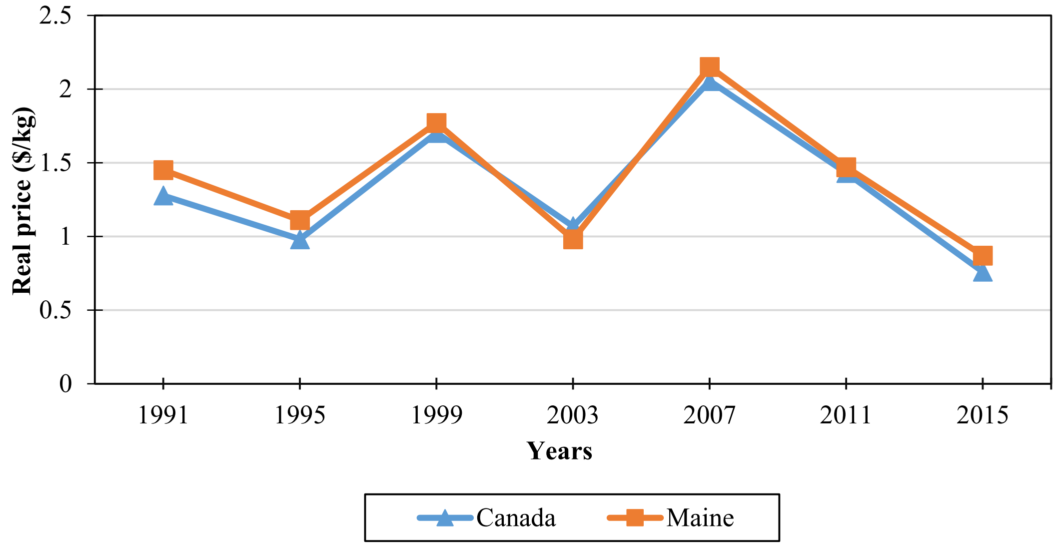

Figure: 1.2: Trends in wild blueberry real farm gate price for Canada and US state of Maine (1991-2015) in Canadian dollars.
Data Sources: Nominal prices were obtained from Wild Blueberry Producers Association of Nova Scotia (2017); Exchange rates were obtained from Bank of Canada (2018) and Statistics Canada (2012); CPI data were obtained from Statistics Canada (2018).
Notes:

1. Nominal farm gate prices for US state of Maine were converted from US$ to CAD$ using annual exchange-rate data.
2. Nominal prices were deflated to real farm gate prices (using Canadian CPI for Canadian prices, and US CPI for the prices for Maine.

Wild blueberries generated about $600 million in revenue in 2016 to Canada's national economy (AAFC 2016). In 2016, the wild blueberry sector generated about $100 million in revenue to Nova Scotia economy. Wild blueberries in Nova Scotia are exported mainly to United States, Japan, United Kingdom, and Germany (WBPANS 2016). Wild blueberry industry generates about 1,500 full time jobs in Nova Scotia annually, and the job opportunities further increases (by seasonal employment) during the berry harvesting season (WBPANS 2016).

Prices of wild blueberries received by farmers in Nova Scotia has been declining due to the increased production, especially during recent years. For example, farm gate price dropped from $1.32 per kg in 2014 to $0.66 to 2016 (Blois 2016). Price trends of wild blueberry in Quebec, Nova Scotia and US state of Maine tend to move together (Cheng et al 2000). Farm gate price of wild blueberries shows a fluctuating trend between 1991 and 2015 (Figure 1.2), due to fluctuations in production, adverse weather, and excess supply.

Despite the expansion in wild blueberry production in Atlantic Canada, the sector is facing various challenges, one of the most critical of which is declining availability of agricultural labour (Yarborough 2000). Traditionally, wild blueberries are harvested using hand-held metal rakes, with the rake design similar to cranberry scoops (Yarborough 2000). Harvesting using a metal rake is time inefficient and labour intensive. During the 1990s, berry picking efficiency using metal rake with skilled labour was about 80%, with 20-40% loss in berries depending on worker skill and experience (Kinsman 1993). Hand raking of berries is still practiced in small farmfields, and other fields with rock and rough terrain which cannot be harvested using a mechanical harvester (Yarborough and Hergeri 2010). Hand raked berries tend to have less berry damage and often sold fresh (Hu et al 2016). About 95% of wild blueberries produced in NS are frozen and processed while the remaining proportion is sold fresh (Larouche 2016). Hand raking is a labour intensive operation which increases harvesting cost (Yarborough and Hergeri 2010), and accounts for about 40% of total production cost (Esau 2017). Another complication with manual harvesting using hand rakers in wild blueberry fields is disruption from weeds which reduces the speed of raking, resulting in further harvest losses (Farooque et al 2014).

In the Maritimes, wild blueberries have a narrow time window for harvesting (Ali 2016), typically from August and ends in late September (WBPANS 2016). Availability of quality labour during harvest is a major challenge faced by growers (Jeffries 2010). Declining availability of skilled labour and the narrow time window for harvesting sometimes results in berries left unharvested in the fields, thereby resulting in lower average berry harvested (in terms of kg ha^{-1}) and revenue for growers. The short harvesting time window for the blueberry crop, along with the price-cost squeeze, and unavailability of skilled labour have prompted a need for labour-saving and production cost-reducing technologies such as mechanical harvester (Sibley et al 1993; Hu et al 2016).

Wild blueberry presents a relevant case for investigating economics of adopting mechanical harvesters. In Canada, more than 80% of wild blueberry fields are mechanically harvested. Initial studies have reported that variability in topography, variability in wild blueberry plant height, bare land, weed incidence, and debris are important compounding factors to the engineering and technical feasibility of wild blueberry mechanical harvesters (Yarborough 2000; Farooque et al 2014). Wild blueberry harvester can be cost-effective but also damages the berries and affects overall berry quality (Hall et al 1983; Marra et al 1989). A recent study revealed that high losses in wild blueberry mechanical harvesting is influenced by crop characteristics such as height, density, weeds incidence, and yield (Farooque et al 2014).

Introduction of precision agriculture (PA) technologies have significantly benefitted the wild blueberry industry in North America (Chang et al 2012). Engineering studies involving partnerships between industry and university precision agriculture scientists in Canada have resulted in engineering improvements in wild blueberry harvesters including: i) Optimizing harvester configuration (with 0.66 m harvester head, and 16 bar with 65 tooth configuration) to improve berry harvest efficiency and quality (Farooque et al 2014); ii) 0.66 m harvester head and wide conveyer has improved berry handling capacity; and iii) determination of optimum harvester ground speed of 0.31 ms^{-1} and head rotational speed of 19 rpm for 0.66 m diameter head in reducing berry losses (Farooque et al. 2014).

The rising production cost and declining farm gate price have remarkably decreased the profit margins for wild blueberry growers in Atlantic Canada. Excess supply from berry production

(Statistics Canada 2017) have not been matched with increased local consumer demand, and therefore significantly decreased the price and profit margins for farmers (Blois 2016). Options for sustaining the financial viability of the wild blueberry industry include reducing harvesting cost and increase production efficiency. Innovations in mechanical harvesters have the potential to help wild blueberry growers become competitive. However, the harvest efficiency and farm level profitability of the conventional small box system and modified bin handling system of harvesters have not been quantified and compared.

1.2 Economic Problem

The economic problem involves providing missing information to important market and economic agents, including; i) wild blueberry producers and processors; ii) commercial mechanical harvester manufacturers; and iii) government policy makers. The most economically viable wild blueberries mechanical harvesters will likely change overtime due to overall changes in economic conditions, availability of investment capital to farmers, relationships between output prices and input costs, new advances in technology and changes in government polices (Gallardo and Zilberman 2016).

During the past decade, there have been significant changes in the wild blueberry industry in Atlantic Canada with regard to the price/cost relationship due, in part, to increase in wild blueberry production and supply. Improving harvester efficiency require producers to adjust labour substitution and requirements, and obtain viable economic return on investments in mechanical harvesters. Growers who make such investments in harvesting equipment require technical knowledge of threshold (or break-even) crop acreage over which to spread the investment cost in order to generate profitable farm returns on such initial investments.

Improved mechanical harvesters have the potential to save on labour cost, mitigate risks of labour scarcity, and improve the opportunity to increase worker productivity (Gallardo and Zilberman 2016). Increased harvest efficiency has potential to decrease overall cost of production and increase profit margin for producers (Moseleya et al 2012). The economic viability of mechanical harvester to blueberry producer also depends on the blueberry price received, labour wages, and berry acreage harvested (Schmitz and Moss 2016), as well as berry damage and yield loss using one harvester compared with using alternative mechanical harvesting methods (Dalfsen and Gaye 1999). Thus, technical information on harvester efficiency and associated labour savings is required for prospective farmers considering purchasing a harvester or timing of the purchase decision.

Availability of labour is an important consideration for wild blueberry producers considering mechanical harvesting technologies, especially for the small box handling system which requires extra worker for manual handling (i.e., loading and unloading) of boxes. Wild blueberry harvesters with automated hydraulic bin handling systems have the potential to increase harvesting efficiency and labour savings, but may come at higher investment and harvesting costs compared with the small box handling systems.

There are also inherent risks associated with ownership and operation of the mechanical harvesters. Factors contributing to risks include cost and availability of farm labour, prices of inputs such as fuel, fertilizer and other chemicals, and fluctuations in berry prices received by farmers. Experience from introduction of mechanized commercial apple harvesters in US state of Washington suggest that commercial mobile platforms used for harvesting helped mitigate challenges of labour availability and high production cost (Lesser et al 2008), and also decreased harvest time by up to 15% (Zhang 2015). Besides labour cost-efficiency considerations, both producers and policy makers need to know the risks and impacts of labour use associated with alternative harvesting technologies.

Adoption of blueberry mechanical harvesters may be accelerated if such innovations are concurrently accompanied by related technologies or changes in government policies and regulations. A government farm business risk management program by the United States Department of Agriculture (USDA) involving buying excess wild blueberries in the local market helped to mitigate producer price declines in Maine, during 2016 and 2017 harvesting seasons (Wild Blueberry Association of North America (WBANA) 2017). The US government launched a Wild Blueberries School Foodservice Program which provide wild blueberries in breakfast and lunch to public and private schools in 22 states, to mitigate declining profits of farmers (WBANA 2017). A similar government farm business risk management program in Atlantic Canada could help mitigate the excess supply problem. Such changes in government policies and regulation can help increase blueberry demand and, ultimately, profitability associated with adopting mechanical harvesters. Policies and strategies on promotion and marketing of nutritional and health aspects of wild blueberries in local and international markets can help sustain the profitability of the industry.

Various initiatives by commercial manufacturers have helped to improve the technical and engineering performance of wild blueberry harvesters and harvesting operations (Forney et al 2006). However, so far no studies have investigated the economic viability for prospective farmers who may want to purchase such harvesters. The economic feasibility need to take into consideration the useful life over which the harvester can be put into productive operation. Both farmers and harvester manufacturers also need information on returns on investments associated with the outright purchase, compared with rent/lease or custom hiring options.

1.3 Research Problem

Wild blueberry farmers contemplating purchasing a harvester need information on mechanical harvester harvest rate and, ultimately, the economic returns associated with purchasing the alternative harvesters and box handling systems. Harvest rate, measured in terms of hours per ha is important in determining total area of berries which can be mechanically harvested during a growing season. Similarly, harvest rate quantified in terms of tonnes per hour is important in order to determine what threshold total berry production or quantity can be harvested from farms in order to break even and become competitive.

Farmers need to know information about operating costs and potential labour savings associated with the two harvest handling technologies in wild blueberry production. Fixed and variable cost are important to determine and allocate the farm budgets associated with the two alternative harvester handling systems. Enterprise budgeting methods allow for comparing net revenues or profitability from wild blueberry operation by estimating the harvesting and other production costs.

Production decisions are also influenced by risk considerations, including availability of labour, yield, and fluctuations in input price and farm gate price. Risk-rated enterprise budget analysis, for example, allows for comparing risk rated farm returns over specified production costs based on realistic probabilities or chances of generating alternative outputs and associated returns (Fonsah et al 2007). Alternative scenarios of yield and output prices were developed to reflect categories such as optimistic, typical, and pessimistic chances of yield and price occurrence.

1.4 Purpose and Objectives

The purpose of this study is to better understand the economic viability of adopting two alternative mechanical harvesters for wild blueberry production in Atlantic Canada. The two mechanical harvesters are distinguished in terms of berry handling systems, namely: i) small box handling system; and ii) semi-automatic bin handling system. Specific objectives of this study are:

1) *To decompose and compare total harvest time, and harvest rate of small box and semi-automatic bin handling systems for wild blueberries.*

Mathematical equations were developed and used to quantify and compare berry harvesting and handling times (includes loading and unloading time). The harvesting time and berry handling times were then used to determine machine harvest rate. Harvest rate was estimated in terms of: i) hours per unit area harvested; and ii) tonnes of berries harvested per hour. Applied statistical methods were used to test the effect of weed coverage and technology type on wild blueberry yield.

2) *To determine the economic impacts of switching from the small box to semi-automatic bin handling technology.*

Partial budgeting methods were used to determine net change in profit associated with switching from small box to bin handling technology. A deterministic partial budgeting model was used to estimate costs and benefits using average market data, while a parametric partial budgeting model was used to examine the sensitivity of selected parameters on net change in profit. Furthermore, a stochastic partial budgeting model was used to account for uncertainty associated with various economic parameters, and net change in profit evaluated.

3) *To estimate and compare profitability of wild blueberry production using mechanical harvesters with two berry handling systems.*

A theoretical economic model was developed to estimate net revenues realized from blueberry harvesting operation using the alternative handling systems. Enterprise budgeting techniques were used to determine important fixed and variable costs associated with the two harvest handling systems. To address uncertainty associated with economic model parameters, the sensitivity of the effects of selected market factors and technology factors on wild blueberry production was investigated.

1.5 Outline of Thesis

This thesis is organized into six chapters. Chapter two describes an economic profile of wild blueberry crop in Atlantic Canada. In addition, a review of a graphical and theoretical economic model is also presented in Chapter two. Chapter three involves comparison of harvest efficiency and harvest rate of small box handling system and semi-automatic bin handling system. The study area and description of the two mechanical harvesters are also presented in Chapter two. Statistical analysis includes harvest time and handling time comparison, and the effect of the weed coverage and technology type on wild blueberry yield. The economic impacts of switching from a small box to semi-automatic bin handling system is investigated in Chapter four, using partial budgeting methods. In chapter 5, the profitability of wild blueberry production is investigated, with and without government harvest efficiency program, and for alternative asset ownership scenarios. Chapter six presents a summary of the study, major findings and recommendations for consideration in a further study.

CHAPTER 2: LITERATURE REVIEW AND INDUSTRY PROFILE

2.1 Economic importance of wild blueberry industry

2.1.1 Overview of Wild Blueberry Industry

The wild blueberry (*Vaccinium angustifolium* Ait.) crop is traditionally native to Northeastern North America. Commercially, wild blueberry is produced on a large scale and considered one of the four major fruit crops of this region (Yarborough 1996). The other major fruit crops are cranberry, concord grape and highbush blueberry. The two main species of blueberries commonly produced in Canada are: i) cultivated highbush blueberry and ii) wild blueberry. In Canada, a large proportion of wild blueberries are produced in the Maritime provinces (i.e., Nova Scotia (NS), New Brunswick (NB), Prince Edward Island (PEI)) and Quebec on commercial scale. The wild blueberry industry is expanding in Canada due to increase in production as a result of better management practices and development of mechanical harvesters in recent decades (Yarborough 2004, 12; Farooque et al 2014).

Oxford, Nova Scotia is considered the wild blueberry capital of Canada in producing and processing wild blueberries (WBPANS 2017). Consumer demand for wild blueberries has increased all over the world (AAFC 2016), due largely to increased awareness of its beneficial health properties; for example, anthocyanins in the wild blueberries have anti-inflammatory, anti-oxidant and cell regulatory properties (Beattie et al 2005).

2.1.2 Wild Blueberry Farming Systems

Wild blueberry is a unique crop that is not traditionally cultivated as other horticultural crops (Zaman et al 2008). The plants commonly emerge from native stands by removing competing natural vegetation or by clearing woodlands (Eaton 1988). A primary requirement is the presence of wild blueberry plants in the field before the land development (Chattha 2013). Newly developed blueberry fields often have large weed patches and bare spots (Zaman et al 2010).

Wild blueberry crop follows a two-year production cycle. Vegetative growth occurs during the first year, followed by berry production in the second year (Kinsman 1993). The sequence and timing of wild blueberry management and production practices are summarized in Table 3.1. Wild blueberries are low growing plants with average height range from 0.1 to 0.16 m (Hall et al 1979). New shoots start developing from dormant floral buds on underground rhizomes (Hall et al 1979). Wild blueberry crop is pruned by flail mower or burning in early Spring of the vegetative year or late in the fruit year after harvest (Eaton 1988), to improve plant dominance by controlling grass and weed germination (Hall et al 1979; Yarborough 2004). During the vegetative year, plant growth begins in May, after pruning. Development of floral buds starts from August to October in the vegetative year. In winter, wild blueberry fields are covered with snow and plants remain dormant until the floral buds develop in Spring (Eaton and Nams 2006). Flowering starts in May of the fruit year.

Agronomic practices including application of fertilizer and weed management in blueberry fields occurs in the year of vegetative growth (Kinsman 1993). Flower pollination by bees or other insects takes place for berry production, and ovary develop quickly after ovule fertilization (Eaton and Nams 2006). Wild blueberry fruits remain quiescent during June and July of fruit year, and size increases near harvest (Eaton and Nams 2006). Wild blueberry crop can be harvested using traditional manual hand rakes or mechanical harvester in August to mid-September, when approximately 90% of berries are ripe (Kinsman 1993).

Table 2.1: Sequence and timing of wild blueberry management and production practices.

Agronomic practice	Time
a) Vegetative year	
Emergence of plants	May
Fertilizer application	May
Vegetative growth of plant stem	June
Fungicide application	July
Development of floral buds	August-October
Development of plant stem for fruit year	Fall
Leaves begin to drop after first killing frost	Fall
b) Fruit year	
New plant dormant buds begin to swell	April
Buds break, bloom and growth of new leaves occur	May
Fungicide application	May-June
Pollination	June
Berry size increases and blue color begins to develop	July
Insecticide application	July
Harvesting season	August-September
Leaves begin to drop after killing frost	Fall
Pruning (burning and mowing) after first frost	October/November

2.1.2.1 *Farm value of blueberry production*

Farm value of wild blueberries are generally higher in Quebec, followed by Nova Scotia, Prince Edward Island and New Brunswick (Figure 2.1). Figure 2.1 suggest dramatic fluctuations in blueberry farm value for Quebec. In 2017, for example, farm gate value of blueberries was $23,843 for Quebec and $16,893, for Nova Scotia. By comparison, farm gate value was $13,490 for New Brunswick and $5,341 for Prince Edward Island.

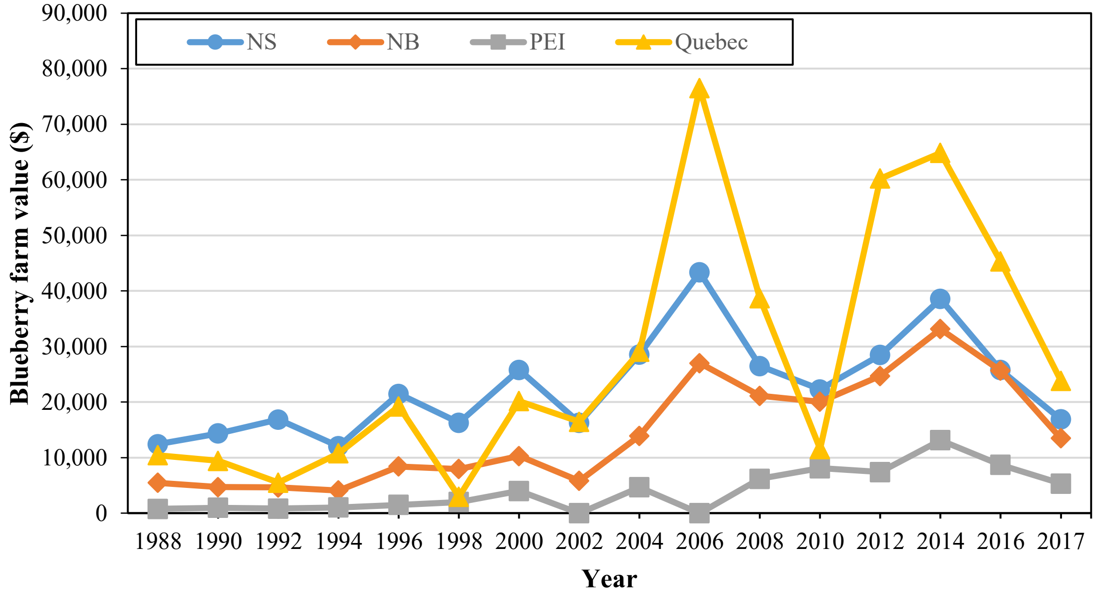

Figure 2.1: Blueberry (wild blueberry and High farm gate value in Quebec, NS, NB and PEI. Data source: Statistics Canada, (Various Years, CANSIM Table No: 32-10-0364-01)

In Canada, wild blueberries is produced in Quebec and the Maritimes provinces (i.e., NS, NB, PEI) whereas a large proportion of highbush blueberry is cultivated in British Columbia (Statistics Canada 2018). In 2016, for example, wild blueberry earnings was highest in Quebec, compared with the other major wild blueberry producing provinces in Canada (Statistics Canada 2018). During the period from 2000 to 2016, farm gate value of blueberries in Nova Scotia declined by 0.06% from $25,797 to $25,779. During the same period, blueberry farm gate value for New Brunswick increased by 150% from $10,280 to $25,660. Earnings to farmers from blueberry production during the same period also increased by 124% for Quebec, and 117% for PEI. In 2017, farm gate value of both highbush and wild blueberries for Canada as a whole was $203,353 (Figure 2.2), of which $23,843 accrued to producers in Quebec, $16,893 to Nova Scotia and $13,490 to New Brunswick.

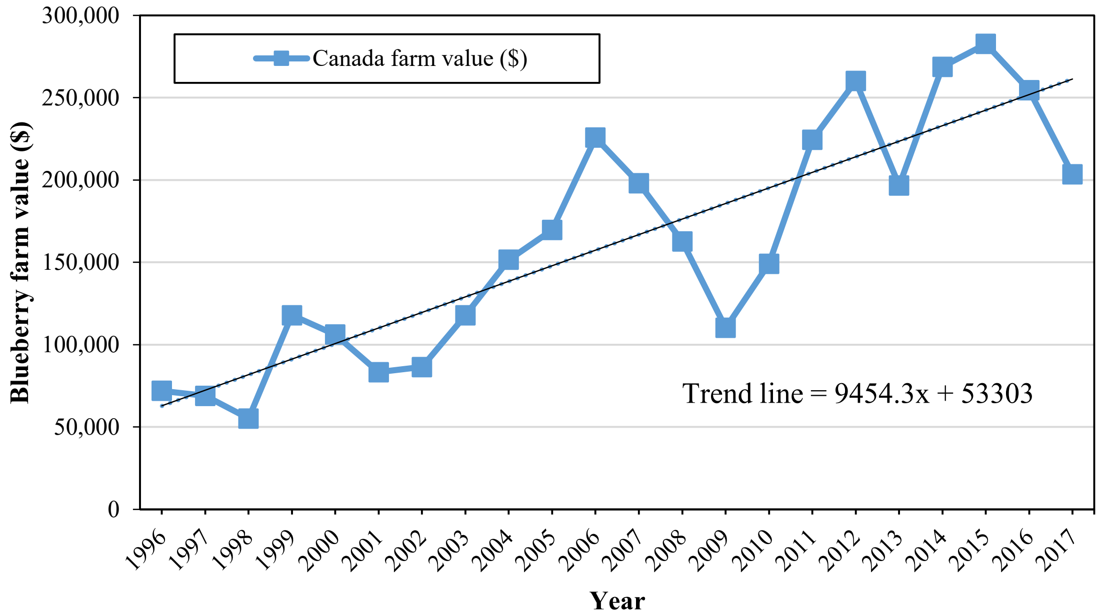

Figure 2.2: Blueberry farm gate value (1996-2017), Canada.
Data source: Statistics Canada, (Various Years, CANSIM Table No: 32-10-0364-01)

2.1.2.2 Area under production

Wild blueberry acreage for Canada shows a gradual increase since 2000s (Figure 2.3). Area under production for Canada as a whole increased from 50,159 ha in 2002, to 78,428 ha in 2017, representing a 56% increase. Acreage of wild blueberries increased tremendously in all wild blueberry producing provinces between 2002 and 2017 (Figure 2.4). The percentage increase in acreage was highest for New Brunswick (92%), followed by Prince Edward Island (76%) and Quebec (54%), and lowest for Nova Scotia at 3%. In 2017, wild blueberry acreage was highest for Quebec (29,835 ha), followed by New Brunswick (16,691 ha) and Nova Scotia (15,716 ha), and lowest for Prince Edward Island (5,424 ha).

Overall, there is consistent increase in acreage for wild blueberries producing provinces in Canada except Nova Scotia. For example, in Nova Scotia the area under production has decreased in the last 7 years (2011-2017) from 18,240 ha to 15,716 ha, representing 13.83% decline.

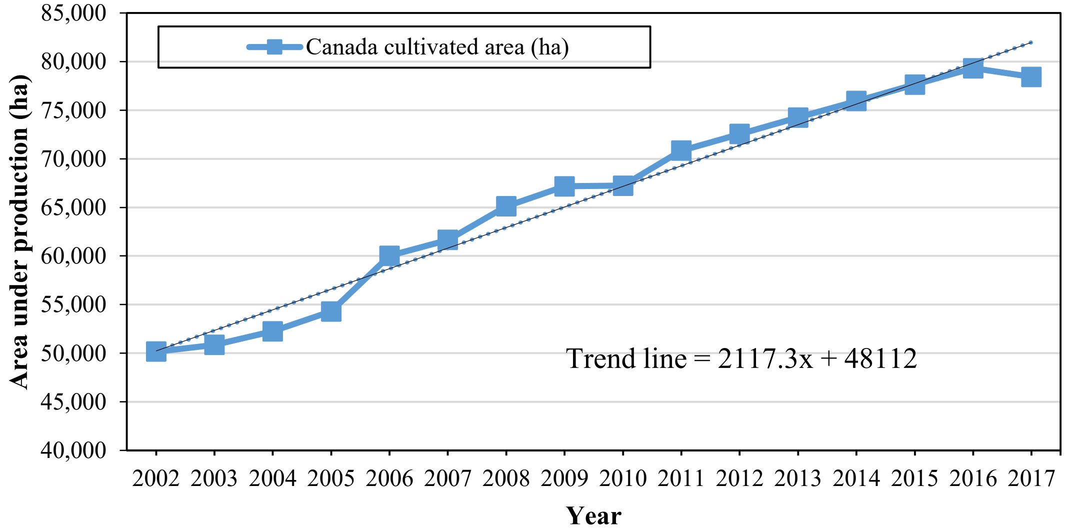

Figure 2.3: Area under production (2012-2017), Canada.

Data source: Statistics Canada, (Various Years, CANSIM Table No: 32-10-0364-01)

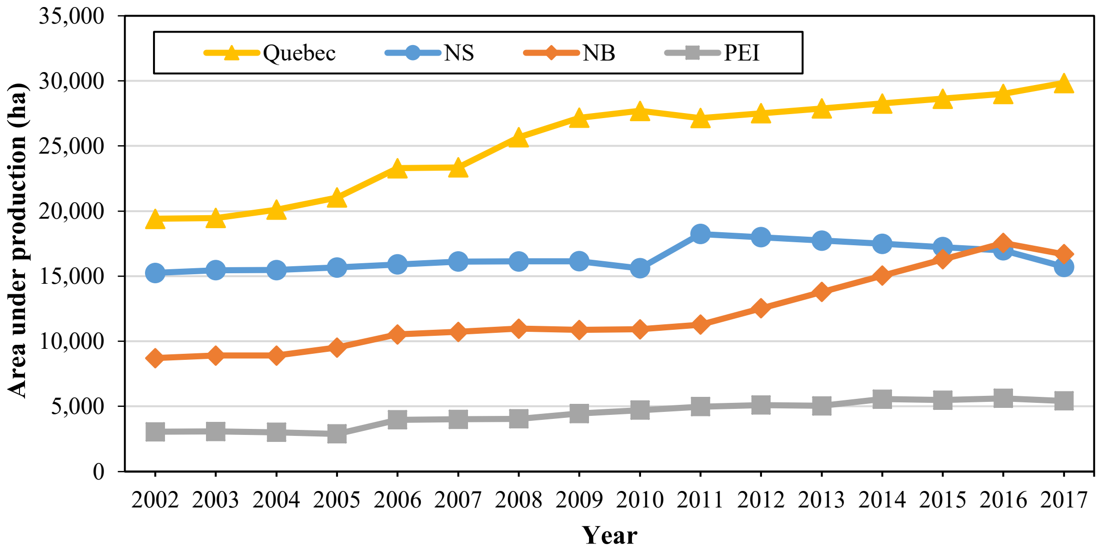

Figure 2.4: Blueberry area under production in Quebec, NS, NB and PEI.

Data source: Statistics Canada, (Various Years, CANSIM Table No: 32-10-0364-01)

2.1.2.3 Volume of blueberry production

Marketed production of blueberries suggests a generally increasing trend for all provinces considered (Figure 2.3). Among the major wild blueberry producing regions in Canada, marketed production was highest for Quebec in 2017 (40,351 tonnes), compared with the Maritimes provinces (Figure 2.5). In the Maritimes, in 2017, New Brunswick generated the highest marketed production (29,639 tonnes), followed by Nova Scotia (25,478 tonnes) and Prince Edward Island (11,749 tonnes).

The marketed production for Canada as a whole (for highbush and wild) blueberries has been steadily increasing for the past 20 years (Figure 2.4). For example, volume of (highbush and wild) blueberry production increased from 66,818 tonnes in 2000, to 176,641 tonnes in 2017, representing a 164% increase.

In 2017, wild blueberries accounted for 59% of total blueberries produced in Canada, compared with 41% for highbush blueberries. Quebec and the Maritime provinces are the leading producers of wild blueberries in Canada (Table 2.2). For Nova Scotia, wild blueberry production increased from 11,288 tonnes in 1988 to 25,478 in 2017 (Figure 2.5). Observed annual fluctuations in production are due to various factors, including adverse weather conditions, expansion in wild blueberry area, and introduction and adoption of improved mechanical harvesters. Introduction of mechanical harvesters encourages farmers to increase acreage to generate additional revenue. Declines in berry production during the last two decades were due to adverse weather conditions and low farm gate prices.

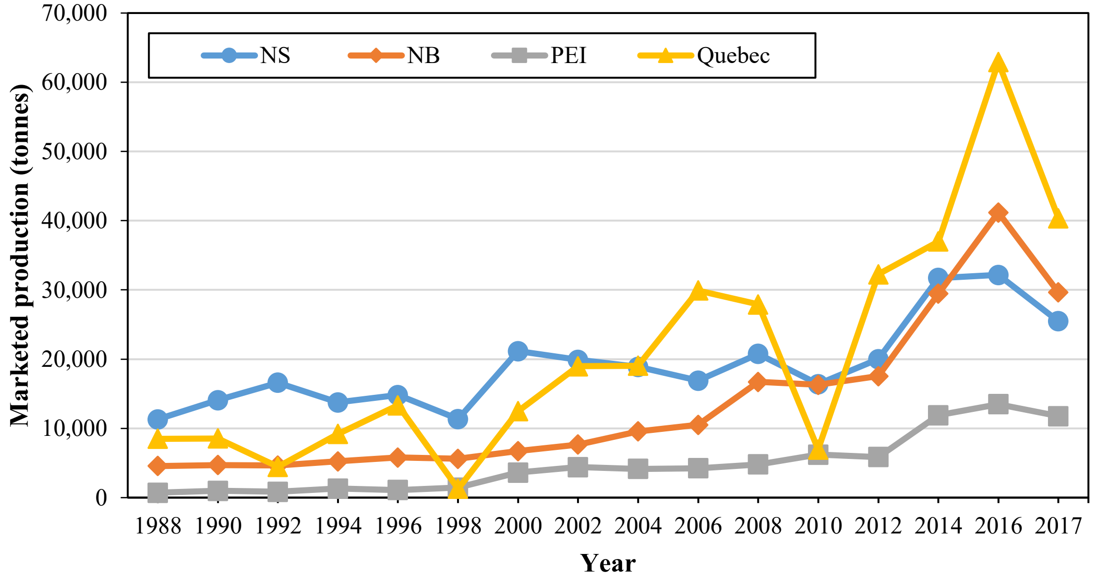

Figure 2.5: Blueberry marketed production in Quebec, NS, NB and PEI.
Data source: Statistics Canada, (Various Years, CANSIM Table No: 32-10-0364-01)

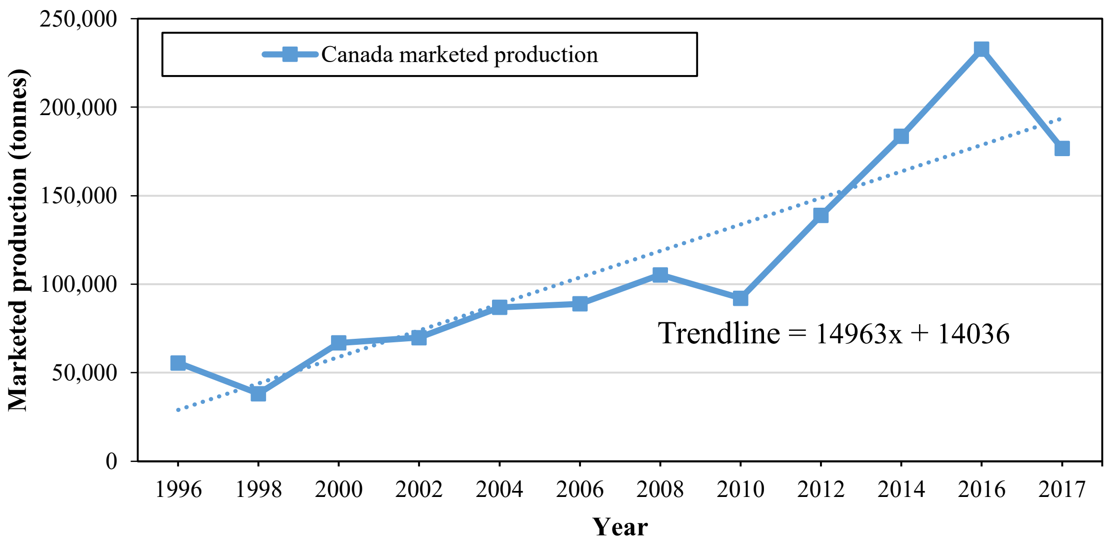

Figure 2.6: Blueberry marketed production (1996-2017), Canada.
Data source: Statistics Canada, (Various Years, CANSIM Table No: 32-10-0364-01)

Table 2.2: Proportionate of wild blueberries produced in Canada, Quebec and Maritimes.

Year	Wild Blueberries Production				
	Canada	Quebec	NS	NB	PEI
2013	52%	91%	94%	100%	100%
2014	57%	95%	97%	100%	100%
2015	54%	96%	98%	100%	100%
2016	63%	97%	96%	100%	100%
2017	59%	97%	95%	100%	100%

Data source: Statistics Canada, (Various Years, CANSIM Table No: 32-10-0364-01)

2.1.3 Importance of Wild Blueberry in Nova Scotia

The sharp growth in wild blueberry production has increased the supply of frozen blueberries as compared with fresh blueberries (Figure 2.7). Available statistics suggests that available frozen blueberries for per capita consumption increased from 0.18 kg per person in 1988 to 1.4 kg in 2017, representing 677% increase during this period. By comparison, available fresh blueberries for per capita consumption increased from 0.29 kg in 1988 to 1.1 kg in 2017. The trend in available blueberries for per capita consumption reflects annual fluctuations in wild blueberry production during the same period. Per capita consumption of wild blueberry data was not available.

Wild blueberries can be processed into sweetened juice extracts, jam/jellies and syrups. However, frozen blueberries are available after processing, in the retail market throughout the year. Nutritionally, wild blueberries are important as a source of fiber and important nutrients such as vitamin K1, vitamin C and manganese (AAFC 2016).

Table 2.3: Number of Blueberry[1] farms and area, in Quebec and Maritimes provinces.

Blueberries	Number of farms				Numbers of hectares			
	2001	2006	2011	2016	2001	2006	2011	2016
Quebec	371	537	804	932	13,576	16,898	27,148	29,002
Nova Scotia	695	843	912	816	15,179	15,635	18,240	16,982
New Brunswick	300	270	330	343	8,328	8,946	11,282	17,551
Prince Edward Island	104	118	147	153	3,148	3,967	4,979	5,619

Data Source: (Statistics Canada 2016).
[1]Blueberries include both wild blueberry and highbush blueberry.

Wild blueberry area and number of farms has been increasing since the 1980's. The number of farms and area of blueberries suggest a generally increasing trend for all provinces considered, for the census years considered (Table 2.3). Among the major wild blueberry producing regions in Canada, in 2016 for example, number of farms was highest for Quebec (932 farms), compared with the Maritimes provinces (Table 2.3). In the Maritimes, Nova Scotia had the highest number of blueberries farms (816 farms), followed by New Brunswick (343 farms) and Prince Edward Island (153 farms). For the census years from 2001-2016, the percentage increase in wild blueberry farms was highest for Quebec (151%), followed by Prince Edward Island (47%), Nova Scotia (17%), and lowest for New Brunswick at 14%.

Wild blueberry industry plays an important role in rural development of Quebec and Maritimes provinces. In Nova Scotia, for example, the wild blueberry industry generates about 1,500 full time jobs annually (WBPANS 2016), and seasonal job opportunities further increases during the berry harvesting season. In Quebec, more than 3000 seasonal workers harvest wild blueberries, while 700 jobs are directly related to berry processing, and 200 jobs are related to production (Ferland 2017). Increased wild blueberry production in New Brunswick has generated more than 430 full time-employment annually (Government of New Brunswick 2018).

2.1.4. Wild blueberry Marketing

Most of the wild blueberries produced in Atlantic Provinces and Quebec marketed in processed form. Only a low proportion (5%) is sold on the fresh market in Canada. In Nova Scotia, about 95% of wild blueberries produced are marketed as frozen and processed, while the remaining proportion is sold fresh (Larouche 2016). In 2016, Canada was the largest producer and exporter of wild blueberries in the world (AAFC 2016).

2.1.4.1 Wild blueberry exports and imports

The highbush blueberry is imported and exported, commonly as fresh fruit in Canada. Imports of fresh blueberries in terms of volume has increased since 2005 (Figure 2.8). The sharp

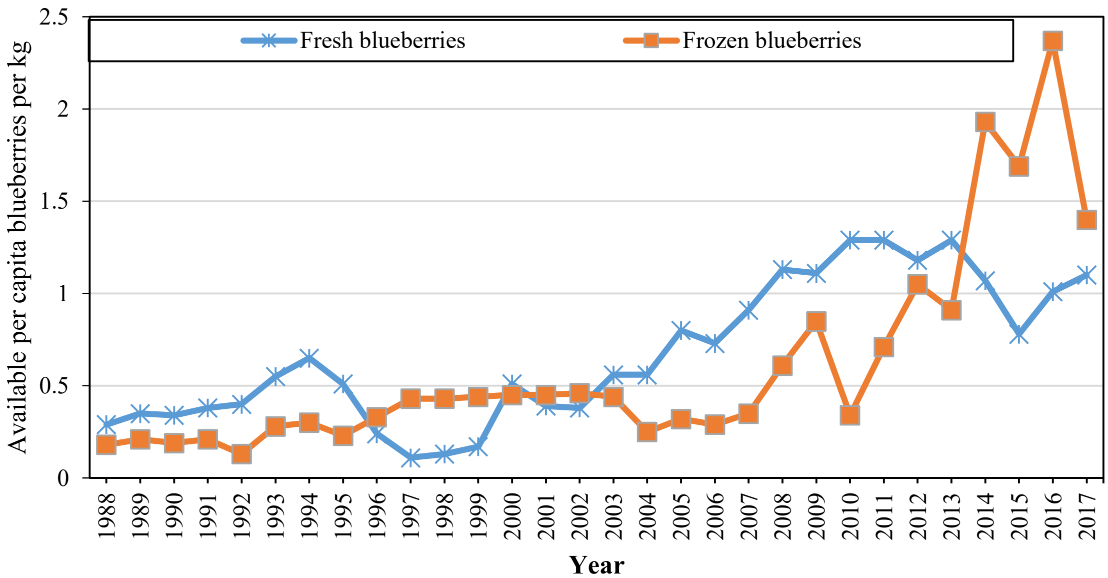

Figure 2.7: Available per capita blueberries, Canada.
Data source: Statistics Canada, (Various Years, CANSIM Table No: 32-10-0364-01)

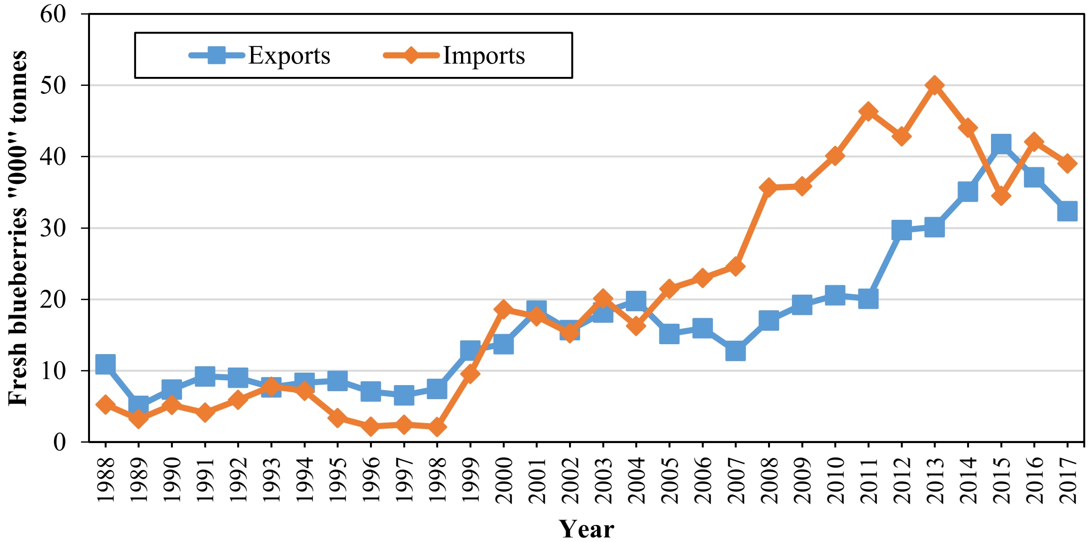

Figure 2.8: Fresh blueberries Exports/Imports (1988-2017), Canada.
Data source: Statistics Canada, (Various Years, CANSIM Table No: 32-10-0364-01)

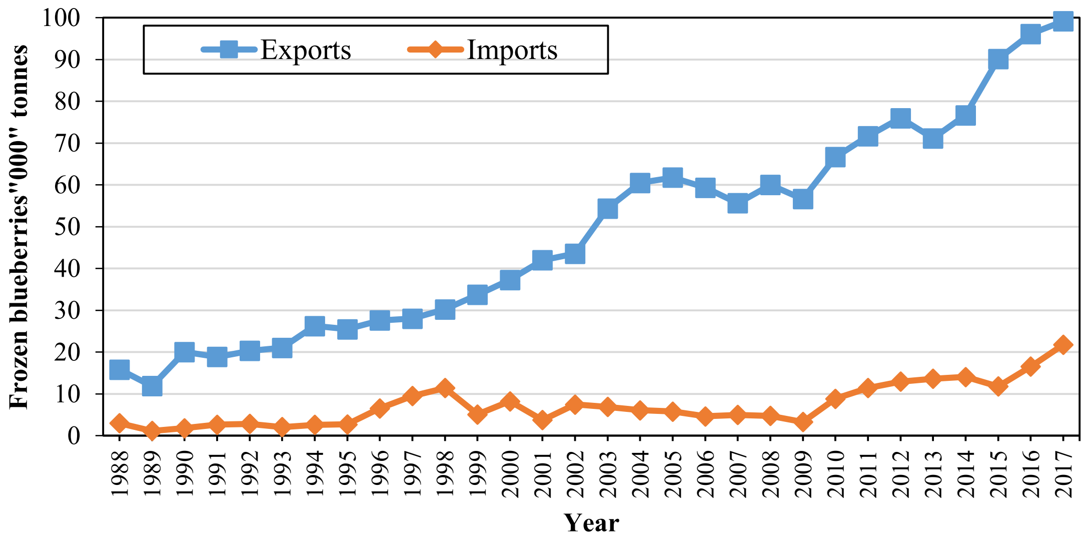

Figure 2.9: Frozen blueberries Exports/Imports (1988-2017), Canada.
Data source: Statistics Canada, (Various Years, CANSIM Table No: 32-10-0364-01)

increase in imports may be due to increase in domestic demand of fresh blueberries. In 2017, for example, fresh blueberries imports (39,040 tonnes) was higher than exports (32,370 tonnes) by

23%. Blueberries (especially highbush) are imported from United States, both in fresh and frozen form.

Canada is also major exporter of frozen blueberries in the world market. Figure 2.9 shows that exports of frozen blueberries are much higher than the imports. The export volume of frozen blueberries (mainly wild blueberry) has been increasing since the 1990's. The rapid increase in export volume of frozen blueberries is consistent with the increasing trend in production of wild blueberries. The sharp increase brought additional revenue to the Canadian economy. For frozen blueberries, the volume of exports for Canada as a whole shows a rapid growth from 15,840 tonnes in 1988 to 99,130 tonnes in 2017 (Figure 2.9). Data related to exports/imports revenue specifically for wild blueberry was not available. Wild blueberries are exported mainly to United States, Japan, United Kingdom, and Germany (WBPANS 2016).

2.1.5 Summary

Wild blueberries are an economically important crop, especially in Atlantic Canada. Wild blueberries contributed about $91.9 million in farm receipts to producers across Canada in 2016, of which $19.2 million was generated by Nova Scotia farmers. Frozen blueberries available for consumption per capita in Canada, increased from 0.18 kg per capita in 1988 to 1.4 kg in 2017, representing a 677% increase.

The dominant wild blueberries producing regions in Canada are the Maritimes provinces (i.e., Nova Scotia, New Brunswick and Prince Edward Island) and Quebec. Better farm management practices have contributed to observed increased wild blueberries production in Canada. However, prices of wild blueberries received by farmers in Nova Scotia has declined, especially during recent years.

Wild blueberries generated about $600 million in revenue in 2016 to the national economy of Canada. In 2016, the wild blueberry sector generated about $100 million in revenue to Nova Scotia economy. Wild blueberries are mainly exported in processed form. Economic benefits from wild blueberries are generated mostly from the frozen whole fruit, value added products and processing sector.

2.2 Economic Model and Analysis

2.2.1 Conceptual Graphical Analysis of Producer Benefits

Mechanization of wild blueberry harvesting has the potential to increase harvest efficiency and expand acreage. Producers in Atlantic Canada contemplating a mechanical harvester have a choice between a traditional small box handling system or a semi-automatic bin handling system.

The two mechanical harvesters generally differ in terms of harvest efficiency. A more efficient harvester is assumed to reduce overall harvesting costs through input substitution (e.g., by substituting capital for labour), but not yield per unit area (Kim et al 1987). In this analysis, it is assumed that berry supply increases as a result of harvester technology-induced expansion in berry acreage. The expansion in acreage in turn is influenced by factors such as harvester efficiency, and berry price, *P*.

Figure 2.2 illustrates a graphical analysis in which producers are assumed to switch from the traditional small box handling system (*s*) to the semi-automatic bin handling system (*b*). Berry farmers who adopt harvester and handling systems with lower harvesting costs are assumed to increase crop area, and quantity produced by $Q_b - Q_s$. Producer surplus before the switch (PS_s) and after the switch (PS_b) are represented by (see Figure 2.2):

$$PS_s = P_s E_s A \tag{2.1}$$

$$PS_b = P_b\, E_b\, B \tag{2.2}$$

The benefits to producers in terms of change in producer surpluses is illustrated in the graph by area $PS = P_b\, E_b\, C\, P_c$, and can be estimated using the following equation:

$$PB = 0.5\,(P_b - P_c)(Q_b + Q_s) \tag{2.3}$$

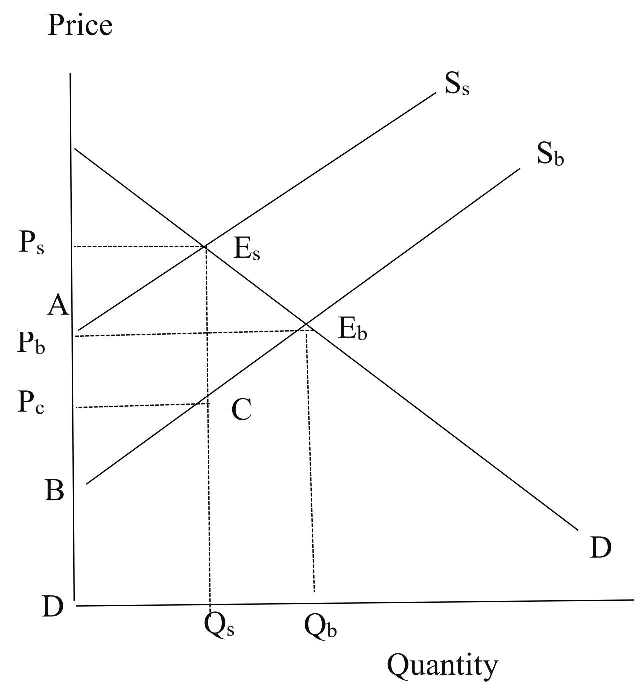

Figure 2.10: Change in farmer benefits resulting from mechanical harvesters with alternative handling systems.
Source: Adapted from Kim et al (1987)

where P_c is the price at which the area of producer surpluses $P_c\, C\, B = P_s\, E_s\, A$ (represents area of producer surpluses prior to semi-automatic bin handling system). The specification in Equation 3 assumes a parallel shift in the supply curve. A pivot or convergent shift in the supply curve will underestimate or overestimate producer surpluses. (Kim et al) 1987 noted that a plausible or only realistic scenario is to assume that the supply shift is parallel.

2.2.2 Theoretical Economic model

Production of wild blueberries for processing and fresh markets is common among farmers in Atlantic Canada. Frozen berries for the processing market allows farmers to mitigate risk of low prices during the harvest season. The economic model allows for a farmer that produces berries for both processing and fresh markets, and follows Gallardo and Zilberman (2016). Relative prices of fresh and processing wild blueberries will determine the proportion of berries for either market. Let berry price of the fresh market be denoted by P_f, compared with P_r for the processing market price. Production parameters which differ for the mechanical harvesters with alternative berry handling systems include harvestable yield, harvest rate, and harvesting cost.

Suppose that potential output that can be harvested from a wild blueberry farm is Q_0. Also, let Y_{lossi} represent yield cullage or percentage of output (Q_0) that is lost due to harvest-induced damage during field harvesting (where *i*=1 denotes harvester with small box handling (*s*), and *i*=2 denotes harvester with semi-automatic bin handling system (*b*). Furthermore, let Q_{lossi} represent percentage of output with bruises on the external fruit surface due to long-term refrigeration storage. Thus, the quantity harvested for the fresh market using either harvester is represented as:

$$Q_{fi} = Q_0(1 - Y_{lossi})(1 - Q_{lossi}) \qquad [i = 1,2] \tag{2.4}$$

Similarly, the quantity harvested for the processing market using either harvester is represented as:

$$Q_{ri} = Q_0(1 - Y_{lossi})(Q_{lossi}) \tag{2.5}$$

Total revenue per ha generated from fresh and processing markets for harvester (*i*=1,2) is represented by:

$$TR_i = (Q_{fi}P_f) + (Q_{ri}P_r) \tag{2.6}$$

Harvesting cost is a major expense in wild blueberry production. In general, mechanical harvester ownership options available to farmers include: i) outright purchase; ii) rental or lease; or iii) custom harvesting service. Custom harvesting and rental services are common in Atlantic Canada for wild blueberry harvesting. Compared with a new purchase, used machinery can provide similar service with low initial investment and ownership cost, but can increase the risk of high maintenance cost (Kay et al 2016). By comparison, rent or lease options may be preferred when initial investment capital is a constraint and interest rates are high (Kay et al 2016). Machinery on lease is usually a long term agreement (usually three to five years or longer) as compared with rental agreement (for a few days to full harvesting season). Harvesters are usually rented by field owners for relatively short period of time. Custom hiring is usually preferred during labour scarcity or when it is economical rather than to own or rent a machine.

For simplicity and tractability of the theoretical economic model, it is assumed that mechanical harvesting cost includes annual harvester rental cost (H_r), and labour cost (L_{ci}). Machine cost per ha (H_c) equals the harvester annual rent (H_r), divided by berry area harvested (H_a).

$$H_c = \frac{H_r}{H_a} \tag{2.7}$$

Small box handling system requires a tractor operator and extra worker at the rear of the harvester to manually load and unload the boxes, whereas the semi-automatic bin handling system only requires an operator. Labour cost per ha (L_{ci}) for harvester ($i=1,2$) equals potential output, Q_0 minus harvest induced damage times labour cost per kg, and is represented by:

$$L_{ci} = Q_0(1 - Y_{lossi})L_{ki} \tag{2.8}$$

Labour cost per kg (L_{ki}) is the sum of worker wage per hour (w_h), divided by harvester picking rate per hour (q_{hi}) plus the quotient of operator wage per hour (w_o) divided by operator output rate per hour (q_o).

$$L_{ki} = Q_0(1 - Y_{lossi})\left(\frac{w_h}{q_{hi}} + \frac{w_o}{q_o}\right) \tag{2.9}$$

Thus, total cost is represented by this equation:

$$TC_i = \frac{H_r}{H_a} + \left[Q_0\,(1 - Y_{lossi})\,\left(\frac{\boldsymbol{w_h}}{\boldsymbol{q_{hi}}} + \frac{\boldsymbol{w_o}}{\boldsymbol{q_o}}\right)\right] \tag{2.10}$$

Net revenue for harvester (*i=1,2*) is estimated as total revenue per ha minus total cost per ha:

$$N_{ri} = TR_i - TC_i = \left(Q_{fi}P_f\right) + \left(Q_{ri}P_r\right) - \left[\frac{H_r}{H_a} + Q_0(1 - Y_{lossi})\left(\frac{w_h}{q_{hi}} + \frac{w_o}{q_o}\right)\right] \tag{2.11}$$

It is hypothesized that the semi-automatic bin handling system has higher machine cost per ha and lower labour cost because of higher harvest picking rate due to the mechanical hydraulic handling of boxes compared with the additional worker needed for manual handling of small box handling system. In summary, net revenues will depend on the berry market price (i.e., fresh and processing), harvest losses (yield and quality), labour cost, machine cost, and yield.

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CHAPTER 3: MECHANICAL HARVEST EFFICIENCY OF TRADITIONAL SMALL BOX AND SEMI-AUTOMATED BIN HANDLING SYSTEMS FOR WILD BLUEBERRY HARVESTING

3.0 Abstract

Wild blueberry harvestable yield has increased significantly especially after introduction of commercial mechanical harvesters in the early 1980s. Important factors leading to the transition from traditional to semi-automated harvester include narrow harvesting time window, declining availability of skilled labour and increased high wages, and other production costs. Berry boxes are handled manually with the traditional wild blueberry harvester (with implications for additional labour use), whereas the semi-automated harvester requires a large bin and loader tractor. Mechanical harvesters with small box and semi-automated bin handling systems are commonly used for harvesting wild blueberries in Maritimes, Quebec and Maine. However, their performance in terms of field harvest efficiency and harvest rate have not been quantified and compared. This study evaluated the field efficiency of the berry small box handling system of a traditional mechanical harvester compared with a semi-automated bin handling harvester. Data for the harvest efficiency were obtained from on-farm field experiments conducted at selected sites in Nova Scotia in 2017 and 2018. Traditional small box and semi-automatic bin handling harvesters with double head configuration were used, with similar engineering configuration, including: i) 0.66 m picking reels; ii) 16 picker bars per head and 65 tooth per bar; iii) 1.72 m picking width; iv) 21 rpm head speed and v) 0.31 ms^{-1} ground speed. Each harvester was operated for 120 minutes during which period, yield harvesting time and box handling time were recorded using a stopwatch, with six replications during each year. Paired *t*-test and student *t*-test were used to compare the harvest efficiency of the two mechanical harvesters, while regression modeling was used to check the effect of weed coverage and technology type on yield. Harvest time efficiency of the semi-automatic bin handling system was 88% in 2017 and 98% in 2018. By comparison harvest time using the small box handling technology was 72% in 2017 and 76% in 2018. Thus, harvest time efficiency was significantly higher for the semi-automatic bin handling technology than for the small box handling technology by 22% in 2017 and 29% in 2018. Field efficiency for the two box handling systems depended on factors such as: i) experience of harvester operator; ii) weed incidence; and iii) berry yield intensity. In 2018, berry production was adversely affected by frost, and influenced the field efficiency. Regression results indicated that average yield in fields with low weed coverage area was higher than for fields with high weed coverage area, and was significantly different from zero. The findings provide useful insights for decision makers contemplating choice of harvesting technology to sustain profits from blueberry production.

3.1 Introduction

Technologies for harvesting wild blueberries continue to evolve, with earlier types of mechanical harvesters replacing hand-held metal rakes and, more recently, introduction of semi-automatic (hydraulic) systems for box handling. Major challenges faced by wild blueberry producers during harvesting include declining availability of labour (Yarborough 2000; Bojras 2003), short harvesting time window (Ali et al 2018), high agricultural labour wages (Government of Nova Scotia 2019) and high overall harvesting costs (Esau 2017). Expansion in wild blueberry area under production especially during the past decade has prompted a need for more efficient berry harvesting and handling systems.

Semi-automatic bin handling technology with hydraulic system eliminate the need to pause and unload berry boxes and load empty boxes and, therefore, may increase field harvest efficiency (in terms of harvested area per hour). However, the semi-automatic bin handling system may come at additional equipment cost, compared with the small box handling system. On the other hand, the increased cost associated with a semi-automatic bin handling technology may be offset by labour savings (and increased field harvest efficiency). Higher field harvest efficiency allows berry producers to harvest more hectares during the traditionally short harvest season than may be possible with less efficient technologies such as hand rakes or the manual small box handling systems. The increase in harvested area may translate into lower average cost per unit area to operate the harvester.

Harvesting cost is a major expense in wild blueberry production (Gallardo and Zilberman 2016; Esau 2017). Compared with the semi-automatic bin handling technology, extra labour is required for wild blueberry harvesting using hand-held metal rakes and small box handling systems. Hand raking is a manual labour-intensive harvesting operation (Yarborough and Hergeri 2010), and requires substantial labour depending on size of the farm. A mechanical harvester with small box handling system requires two workers; a tractor operator and a second worker located on the back of the tractor for box handling. By comparison, the semi-automatic bin handing system requires a tractor operator, who also loads and unloads the empty and filled boxes using a hydraulic mechanism. The semi-automatic bin handling technology may also require a support tractor loader for loading and unloading of empty/filled boxes, especially for some large farms.

The agriculture sector as a whole faces perennial seasonal labour shortages in Atlantic Canada, especially during the spring and summer months when labour is needed for many other competing crop and livestock operations. For wild blueberry production, the farm labour challenges are particularly critical during the short harvesting season, from mid-August to September (WBPANS 2017). Investment in labour saving technologies has potential for addressing constraints to further expanding crop acreage (Taylor et al 2012), and enhancing worker productivity (Gallardo and Brady 2015). Increased adoption of mechanical harvesters has potential for reducing overall cost of production compared with alternatives such as manual hand raking (Yarborough 2004).

Mechanical harvesters with small box and semi-automatic bin handling systems are currently commonly used in Atlantic Canada, and Maine, USA. Previous engineering studies have examined losses and picking efficiency of harvester head (Farooque et al 2014), but no studies have quantified and compared the harvest efficiency and performance of the two harvesters with alternative handling technologies. Specifically, their performance in terms of harvest efficiency and harvest rate have not been quantified and compared. Producers can enhance profit margins by adopting efficient harvesting systems (Moseleya et al 2012).

Various studies have evaluated mechanical harvesters for various crops by quantifying and comparing various aspects of harvesting operations, including harvest time and handling time (Taylor et al 2002; Harrigan 2003; Faulkner et al 2011), harvest rate (Erdogan et al 2003; Polat et al 2007), and field efficiency (Willcutt and Branes 2008; Hanna 2016). Different methods have been used to measure harvesting time, produce handling time, and field efficiency depending on the type of crop of fruit tree. Harvest time is an important component of harvesting operation because producers have often limited time to harvest the crop. Field efficiency is also important determinant of the performance of harvesters at its maximum capacity. The components of total harvest time (i.e., harvest time and handling time) and harvest rate associated with the wild blueberry mechanical harvesters of interest have not been evaluated.

The purpose of this study was to quantify and compare the harvest efficiency of the wild blueberry mechanical harvesters with alternative box handling technologies. A first objective was to quantify and compare harvest time and berry handling times of alternative harvesters with the two box handling technologies. Data for the harvest efficiency comparison were obtained from on-farm field experiments conducted at selected sites in Nova Scotia, Canada. The second objective was to quantify and compare harvest rate of the small box with the semi-automatic bin handling systems. Harvest rate of wild blueberry mechanical harvesters is measured in alternative ways, namely: i) hours per hectare; and ii) tonnes per hour.

3.2 Literature review

Various studies have quantified and compared various components of harvest time because this information is important to evaluate the efficiency of different harvesters, especially for crops with narrow harvesting time windows. Faulkner et al (2011) evaluated the performance of a cotton harvester (i.e., picker and stripper) for irrigated cotton production in Texas, USA, and quantified the harvest losses and time spent in each harvesting operation. Faulkner et al (2011) quantified various harvest times during the operation: (i) beginning and end of the row; (ii) start and turn at end of row; (iii) stop harvest at full basket; (iv) start and end for the boll buggy to receive cotton from the harvester; (v) start and end down time; and (iv) unloading time. The results indicate that harvest time depended on the harvester operator and support equipment. The picker harvester had higher efficiency than the stripper harvester, where support equipment (i.e., modules builder) was available.

Erdogan et al (2003) compared the harvest rate and harvest time of different methods of harvesting apricots in Turkey. The alternative methods considered included hand, traditional, and mechanical harvesting. Various harvesting times quantified included time needed to shake a tree limb, harvesting rate (i.e., trees h^{-1}, kg h^{-1}, and ha h^{-1}) and comparisons with other methods. The results indicated that optimum time required to harvest a tree limb was 5 s by inertia type shaker. Harvest rate of an apricot tree by hand was 400 min, compared with 20 min using traditional harvesting and 6 min using mechanical harvesting.

Polat et al (2007) compared manual and mechanical harvesting of pistachio nuts in Turkey. Inertia type shaker was used to harvest nuts mechanically, and worker was used to harvest nuts by hand manually. In this study, the area harvested per hour (ha h^{-1}), the number of trees harvested per hour (tree h^{-1}), and time required to harvest a tree (min $tree^{-1}$) were quantified and compared. The results showed that mechanical harvesting required an average of 4.85 min to harvest a tree, compared to 14.7 min for hand harvesting. Harvest rate was important determinant of the average time to harvest the crop in a limited time.

Taylor et al (2002) quantified harvest time, handling time and field efficiency of a combine harvester for four different crops, including soybeans, grain sorghum, corn and wheat in Kansas, USA using GPS time values. Turning time, unloading time, stopped time and overnight time were estimated from the change in GPS values. Field efficiency was also estimated by dividing the theoretical time by the field time, consistent with ASABE (American Society of Agricultural and Biological Engineers) guidelines. It was found that harvest efficiency depends on the turning time of the harvesters. The authors concluded that, to improving harvesting patterns of different crops, farmers can improve the harvest efficiency by minimizing the turning.

For wild blueberry crop, harvest time, berry handling time, field efficiency and harvest rate are important to determine harvest efficiency of mechanical harvesters with small box and semi-automatic bin handling systems.

3.3 Research Methods

3.3.1 Study Area and Farms

Field harvesting trials were conducted for two years, during 2017 and 2018. The choice of farms was influenced by availability of cooperating farmers on the research project, and the harvesting technology (i.e., small box versus semi-automatic bin handling technology) usage of the farmers. In 2017, on-farm field trials were conducted in central Nova Scotia, near the small rural town of Debert. This privately-owned commercially-managed farm had been under operation during the previous 50 years. Investigating the harvest operations using a farmer's farm allowed for compiling data that reflects actual farming conditions. For example, the farm had weeds and a few bare spots along the field boundaries compared with the inner area of the farm. The farm studied was considered a high yield operation. The field selected was in blueberry vegetative growth year in 2016 and fruit production in 2017.

In 2018, the field experiments were conducted in two wild blueberry farms in the rural farming communities of Portapique and Antigonish, both in Nova Scotia. In 2018, berry production throughout the Maritimes was adversely affected by frost damage. As a result, weed (berry vine) coverage in the fields were high (low, with low potential yields). Both fields were in blueberry vegetative growth in 2017 and fruit production in 2018.

For all the farms studied in both years, recommended blueberry agronomic and management practices had been implemented over the past decade, including herbicides, fungicides, insecticides, induced pollination and mechanical pruning. The harvest operations conducted allowed for comparing blueberry harvest efficiency of the mechanical harvesters with alternative handling technologies.

3.3.2 Description of Mechanical Harvesters

During most of the past 100 years, wild blueberry fields have been traditionally harvested with hand-held metal rakes (Yarborough 2000). Initial efforts to reduce production cost using mechanical harvesters started in the 1950's (Dale et al 1994). During the past decade, most wild blueberry farms in Atlantic Canada were harvested using mechanical harvesters (AAFC 2017). Although various prototype mechanical harvesters for wild blueberries have been developed over the years (Rhodes 1961; Grant and Lamson, 1972, Richard, 1982; Sibley 1994; Farooque et al 2014; Esau et al 2018), improving field harvest efficiency remain an on-going effort and challenge. Commercial producers were reluctant to adopt earlier prototype harvesters because of technical engineering problems (e.g., rough field terrain, damage to plants and berries) and harvester cost inefficiency (Farooque et al 2014).

In 1979, Bragg Lumber Company in Nova Scotia successfully developed a mechanical harvester with a circular reel head mechanism (Yarborough 2000). Various technical and engineering studies led to release of two mechanical harvesting systems, which are distinguished in terms of box handling technology: i) small box system; and ii) semi-automatic bin handling system. The main distinguishing features of the two box handling systems are summarized in Table 3.1.

The manual small box handling system requires two workers; one tractor operator and a second worker located at the back of the tractor/harvesting system for manually loading and unloading the berry boxes. The small box handling system requires the worker at the back of the harvester to manually replace a box filled with harvested berries with an empty box in a time-efficient manner.

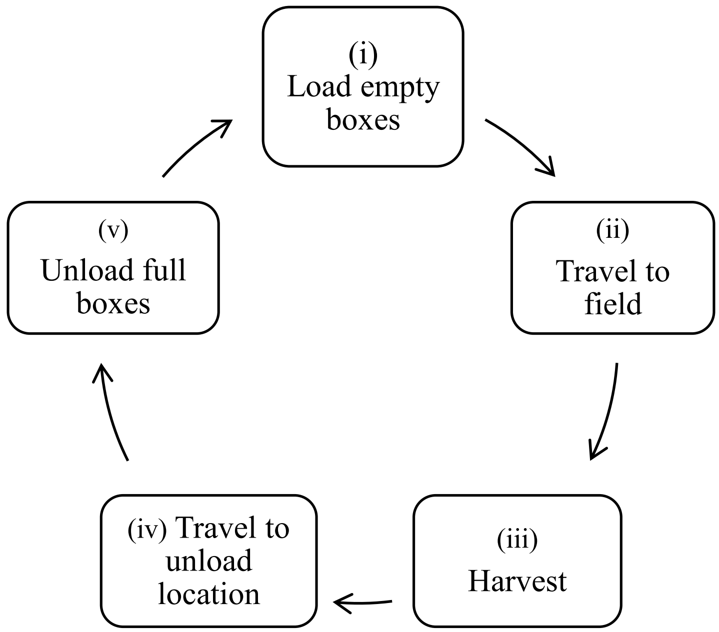
The semi-automatic bin loader with a modified handling system uses a hydraulic tractor loader with forks for the entire wild blueberry harvesting operation, and requires a tractor operator for the berry harvesting. Fruit filled boxes are moved and replaced with an empty box using a hydraulic mechanical device controlled and adjusted by the tractor operator. In semi-automated bin handling systems, a support worker or tractor loader with forks to load empty bins on the harvesters and to pick berry filled bins from the field is needed. A second tractor loader is not required in small field operation to reduce the harvesting cost (i.e., labour cost) at the expense of field efficiency. The steps associated with the harvesting operations for the small box and semi-automatic bin handling systems area illustrated in Figure 3.1.

The berry fruit harvesting mechanism for both the small box and semi-automatic bin handling systems are similar, with circular reel type picking-head mounted to the side of a tractor

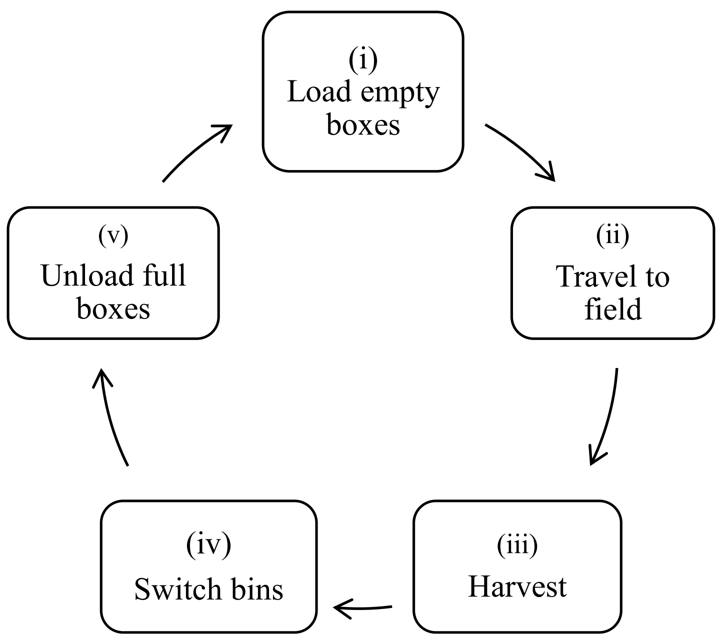
Table 3.1: Major components of harvesters with alternative handling systems

Box handling system	Small box handling system	Semi-automatic bin handling system
Tractor	Minimum 100-watt (W) farm tractor	
Harvester configuration	0.66 m picking head 16 picker bars per head 65 tooth per bar 0.86 m wide swath width per head Double head configuration (1.72 m effective picking width)	
Debris removal method	Blower fan	Blower fan with wind flow isolator
Box stacking and loading	Rear platform for manual stacking of boxes	Hydraulic rear handling system operated by tractor operator
Box loading/unloading	Manual labour	Loader tractor with forks
Empty box weight	1.36 kg	30 kg
Full box weight	12 kg	136 kg

(Figure 3.2). The reel in the picker head rotates in the same direction as the moving tractor. Comb type picking bars rake the berries from low growing plants and deposit them into a side conveyer. A blower fan cleans the berries as they travel from a side conveyer system to a back conveyer/harvester bin. The tractor provides hydraulic and electrical power to the harvester during the harvest operation. The mechanical harvester with double head configuration can be mounted to a tractor with horse power ranging from 75 to 150 kW. In this study, mechanical harvester with small box handling system with horsepower of 100 kW and semi-automatic bin handling system with horsepower of 82 kW were used in 2017 and 2018. A tractor loader with horsepower of 48 kW was also used in both years for loading and unloading of large bins.



(a) Harvest operation using small box handling system



(b) Harvest operation using semi-automated hydraulic bin handling system

Figure 3.1: Steps in harvest operation using (a) small box handling system and (b) hydraulic bin handling system.

(a) Small box handling system showing manual handling of boxes.

(b) Mechanical harvester with semi-automatic bin handling system.

Figure 3.2: Mechanical harvesters with alternative box handling systems.

About 1,500 mechanical harvesters with single or double head configuration were in use in 2014 in Atlantic Canada (Farooque et al 2014). Compared with the single head system, the double head system increases the area harvested per unit time, but may come at higher power consumption. The semi-automatic hydraulic bin handling system eliminates the need to pause and manually unload filled boxes and load empty boxes onto the harvester, but may come at additional costs such as purchase cost and operating cost of the semi-automated bin handling system.

3.3.3 Field Data

The two harvesting technologies studied were fitted with double head configuration with 1.72 m effective picking width. The harvester head in the two box handling systems had similar engineering configuration, including: 0.66 m (diameter) picking reel, 16 picker bars and 65 tooth configurations. In addition, the berry harvest operations were similar for the small box and semi-automatic bin handling systems, with ground speed of 0.31 ms^{-1} and head speed of 21 revolutions per minute. Each harvesting technology was operated for two hours, with six replications during each year. Total harvest time and handling time during harvesting were measured using a stopwatch. Berries harvested during each replication were weighed using an electronic weighing scale at a privately owned wild blueberry produce receiving shed in Debert, Nova Scotia.

3.3.3.1 Harvest time

Harvest time is operationalized as the period during which the mechanical harvester is picking fruit. Actual berry harvest time (T_A) measured in hours was calculated by subtracting time spent handling boxes using technology i (T_i) from total time available (i.e., 2 hours).

$$T_{Ai} = 2 - T_i \qquad [i = 1,2] \tag{3.1}$$

where (T_{Ai}) denotes the actual berry harvesting time (in hours) of alternate box handling system, the index i=1 denotes harvester with small box handling (S), and i=2 represents harvester with semi-automatic bin handling system (B). The constant 2 is the total time (h) considered for each replication, and Ti is the handling time (h) for small box and semi-automatic bin handling systems.

For the small box handling system, box handling time is the time during which the worker is loading and unloading empty/full boxes/bins. Berry handling time for the small box system was calculated using the equation:

$$T_1 = t_{11} + t_{12} \tag{3.2}$$

where (T_1) represents total handling time for the small box system (h), t_{11} is time to load empty boxes on harvester (h), and t_{12} is time to unload boxes on harvester (h).

For the semi-automatic bin handling system, box handling time is the time to replace empty/full boxes/bins by harvester operator using mechanical hydraulic system. Handling time for the semi-automatic bin handling system was determined using the following relationship:

$$T_2 = t_{21} + t_{22} \tag{3.3}$$

where T_2 represents total handling time for the semi-automatic bin handling system (h), t_{21} is time to load empty bins on harvester (h), and t_{22} is time to unload bins on harvester (h).

3.3.4 Harvest Rate

Harvest rate is important in harvester purchase decisions as it affects, for example, time required to complete a harvest operation for a given field and, ultimately, overall profitability. Harvest rate of wild blueberry mechanical harvesters is measured in alternative ways, including (Schmitz and Seckler 1970): i) hours per hectare (h ha^{-1}); and ii) tonnes per hour (t h^{-1}). A more efficient harvest rate (using fewer h ha^{-1}) can harvest more area in a season compared with a less efficient harvester. Berry harvest rate (h ha^{-1}) is important in determining total area of wild blueberries which can be picked during a harvesting season. Equation 3.4 was used to determine the maximum area harvested under recommended travel speed and given width of the machine using a double head during field harvesting (Kay et al 2016):

$$HR_i = \frac{2.78}{S * W * FE_i} \tag{3.4}$$

where HRi denotes the harvest rate (h ha^{-1}) of alternative box handling system, the index i is defined as above. S represents the recommended average speed for operating the tractor/harvester system, at 0.31 ms^{-1} (Farooque et al 2014). Both harvesters with small box and semi-automatic bin handling system were operated with the same recommended speed of 0.31 ms^{-1}. W represents the width of the double head harvesters. The width (m) of a single picking head was 0.91 m, with an overlapping 0.05 m to eliminate stoppage while harvesting over uneven terrain. The effective picking width of the double head harvester used in this study was 1.72 m. FE_i represents the field efficiency (%) of alternative harvest handling system. The parameter (2.78) was determined by taking the ratio of number of square feet in a hectare (i.e., 10000) and number of seconds in an hour (i.e., 3600) (Kay et al 2016). Field efficiency was determined using the relationship:

$$FE_i = T_H * 100 \tag{3.5}$$

where FEi denotes the field efficiency of alternate harvest handling system (%) and T_H is the time spent harvesting berries (h) in one hour. Field efficiency (equation 3.4 and 3.5) represents the percentage of time spent harvesting berries in an hour relative to the total time available (for box loading/unloading, and berry picking). Field efficiency varies depending on harvester box handling technology (i.e., small box versus semi-automatic bin handling) and weed intensity (i.e., high versus low berry yield). Field efficiency was calculated based on time spent in picking berries in a single hour (h) for the alternative harvest handling systems in different field types or condition (Equation 3.5). The field efficiencies estimated for the two box handling systems are summarized in Table 3.2.

Berry harvest rate measured in tonnes per hour allows for quantifying berry volume that can be harvested in a growing season or berry harvest window (i.e., with fixed harvest hours) (Schmitz and Seckler 1970):

$$HR_i = \frac{B_H}{T} \tag{3.6}$$

where *HRi* denotes the harvest rate (t h^{-1}) of two box handling system, the index *i* is defined as earlier. (B_H) represents the total quantity of berries harvested in tonnes, whereas *T* is the total time (h). Harvest rate (t h^{-1}) was determined by taking the total quantity of berries harvested in a single hour, and then averaged for six replications. Harvest rate (t h^{-1}) can vary depending on harvester system (i.e., small box versus semi-automatic bin handling) and crop/weed intensity (i.e., high versus low berry yield). A producer contemplating purchasing a mechanical harvester needs to determine if a sufficient volume of blueberries can be harvested from her farm to be competitive. For both years, the fields were grouped into two types based on the weed incidence (or potential berry yield): i) low weed coverage (with high berry yield) and ii) high weed coverage (with low berry yield).

3.3.5 Statistical Analysis

Various steps were involved in the statistical analysis. A first step involved testing for normality of the distribution of the raw field data collected for both years. Methods commonly used to check normality in the distribution of data include (Ghasemi and Zahediasl 2012): i) visual method; and ii) normality test. Options to check normality by visual methods include: frequency distribution histograms, boxplots, P-P plot (probability-probability plot), stem and leaf plot, and Q-Q plot (quantile-quantile plot) (Field 2009). In this study, the frequency distribution (histograms) method was used to check normality in distribution of the data. Normality test was used as a supplementary or second method to confirm results using the visual method.

Normality is commonly assessed using various statistical significance tests, including: Anderson-Darling (A-D) test; Lilliefors corrected K-S test, Cramer-von Mises test (Razali and Wah 2011); D'Agostino skewness test, D'Agostino-Pearson omnibus test, Jarque-Bera test (Yap and Sim 2011); and Sharipo-Wilk test, and the Kolmogorov-Smirnov (K-S) test (Garson 2012). In this study, the Anderson-Darling test was used to check the distribution of the raw data using Minitab version 18 (Minitab Inc., 2018) at 5% level of significance. The significance tests generally compare scores in a sample to a normally distributed set of scores with the same mean and standard deviation; in which the null hypothesis states that the "sample distribution is normal" (Ghasemi and Zahediasl 2012). Compared with significance tests, the visual assessment methods are less precise (Ghasemi and Zahediasl 2012), and do not guarantee that a dataset is normally distributed; (Altman and Bland 2009; Field 2009). The Anderson-Darling test used in this study partly because it is commonly used in field engineering studies (Engmann and Cousineau 2011) and considered suitable for comparison of small samples (<30 or 40) (Ghasemi and Zahediasl 2012). The two hypotheses tested to check for normality were:

H_o: $\mu_i \sim N(0, \sigma^2)$

H_a: $\mu_i \neq N(0, \sigma^2)$

H_o implies that data are normally distributed, while H_a indicates that the data are not normally distributed. For this study, the A-D test was used to check normality in distribution of the data because of the short data set comparison.

A second step in the statistical analysis involved using paired *t*-test and student *t*-test to compare the sample means of harvest time and handling time for the small box and semi-automatic bin handling technologies. The field data for the two years were not comparable due to several reasons. First, data for 2017 were from harvesting a single field. Thus, the two harvesters were tested under similar experimental units or conditions. In contrast, data for 2018 were obtained from the two harvesters tested or operated in separate farm fields with different field conditions. Second, a frost damage adversely affected wild blueberry yields throughout the Maritimes. Consequently, the means comparison was analyzed separately for the data for 2017 and 2018.

During 2017, the two harvesting technologies were operated side by side in a single field. To quantify and compare the handling time and harvest efficiency of both harvesters, paired *t*-test was used to determine the mean difference of harvest efficiency associated with the small box and semi-automatic bin handling systems. A paired *t*-test was applied to the data for 2017, because the data for 2017 were obtained from similar experimental units with equal numbers of replicates (Montgomery 2017). The assumption of normality is important in order to perform the paired t-test. The paired t-test was performed using the equation (Montgomery 2017):

$$t = \frac{\bar{d}}{S_d / \sqrt{n}} \tag{3.6}$$

where t is the student's t distribution, and $\bar{d}$ is the difference between the means associated with each parameter considered for the semi-automatic bin handling system and small box handling system. S_d represents the standard deviation difference of the data sample of the semi-automatic bin handling system and small box handling system and n is the sample size. The hypotheses tested for harvest time was:

H_o: $\mu_B - \mu_S = \mu_d = 0$

H_a: $\mu_B - \mu_S = \mu_d \neq 0$

H_o implies that there is no difference between the sample mean of harvest time of semi-automatic bin handling system (μ_B) and small box handling system (μ_S), while H_a indicates that difference between the sample mean of harvest time of semi-automatic bin handling system (μ_B) and small box handling system (μ_S), is not equal to zero. Similarly, hypotheses tested for handling time was:

H_o: $\mu_B - \mu_S = \mu_d = 0$

H_a: $\mu_B - \mu_S = \mu_d \neq 0$

H_o implies that there is no difference between the sample mean of handling time of semi-automatic bin handling system (μ_B) and small box (μ_S), while H_a suggests that the difference between the sample mean of handling time of semi-automatic bin handling system (μ_B) and small box (μ_S) is not equal to zero.

As noted earlier, data for study year 2018 were collected from two different farms, and the two harvesting technologies applied at different sites. Thus, instead of the paired t-test, the two sample student's t-test was carried out to compare the harvest efficiency and handling time of the harvesting technologies. Equal variance and normality assumptions are important condition for the two-sample student t-test (Montgomery 2017). If the variance of both populations are equal ($\sigma_B^2 = \sigma_S^2$), the two sample t-test is assessed using (Montgomery 2017):

$$t = \frac{\overline{y_B} - \overline{y_S}}{S_P\sqrt{\frac{1}{n_B} + \frac{1}{n_S}}} \tag{3.7a}$$

where t is the student's t distribution, $\overline{y_B}$ denotes sample S_P mean for the semi-automatic bin handling system and $\overline{y_S}$ is the sample mean for small box system, is the estimate of the variance, n_B and n_S are the sample sizes of the semi-automatic bin handling and small box handling system, respectively. Variance (S_p^2) can be estimated using the equation (Montgomery 2017).

$$S_P^2 = \frac{(n_B - 1)S_B^2 + (n_S - 1)S_S^2}{n_B + n_S - 2} \tag{3.7b}$$

where t is the student's t distribution, and n_B and n_S are the sample sizes of the semi-automatic bin handling and small box handling system, respectively. S_B^2 and S_S^2 are the individual sample variances associated with the semi-automatic bin handling and small box handling system, respectively. If the variance for both populations are unequal ($\sigma_B^2 \neq \sigma_S^2$), the two sample t-test is investigated using the relationship (Montgomery 2017):

$$t = \frac{\overline{y_B} - \overline{y_S}}{\sqrt{\frac{S_B^2}{n_B} + \frac{S_S^2}{n_S}}} \tag{3.8}$$

where all the variables are as defined above.

The hypotheses tested for harvest time were:

H_o: $(\mu_B - \mu_S) = 0$,,

H_a: $(\mu_B - \mu_S) \neq 0$,,

H_o implies that there is no difference in the sample mean of harvest time for the semi-automatic bin handling system (μ_B) and the small box handling system (μ_S), while H_a implies that the difference in sample mean of harvest time for the semi-automatic bin handling system (μ_B) and small box handling system (μ_S) is not equal to zero. A similar hypotheses was tested for handling time:

H_o: $(\mu_B - \mu_S) = 0$,,

H_a: $(\mu_B - \mu_S) \neq 0$,,

H_o implies that there is no difference in the sample mean of handling time of semi-automatic bin handling system (μ_B) and the small box handling system (μ_S), while H_a implies that the difference in sample mean of handling time of semi-automatic bin handling system (μ_B) and small box handling system (μ_S) is not equal to zero.

The null hypothesis (H_o) was rejected if p-value > 0.05. Minitab 18 (Minitab Inc., 2018) was used to perform the statistical analysis.

3.3.6 Regression Modeling

The paired *t*-test and student *t*-test were used to compare the sample means of harvest time and handling time for the two harvest handling technologies. However, the paired *t*-test and student *t*-test do not give information about the nature of any relationship between berry yield and dependent variables of interest such as harvesting handling technology and level of weed coverage. To evaluate this, a regression model was developed, as follows,

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_1 X_2 + e \quad (3.9)$$

where Y represents wild blueberry yield (kg ha^{-1}), X_1 is weed coverage dummy variable, X_2 is a dummy variable for wild blueberry harvesting technology and X_1X_2 is an interaction term. β_0 is the intercept term, β_i (i =1-3) are regression coefficients, and e the residual error. Descriptive statistics of the variables used in the regression analysis are summarized in Table 3.2.

Table 3.2: Description of variables and statistics summary of data used in regression analysis.

Variable	Description of variable	Sample mean	Sample SD	Maximum	Minimum
(a) 2017 data					
Yield	Continuous variable (kg ha^{-1})	6517.00	1443.00	8290.00	3450.00
Weed coverage	Binary variable (1- low weed coverage, 0- high weed coverage)	-	-	1.00	0.00
Technology	Binary variable (1- bin handling technology, 0- small box system)	-	-	1.00	0.00
(b) 2018 data					
Yield	Continuous variable (kg ha^{-1})	1790.00	197.40	2053.50	1411.70
Weed coverage	Binary variable (1- low weed coverage, 0- high weed coverage)	-	-	1.00	0.00
Technology	Binary variable (1- bin handling technology, 0- small box system)	-	-	1.00	0.00

Notes: Sample mean and standard deviation for dummy variables were not reported because they have no meaning.

3.4 Results and Discussion

3.4.1 Normality Assessment

Results of the normality test using both the visual (or graphical) assessment and Anderson-Darling test methods are summarized in Table 3.3 and Figure 3.3 and 3.4. The visual results for 2017 data suggest that the distribution of the harvest time and box handling time data do not follow a bell shape, suggesting a non-normal distribution (Figure 3.3a and 3.3b). The Anderson Darling test results are consistent with the visual test results. Specifically, the berry harvest time and box handling time data are not normally distributed as the *p*-values are not statistically significant ($p < 0.05$) (Table 3.3). A cubic transformation was used to normalize the distribution of the harvest time data, while a log transformation was used to normalize the distribution of the handling time data. After transformation of the raw data, visual results showed that the distribution of difference between the harvest time and handling time is still not normal (Figure 3.3c and 3.3d). However, the quantitative results (using Anderson-Darling test) for harvest time ($p = 0.51$) and handling time appears to be normal ($p = 0.55$) (Table 3.3). In other words, the visual results are not consistent with the quantitative results. Anderson-Darling test results are considered in this study because of its precision and accuracy compared to quantitative assessment.

Results of the normality test of 2018 data for harvest time (Figure 3.4a and 3.4b) and handling time (Figure 3.4c and 3.4d) using the visual (graphical) assessment method indicates that the raw data for handling time and harvest time do not follow a bell shape, suggesting a non-normal distribution. However, analysis using the A-D test suggest a normal distribution of the raw handling time and harvest time data ($p > 0.05$) (Table 3.3). As noted earlier, where the test conclusion using the graphical approach conflicts with the A-D test results, the Anderson-Darling test results are considered.

In 2017, harvest time and handling time data was transformed to attain normal distribution of data. A cubic transformation for harvest time and log transformation for handling time was used to normalize the distribution of raw data. In 2018, harvest time and handling time result suggest a normally distributed data using A-D tests. A-D test results (i.e., qualitative assessment) were considered for both years. Normal distribution of raw data leads towards the statistical analysis using paired *t*-test and two-sample student *t*-test.

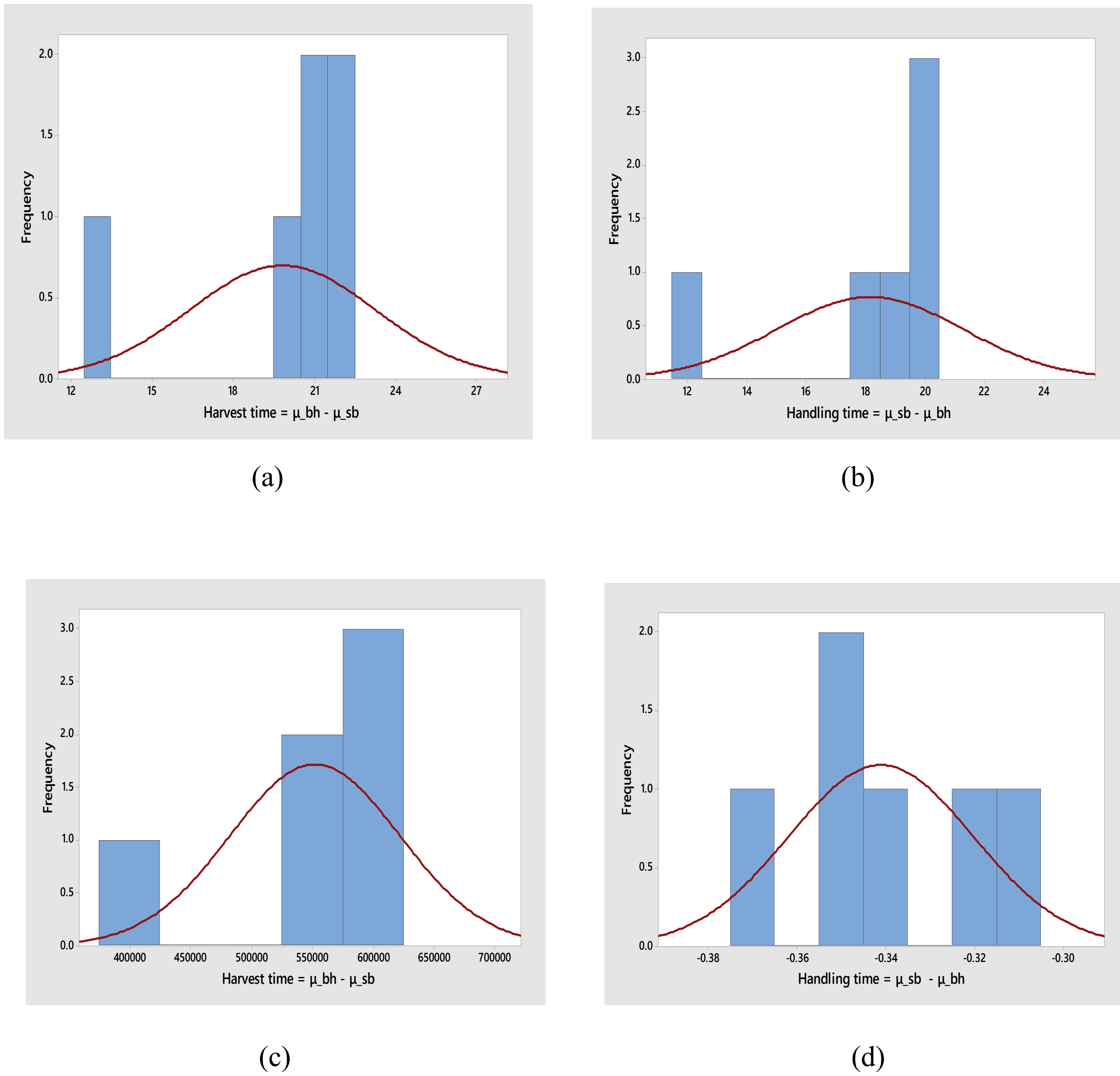
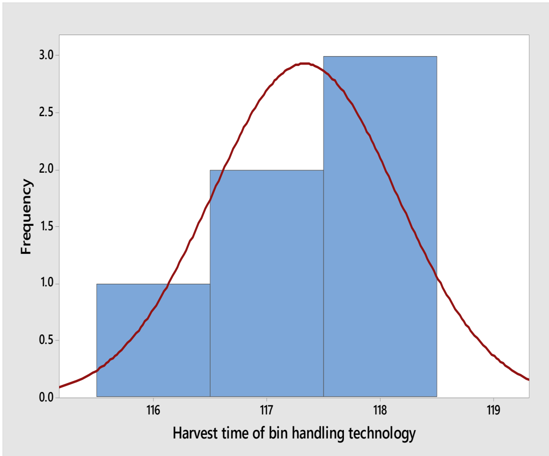
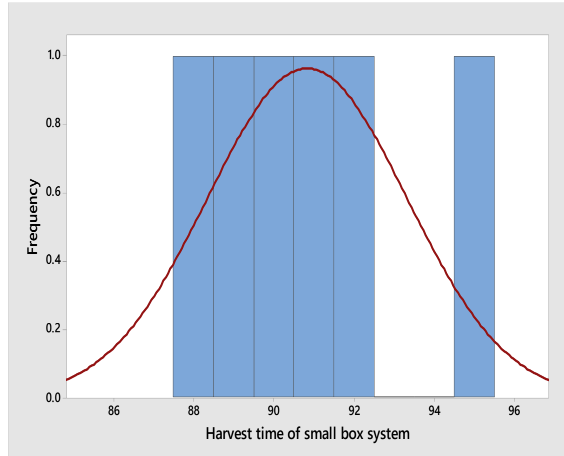


Figure 3.3: Histogram plots of harvest time and handling time for small box and bin handling systems, to check normality assumption for paired t-test (2017 data).

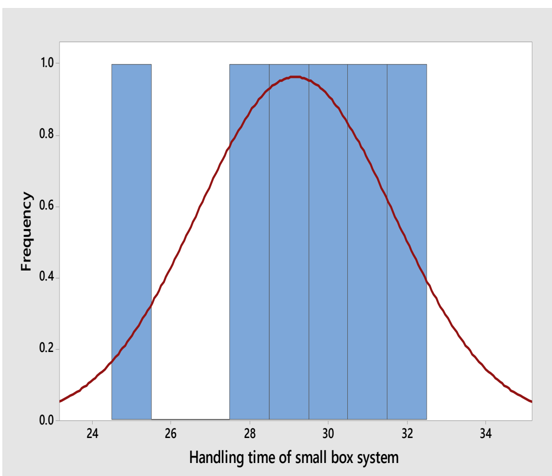
Notes: (i) Figure (a) and (b), normality assumption is checked using raw data.
(ii) Figure (c) and (d), normality assumption is checked using transformed data.



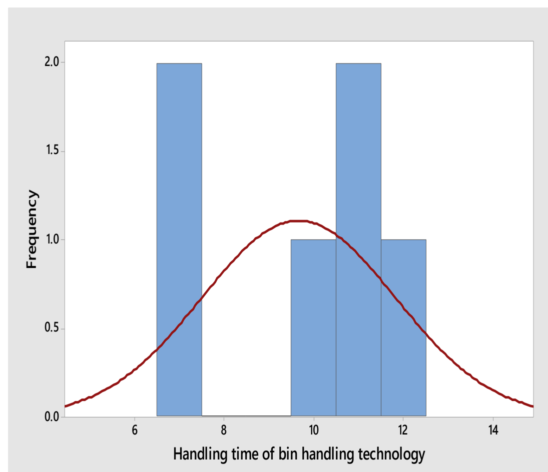
(a)



(b)



(c)



(d)

Figure 3.4: Histogram plots of harvest time and handling time for small box and bin handling systems, to check normality assumption for student t-test (2018 data).

Notes: Normality assumption is checked using raw data.

Table 3.3: Summary results of Anderson Darling (A-D) test to check normality assumption, 2017 and 2018 data.

(a) 2017 data	Mean	Standard deviation	Number of replications	Anderson-Darling Test	
				statistic	*p*-value
Harvest time	19.50	3.27	6	0.89	0.00
Handling time	-18.17	3.12	6	0.90	0.00
Harvest time (transformed)[1]	540909.00	63571.00	6	0.63	0.51
Handling time (transformed)[2]	-0.34	0.02	6	0.26	0.55
(b) 2018 data					
Harvest time (small box system)	90.83	2.48	6	0.20	0.76
Harvest time (bin handling system)	117.30	0.81	6	0.54	0.09
Handling time (small box system)	29.17	2.48	6	0.20	0.76
Handling time (bin handling system)	9.66	2.16	6	0.49	0.12

[1] Cubic transformation was used to normalize the distribution of the harvest time data.
[2] Log transformation was used to normalize the distribution of the handling time data.

3.4.2 Statistical Analysis

Paired *t*-test and two sample student *t*-test using two-tail *t*-test were performed to compare the harvest time and handling time data of the alternate box handling system. The results of the paired *t*-test suggest that harvest time of the semi-automatic bin handling system is significantly different than small box system, as *p* value ($p = 0.00$) is less than the significance level of 0.05. Similarly, handling time of the semi-automatic bin handling system is significantly different than the small box system ($p = 0.00$) as shown in Table 3.4. For the 2018 data, harvest time of semi-automatic bin handling system is significantly different from the sample mean of small box system ($p = 0.00$) (Table 3.4). The results also suggest that the sample mean of handling time of semi-automatic bin handling system is significantly different from the sample mean of small box system ($p = 0.00$).

Both years results were consistent, despite different field conditions. Paired *t*-test and two sample student *t*-test were used to compare the harvest and handling time efficiency of two bin handling system and do not give information about the relationship of wild blueberry yield with alternate harvesting technology and weed coverage. Regression analysis was performed to examine the effect of weed coverage and harvest technology on yield.

Table 3.4: Summary results of harvest time and handling time using paired *t*-test and student *t*-test.

	Sample mean	Standard deviation	*t*-statistic	*p*-value
(a) Paired *t*-test for 2017 data[1]				
Harvesting time	19.83	3.63	14.16	0.00
Handling time	18.17	3.13	14.24	0.00
(b) Student *t*-test for 2018 data[2]				
Harvesting time (bin handling system)	117.33	0.81	24.83	0.00
Harvesting time (small box system)	90.83	2.48		
Handling time (bin handling system)	29.17	2.48	14.51	0.00
Handling time (small box system)	9.67	2.16		

[1]Data represents the difference between sample mean of the small box and bin handling systems.
[2]Data represents the comparison of sample mean of small box and bin handling systems.

3.4.3 Effect of weed coverage and harvest technology type on yield

Regression results of the effect of weed coverage and harvest technology type on wild blueberry yield are summarized in Table 3.5, separately for 2017 and 2018. For 2017 data, the parameter estimate for weed coverage dummy variable was significantly different (as *t*- statistic is 2.54 at 5% level of significance) (Table 3.5). The results suggest that average yield in fields with low weed coverage area was higher than for fields with high weed coverage by 2,223 kg ha^{-1}. Yields associated with the semi-automatic bin handling technology were higher than the small box system, although the difference was not statistically different (Table 3.5). The use of semi-automatic bin handling technology resulted in 579 kg ha^{-1} in extra yield compared with the small box system. The interaction effect between the low weed coverage and semi-automatic bin handling technology yields are not statistically different from high weed coverage with small box system yield. Thus, the effect of low weed coverage on wild blueberry yield does not depend on the technology type, and vice versa.

In 2018, wild blueberry yield was 68% lower compared with the estimate for 2017, partly due to frost damage to wild blueberries across Nova Scotia in 2018. In 2018, about 70% of wild blueberry crop damaged due to frost in Nova Scotia (Rideout 2018). The parameter estimate for the weed coverage was significantly different (as t - statistics is 2.73 at 5% level of significance) (Table 3.5). Furthermore, average yield in fields with low weed coverage was higher than to fields with high weed coverage by 343 kg ha^{-1}. Yield associated with low weed coverage and semi-automatic bin handling technology were not statistically different from high weed coverage with small box system yield.

The regression results for the year 2017 are consistent with 2018 results. The results indicate that high box handling efficiency increases the harvest time compared to small box system. It allows semi-automatic bin handling systems to harvest extra hectares of wild blueberry (i.e., harvesting additional quantity of berry) in both years. Manual handling of boxes by harvester support worker makes the small box system less efficient compared to semi-automatic bin handling system.

Table 3.5: Summary of estimates of regression model

Variable name	Estimates
(a) 2017 data	
Constant	5183.23 (8.37)**
Weed coverage	2223.48 (2.54)*
Technology	579.65 (0.66)
Weed coverage*Technology	-271.64 (-0.21)
Adjusted R^2	0.44
Number of observations	12
(b) 2018 data	
Constant	1680.86 (18.91)**
Weed coverage	343.11 (2.73)*
Technology	-5.00 (-0.04)
Weed coverage*Technology	-238.18 (-1.34)
Adjusted R^2	0.39
Number of observations	12

*Significant at 0.05
**Significant at 0.01
Notes: Values in parenthesis are t-statistics

3.4.4 Harvest and Handling time

Small box and semi-automatic bin handling systems vary in terms of harvest time and berry handling time (Table 3.6 and 3.7). In 2017, for the small box handling system, the percentage of time spent in picking berries in a low weed coverage area was 71%, and 74% for the high weed coverage area of the field. The average percentage of time spent in picking berries for both low and high weed coverage areas was 72% (Table 3.6). By comparison, the average for the semi-automatic bin handling system was 88% and ranged from 87% (low weed coverage area) to 89% (high weed coverage area). The high harvest efficiency of the semi-automatic bin handling system is due to automated mechanical handling of large bins. In general, harvest time of box handling systems depends on factors such as: i) experience of harvester operator ii) weed variability and iii) berry yield intensity. An experienced operator can be more time efficient during harvest. The handling of boxes takes extra time during blueberry field operation. Harvest time of the small box system increased in high weed (i.e., low berry yield) fields, due to less number of boxes being loaded and unloaded. By comparison in high yielding fields, efficiency is reduced due to greater number of boxes being loaded and unloaded.

In 2018, berry production was adversely affected by frost, and influenced the harvest time efficiency. Frost damage affected plant growth and development of plant tissue essential for berry fruit production and, ultimately, reduced berry yield. The lower berry yields increased the harvest time and decreased handling time (less number of boxes loaded and unloaded due to reduction in yield). The average harvest time for the small box handling system was 76%, and ranged from 74% (for low weed coverage area) to 77% (for high weed coverage area). By comparison, for the semi-automatic bin handling system, the percentage of harvest time for low weed coverage area was 97% and 98% for the high weed coverage area of the field, for an average of 98%. Harvest time and handling times data are summarized in table 3.6 and 3.7.

Box handling time during a harvesting operation includes time to load and unload the boxes during the harvesting operation. For the mechanical harvester with a small box handling system, the average percentage of total time spent in manually handling of boxes during harvest operation is 28% in 2017 and 25% in 2018 (Table 3.7). The small box handling system takes more time in loading and unloading of boxes because it required manually switching (or loading and unloading) boxes by the second farm worker. The small box handling technology was less efficient in high yielding fields due to greater number of boxes being loaded and unloaded. The small box technology takes an average of 29% of 2017 total handling time and 31% of total handling time in 2018 in loading of empty boxes onto the harvester, compared with 71% in 2017 and 69% of total handling time in 2018 in unloading of full boxes from the harvester. Empty boxes were loaded on the harvester manually, while berry filled boxes were unloaded both by the tractor operator and a second farm worker manually.

For the semi-automatic bin handling technology, in 2017, 13% of the time was spent loading and unloading bins. The semi-automatic bin handling technology used an average 41% of total handling time in loading and spent 59% of time in unloading of the large bins (Table 3.7). In contrast, in 2018, 8% of total handling time was spent in loading and unloading of boxes. The semi-automatic bin handling technology spent an average 30% of total handling time in loading, and 70% of time in unloading of boxes. Total handling time was spent to adjust the boxes using the mechanical hydraulic device. Empty bins were loaded and unloaded with the help of an additional tractor loader with forks. Handling time of semi-automatic bin handling system is shown in Table 3.7.

Harvest time efficiency of the semi-automatic bin handling system was 88% in 2017 and 98% in 2018. By comparison harvest time using the small box handling technology was 72% in 2017 and 76% in 2018. Thus, harvest time efficiency was significantly higher for the semi-automatic bin handling technology than for the small box handling technology by 22% in 2017 and 29% in 2018 (Table 3.7).

Table 3.6: Harvest time and handling time (%) of small box and bin handling system, according to field type.

Crop/Weed Variability	Small box handling system		Bin handling system	
	2017	2018	2017	2018
(a) Harvest time[1]				
Low weed coverage (with high berry yield)[2]	70.55 (0.48)	74.16 (0.83)	87.05 (0.02)	97.22 (0.48)
High weed coverage (with low berry yield)[3]	73.88 (6.02)	77.22 (1.73)	89.44 (1.92)	98.26 (0.11)
Average	72.22 (4.23)	75.69 (2.06)	88.75 (1.55)	97.77 (0.68)
(b) Handling time[4]				
Low weed coverage (with high berry yield)	29.45 (0.48)	25.84 (0.83)	13.61 (0.48)	6.38 (0.96)
High weed coverage (with low berry yield)	26.12 (6.02)	22.78 (1.73)	11.66 (2.20)	8.61 (1.27)
Average	27.77 (4.23)	24.30 (2.06)	12.63 (1.78)	8.05 (1.80)

Notes: Values indicate means with standard deviations in parentheses.
[1]Harvest time is the period during which the mechanical harvester is picking fruit.
[2]Inner area of the field considered as high yielding and low weed coverage area of the field based on visual observation.
[3]Outer area of the field is considered as low yielding and high weed coverage area of the field based on visual observation.
[4]Handling time is the time during which the worker is loading and unloading the empty/full boxes/bins manually/mechanically.

Table 3.7: Harvest time and handling time (%) for small box and bin handling system, according to field type.

	Small box handling system		Bin handling System	
	2017	2018	2017	2018
(a) Harvest time[1]				
Harvest time	72.27 (4.23)	75.69 (2.06)	88.47 (1.61)	97.77 (0.68)
(b) Handling time[2]				
Loading time[3]	8.19 (1.61)	7.66 (0.62)	5.13 (0.62)	2.36 (0.34)
Unloading time[4]	19.58 (2.72)	16.94 (1.80)	7.52 (1.39)	5.41 (1.72)
Total handling time	27.77 (4.23)	24.63 (2.06)	12.63 (1.78)	7.77 (1.70)

Notes: Values indicate means with standard deviations in parentheses.
[1]Harvest time is operationalized as the period during which the mechanical harvester is picking fruit.
[2]Handling time is the time during which the empty/filled boxes are replaced manually or mechanically.
[3]Loading time is the time during which the empty boxes are loaded on the harvester.
[4]Unloading time is the time during which the filled boxes are unloaded from the harvester.

3.4.5 Harvest Rate

On average, harvest rate was superior using the semi-automatic bin handling system technology compared with the small box technology, and consistent for both measures of harvest rate and for both years (Table 3.8). As expected, harvest rate also varied based on crop/weed intensity (i.e., low versus high harvestable berry yield). For example, in 2017, in low weed coverage area of the field, 1.01 tonnes of berries were harvested in an hour using the small box system, compared with 1.20 tonnes per hour for the semi-automatic bin handling system (Table 3.8). High harvest rate of semi-automatic bin handling system is due to its high field efficiency. For the high weed coverage areas of the field, 0.90 t h^{-1} was harvested using the semi-automatic bin handling system compared with 0.68 t h^{-1} of small box system. The high harvest time efficiency of bin handling system is due to semi-automated handlings of bins (i.e., loading and unloading of large bins) allows bin handling system to harvest extra tonnes of berries in a similar time period compared to small box system.

The average variability for harvest rate (t h^{-1}) in low and high weed coverage were higher for small box handling system compared with semi-automatic bin handling system (Table 3.8) Similarly, average variability for harvest rate (t h^{-1}) in low and high weed coverage for small box handling system were higher in 2017 compared to 2018 data. By comparison, average variability for semi-automatic bin handling system was higher in low weed coverage area in 2017 and high weed coverage area in 2018.

Less berries per hour were harvested in 2018 using either technology, partly due to lower yields from the frost damage (Table 3.8). In the low weed coverage area, on average, 0.42 t h^{-1} was harvested using the small box handling and 0.35 t h^{-1} in high weed coverage areas. By comparison,

Table 3.8: Harvest rate of small box and bin handling systems, according to field type.

Crop/Weed variability	Small box handling system		Bin handling System	
	2017	2018	2017	2018
(a) Harvest Rate (tonnes per hour)				
Low weed coverage (with high berry yield)[1]	1.01 (0.20)	0.42 (0.01)	1.2 (0.13)	0.47 (0.03)
High weed coverage (with low berry yield)[2]	0.68 (0.32)	0.35 (0.10)	0.91 (0.13)	0.42 (0.49)
(a) Harvest Rate (hours per hectare)				
Low weed coverage (with high berry yield)	7.39 (0.05)	7.03 (0.07)	5.98 (0.12)	5.36 (0.06)
High weed coverage (with low berry yield)	7.05 (0.55)	6.75 (0.15)	5.82 (0.01)	5.30 (0.02)

Notes: Values indicate means with standard deviations in parentheses.
[1]Inner area of the field considered as high yielding and low weed coverage area of the field based on visual observation.
[2]Outer area of the field is considered as low yielding and high weed coverage area of the field based on visual observation.

Table 3.9: Field efficiency (%) of small box and bin handling systems, according to field type.

Crop/Weed variability	Small box handling system		Bin handling System	
	2017	2018	2017	2018
Low weed coverage (with high berry yield)[1]	74.16 (5.77)	77.81 (1.73)	89.42 (2.08)	98.04 (0.47)
High weed coverage (with low berry yield)[2]	70.27 (0.58)	74.16 (0.59)	88.05 (0.47)	97.79 (0.58)

Notes: Values indicate means with standard deviations in parentheses.
[1]Inner area of the field considered as high yielding and low weed coverage area of the field based on visual observation.
[2]Outer area of the field is considered as low yielding and high weed coverage area of the field based on visual observation.

0.47 t h^{-1} was harvested using the semi-automatic bin handling system in low weed coverage area, and 0.42 t h^{-1} in high weedy area. Harvest rate measured in tonnes per hour for the two harvest handling technologies is summarized in Table 3.8, according to the level of weed incidence or berry vine coverage. Harvest rate (t h^{-1}) was higher by 19% for the semi-automatic bin handling system than the small box system for the 2017 trial, and 17% for the 2018 trials.

Similarly, on average, harvest rate (h ha^{-1}) was higher for the semi-automatic bin handling system compared with the small box handling system for 2017 and 2018. The more efficient semi-automatic bin handling system allows for harvesting a larger area per given time compared to the small box system. The mechanical harvester with the semi-automatic bin handling system has higher field efficiency as shown in Table. 3.9. In the 2017 farm trials, the semi-automatic bin handling system required 5.98 hours on average, to cover a hectare with low weed coverage, compared to 7.39 hours for the small box system. By comparison, in fields with high weed coverage, the semi-automatic bin handling system required 5.82 hours to harvest 1 ha, compared with 7.05 hours for the small box handling.

Variability in harvest rate (h ha^{-1}) in low weed coverage fields was lower in 2017 for the small box system compared with the semi-automatic bin handling system. By comparison, harvest rate (h ha^{-1}) variability in high weed coverage fields was higher in 2017 for the small box handling system compared with the semi-automatic bin handling system (Table 3.8). Similarly, in both 2017 and 2018, in high weed coverage areas of farm, variability in harvest rate (h ha^{-1}) for the small box handling system was higher than the semi-automatic bin handling system.

Frost damage in 2018 affected harvest rate. Harvest rate measured in both t h^{-1} and h ha^{-1}, according to different field types are summarized in Table 3.8 for the trials in 2018. Given the lower yields in 2018, both harvesters required less time to complete harvesting a hectare. In the low weed coverage area (high berry yield) areas, on average, the small box handling system required 7.03 hours to cover a hectare and 6.75 hours in high weed coverage (low berry yield) areas. By comparison, 5.36 hours were used to cover a hectare using the semi-automatic bin handling system in low weed coverage areas, and 0.42 t h^{-1} in high weedy area.

3.5 Summary and Conclusions

Wild blueberry farmers are currently facing farm labour shortages and high labour wages specially during short harvesting seasons. These pressures have increased overall wild blueberry harvesting costs. Wild blueberry farmers in Atlantic Canada are seeking alternatives to the traditional small box handling system, such as the semi-automated bin handling technology, which have higher harvest field efficiency. In this study, a wild blueberry mechanical harvesters with the small box and semi-automatic bin handling systems with double-head configurations were evaluated in terms of harvest handling efficiency. Harvest time, box handling time and harvest rate data were used to quantify and compare the harvest efficiency of the two harvest handling systems. The time efficiency and berry harvest of the two box handling systems were compared using paired *t*-test and student *t*-test. In addition, regression analysis was performed to check the effect of level of weed coverage and type of harvest handling technology on berry yield. Data for this study were collected from on-farm field trials during 2017 and 2018. Data for two years were analyzed separately due to differences in fields conditions.

Harvest time efficiency of the semi-automatic bin handling system was higher by 22% in 2017 and 29% in 2018 compared with the small box handling system. The results suggest that because of the mechanical handling of boxes using the semi-automatic bin handling system, it required less time in loading and unloading of boxes compared to manual handling of small boxes for the small box system. Higher efficiency of the semi-automatic bin handling systems allows for harvesting additional acreage and berries for a given time period. For example, on average, the semi-automatic bin handling system harvested a hectare in 5.98 hours compared to 7.39 hours for the small box system. In addition, berries harvested using the semi-automatic bin handling system was higher than the small box system per unit time. On average, mechanical harvesters with the small box handling system harvested 1.01 tonnes of berries per hour, compared with 1.20 tonnes per hour for the semi-automatic bin handling system. In summary semi-automatic bin handling system with the hydraulic system are more field efficient, with potential to save labour cost and harvest additional area per unit time.

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CHAPTER 4: STOCHASTIC AND PARAMETRIC PARTIAL BUDGET ANALYSIS OF WILD BLUEBERRY HARVESTING TECHNOLOGIES

4.0 Abstract

Wild blueberry mechanical harvester's account for a substantial share of total production cost. Producers are anticipating to switch from traditional small box system to semi-automated bin handling system and required useful information about economic performance and uncertainty associated with the harvesting. Mechanical harvesters with traditional small box and semi-automatic bin handling technologies are commonly used for wild blueberry harvesting on commercial scale in Atlantic Canada and Maine, USA. However, their economic performance in terms of costs and returns to farmers has not been investigated. This study evaluated the profitability associated with the switching from a traditional small box to the semi-automatic bin handling harvesting technology. Different partial budgeting approaches including i) deterministic partial budgeting; ii) parametric partial budgeting; and stochastic partial budgeting approach was used to investigate and compare the economic profitability of the wild blueberry mechanical harvesters. Production data for the economic analysis were obtained from field trials conducted in 2017 and 2018 in Nova Scotia, Canada. Financial and economic time series data were obtained from wild blueberry producers, manufacturers, and government and private organizations. Data for the two years were analyzed separately, due to different field conditions. The result indicated that net change in profit was \$674.69 ha^{-1} in 2017 and \$175.71 ha^{-1} in 2018 and implies that switching from the small box handling system to the semi-automated bin handling technology is financially viable. Sensitivity analysis was also conducted to access the changes in berry production and selected economic parameters. Sensitivity analysis results suggest that wild blueberry production and labour wage was positively influenced and interest rate on loans was negatively influenced when switching from small box to bin handling technology in all three scenarios considered. The stochastic partial budgeting results were also consistent with deterministic partial budgeting results.

4.1 Introduction

Profitability and competitiveness of the wild blueberry industry in Atlantic Canada will largely depend on availability of labour-saving and cost-effective mechanical harvesters to reduce overall cost of production (Gallardo and Sauer 2018; Yiridoe 2018). Producer price of wild blueberries has stagnated since 1991 (Figure 1.2), and have actually declined since 2014 (Statistics Canada 2017). On the other hand, farm labour wages[1] and other wild blueberry production costs are projected to increase in the foreseeable future (Strik and Yarborough 2005; Takeda et al 2013; Hu et al 2016; Rodgers et al 2017).

Wild blueberry harvest cost accounts for a substantial component of total production cost (Yarborough 2000; Gallardo and Zilberman 2016; Esau 2017), and current wild blueberry harvesting systems are labour-intensive (Yarborough and Hergeri 2010). At the same time, availability of farm labour for harvesting field crops, berries and fruits is a major challenge in the Maritimes (Yarborough 2000; Farooque et al 2014). Cost-effective mechanical harvesting technologies have potential to improve labour productivity by about 60 times (Takeda et al 2013), while at the same time reducing harvest costs by up to 85% (Zhang et al 2016; Gallardo et al 2018).

Small box and semi-automatic bin handling systems are two technologies developed for wild blueberry mechanical harvesting in Atlantic Canada and Maine, USA. However, their economic performance in terms of impacts on costs and returns to farmers have not been evaluated. This study investigated whether the semi-automatic bin handling harvesting technology would improve profitability relative to the traditional small box handling system. A wild blueberry farmer

[1] In 2019, the government of Nova Scotia announced that minimum wage will increase by $0.55 each year, for the next 3 years. Specifically, minimum wage rate will increase by $0.55 to $11.55 in 2019 and to $12.65 by 2021. Starting from April 2022, the minimum wage rate in NS will be inflation-adjusted annually, using the Bank of Canada's Consumer Price Index (Government of Nova Scotia 2019).

may not automatically switch from the small box technology to semi-automatic bin handling system without considering the economic viability of the new berry harvest handling technology. Other factors associated with the berry harvest handling technology adoption decision include technical (engineering) performance of the harvesting technology, user-friendliness, and socioeconomic factors (Gallardo and Zilberman 2016), but these are beyond the scope of the current study.

The purpose of this study was to compare the economic performance of two blueberry mechanical harvesting technologies involving a small box handling technology and a semi-automatic bin handling technology. The first objective was to use deterministic partial budgeting methods to determine the economic impacts of switching from the small box handling to semi-automatic bin handling technology. Partial budgeting methods were used to quantify and compare the economic performance of the two blueberry mechanical harvesting technologies. In a second objective to account for uncertainty in important parameters that influence economic performance, a stochastic partial budgeting model was developed and used in a secondary analysis, and net changes in profit compared.

4.2 Applications of Partial Budgeting in Agricultural Management: A Review

Partial budgeting methods are commonly used to examine the effects of a small change within an enterprise (Dalsted and Gutierrez 1990); only those costs and benefits affected by the change are considered in the analysis (Flinn et al 1991). An initial step in a partial budget analysis involves identifying the proposed change and the associated alternatives (Boehlje and Eidman 1984; Kay et al 2016). A second step involves identifying key positive and negative effects of the change (Dhoubhadel and Stockton 2010). Finally, accurate estimates of important positive and negative effects are determined, and then used to calculate net change in profit (Dhoubhadel and Stockton 2010).

Although partial budgeting has relevant and important uses and applications, the method also has some limitations. First, it compares only two alternatives at a time, to identify the financially viable alternative, when many alternatives may need to be considered (Pflueger et al 1993). Second, reliability of the partial budgeting results may be limited due to uncertainty or variability associated with important input and parameter values used in the analysis (Dhoubhadel and Stockton 2010). The partial budgeting methods commonly used to examine changes in agricultural production may be classified into (Alimi 2000; Dijkhuizen et al 1995): i) deterministic partial budgeting; ii) parametric partial budgeting; and iii) stochastic partial budgeting.

Deterministic Partial Budgeting

In deterministic partial budget analysis, single values are assigned to particular costs and benefits parameters. Often such a base analysis considers point estimates as "true" values, and does not consider uncertainty associated with important costs and benefits variables.

In practice, input costs, output prices and other financial information change with time and economic conditions. Thus, deterministic partial budgets often rely on assumed or best input and output values. Examining how sensitive costs and benefits are to changes in the levels of prices, inputs, and outputs may be insightful. In addition, decision makers may be interested in what break-even output levels or prices are required to make a change profitable.

Parametric Partial Budgeting

Parametric partial budget analysis allow for evaluating the effects of changes or uncertainty in selected costs and benefits parameters on net change in profit (Dillon and Hardaker 1980; Flinn et al 1984; Alimi 2000). Parametric partial budget analysis is also sometimes referred to as sensitivity analysis (Flinn et al 1991). Two alternative ways of undertaking sensitivity analysis include: i) one-way sensitivity analysis; and ii) two-way sensitivity analysis. One-way sensitivity analysis examines the impact of changing one parameter at a time on the model results. By comparison, two-way sensitivity analysis examines the impact of changing two or more parameters on net change in profit.

Partial budgeting analysis can be parametrized by evaluating discrete values of a variable, such as low, average, and high levels of a particular variable (Kay et al 2016). Recent examples of studies which used this approach include Brumfield et al (2000) and Doupe and Lymbery (2002). A plausible range for the parametric analysis may also consider the 95% confidence interval for a point estimate used in the base or deterministic analysis. Examples of such applications include Rafiee et al (2010) and Bastidas et al (1999). Another approach commonly used in parametric partial budget analysis involves changing (i.e., increasing or decreasing) a parameter by a desired percentage level. Studies that used this approach include O'Brien et al (1998), Sharmasarkar et al (2001), and Swinkels et al (2005). A comparison of results can show how sensitive the net change in profit is to the selected range of a given parameter.

Parametric budgets allow for ex ante investigation or consideration of new production or management possibilities or scenarios, if changes occur in particular variables. Sensitivity analysis generates outcomes on only a selected range of a given or desired input or parameter. To overcome this limitation, stochastic partial budget approaches allow for generating a wide range of possible outcomes of an uncertain variable.

Stochastic Partial Budgeting

Stochastic analysis is based on assumed statistical properties of selected important variables in the economic analysis. The method involves assigning probabilities to the possible values of important variables in a farm budget, and generating a probability distribution of the budget outcomes. The stochastic budgeting method can account for risk associated with the measure of financial performance. The method provides a specific range of financial performance to a decision maker for achieving a particular level of performance, over a period of time (Milham et al 1993).

Stochastic analysis can also be applied to partial budgeting. Stochastic partial budgeting addresses the uncertainty problem associated with deterministic partial budgeting by using a range of values to a variable between the highest and lowest, to create a probability density function (PDF). A combination of variables in the model and their probability distributions are used to determine the range and probability of final possible outcomes. The final outcome can be graphed as a Cumulative Distribution Function (CDF). The stochastic method can be applied to important variables in the analysis (e.g., output price, output level, interest rate, or labour wage).

Applications of Partial Budgeting in Agriculture

Partial budgeting methods have applications in agriculture; including crop production, animal production, agricultural engineering, etc.

Applications in Crop Production

Devi and Ponnarasi (2009) used deterministic partial budgeting methods to estimate and compare costs and revenues of a System of Rice Intensification (SRI) (i.e., a new rice cultivation system to increase rice productivity) with a conventional production method in Tamil Nadu, India.

The SRI system efficiently utilize land and water resources and labour, as well as protect groundwater from depletion, and soil from chemical pollution. Only those costs and benefits associated with the two production systems (e.g., input cost linked with seed, irrigation, chemical fertilizers and pesticides, and labour) are evaluated and compared. Harvest costs and transportation costs were not considered in this study. Devi and Ponnarasi (2009) found that switching from the conventional method to the SRI system generated additional Rs16,969 ($340 ha^{-1}) profit to growers. Cost reduction using the SRI technique were due to labour savings, plant protection chemicals (i.e., fertilizers and pesticides), and also involved using less seeds and irrigation water.

Gallardo and Brady (2015) compared the cost of using ladders versus platforms to harvest apples produced in Washington state, USA using a deterministic partial budgeting method. Only those costs and revenues that affect the harvesting operation were evaluated. Production costs such as pruning, fertilizers, pesticides, insecticides, and transportation costs were not included as these do not affect the harvesting operation. The results showed that switching from ladders to platforms for harvesting apple cost an extra $4.72 bin^{-1}. Also, a 13% increase in picking efficiency of the platform harvester was needed to cover the additional cost of using platforms for harvesting apples.

Brumfield et al (2000) combined deterministic and parametric partial budgeting methods to evaluate the economic costs and benefits of alternative vegetable farming methods, including Integrated Crop Management (ICM), conventional, and organic methods for three vegetable crops (i.e., tomatoes, sweet corn, and pumpkins) produced in Pittstown, New Jersey. The analysis considered only important costs and benefits that were expected to change due to the change in farming system. Results showed that ICM systems were more profitable than organic and conventional systems. Consumer willingness to pay a premium price (of 20-30% more) for organic products reduced total net returns to (US$2,629) compared with ICM (US$3,169) and conventional farming system (US$2,663). A sensitivity analysis to access the effect of changes in economic parameters (i.e., price and input costs) on net returns indicate that a 20% increase in prices of all three vegetable has a positive effect on net returns for all three production methods. Specifically, when prices and costs were decreased by 20% for tomatoes and pumpkins, ICM had the highest net returns compared with conventional and organic farming methods.

Pemsl et al (2004) assessed the impact of uncertainty in selected variables of Bt cotton varieties grown in India, and their effect on net revenue. A stochastic partial budgeting approach was used to assess farm level profitability of Bt cotton accounting for uncertainty of pest pressure, pest control effectiveness, and input and output prices. Monte Carlo simulations and stochastic parameters based on probability distributions were used to calculate changes in net revenue. Cumulative distribution functions of net revenues were compared using first-degree stochastic dominance (FSD) and second-degree stochastic dominance (SSD). Results revealed that uncertainty in the main variables (i.e., severity of pest pressure, potential yield, and input and output prices) influences profitability of Bt cotton and alternative crop protection methods.

Applications in Agricultural Engineering

O'Brien et al (1998) applied a combination of deterministic and parametric partial budgeting techniques to compare potential profitability of producing corn in the US Great Plains using subsurface drip irrigation (SDI) with an alternative center pivot irrigation technology. The analysis captured only those costs and returns that affect the farm operation (i.e., irrigation costs associated with both systems). Other corn production (e.g., fertilizers, pesticides, etc.) and harvesting costs were not included in this study as they do not directly affect the irrigation operation. Partial budgeting methods were applied on a pre-tax basis (without the impact of tax-deductible depreciation of capital investment). The results suggest that the center pivot sprinkler irrigation system had higher net returns (\$42 to \$57 ha^{-1}), for 38 and 65 ha farms compared with SDI. Investment cost per ha of the center pivot irrigation system increased as field size decreased, whereas SDI had US\$28 ha^{-1} advantage in smaller size fields (i.e., 13 ha). Sensitivity analysis indicated that, as corn price and yield increase, the SDI system was relatively more profitable compared with the center pivot irrigation system.

Alam et al (2009) using a deterministic partial budgeting model to compare alternate wetting and drying methods with conventional irrigation method of producing rice in Bangladesh. The analysis focused on only those costs and revenues that affected the irrigation system but excluded harvest and other production costs associated with rice production. Average values of irrigation costs were used in the deterministic model. Results showed that rice growers could earn additional Tk 4224 ha^{-1} using alternate wetting and drying method compared with the conventional irrigation method.

Applications in Animal Production

Legesse et al (2005) applied deterministic partial budgeting methods to assess the economic viability of raising goats managed using different feeding systems in Ethiopia. Two goat breeds (i.e., Arsi-Bale, n=27; and Somali, n=21, = 48 total goats) were managed under three different feeding systems (i.e., intensive, semi-intensive and extensive). Results showed that Somali breeds managed under semi-intensive feeding systems generated \$10.93 per animal more profit than the other two feeding systems. Arsi-Bale breed managed in all three feeding systems generated negative marginal rate of returns.

Verspecht et al (2011) applied a combination of deterministic and parametric partial budgeting methods to determine the impact of different stocking densities in rabbit production. In this study, only those costs and benefits that affect the stock densities were evaluated. Ventilation and watering systems cost were not included in this study as they as assumed not to play a significant part in this study (i.e., determining the impact of stocking densities in rabbit production). The results indicated that a reduction in stocking density by 50% (resulting in 7.5 rabbits per m²), compared with the standard 15 rabbits per m² generate negative farm income of €44 per doe. Sensitivity analysis results indicate that rabbit meat price has a higher impact in value added than rabbit feed price. For example, a 10% increase in feed price requires the stocking density to 12 rabbits per m² for breakeven.

4.3 Research Methods

4.3.1 Deterministic Partial Budgeting Analysis

In this partial budgeting study, the small box handling technology is the comparator or reference technology, while the semi-automatic bin handling technology is the new alternative to be compared with. Partial budgeting evaluation of the semi-automatic bin handling technology relative to hand raking, a little used wild blueberry harvesting system in Atlantic Canada, will likely generate results that make the new harvesting system highly artificially financially viable. In addition, given the limited use of this increasingly dated blueberry harvesting method, it was reasoned that partial budgeting analysis with hand raking as the comparator will not provide findings that are generalizable and relevant to most commercial wild blueberry farmers.

Wild blueberry farmers contemplating to switch from the small box system to semi-automatic bin handling system requires only a minor modification to the harvester system, and an additional $30,000 to upgrade to or purchase the semi-automatic bin handling system. The tractor and most components of the single head and double head harvesters used with the small box handling technology remain unchanged and are used with the semi-automatic bin handling technology. The upgrade involves a slight modification to the side berry conveyor to attach a debris hood system. Manual loading and unloading of boxes in the small box handling system is replaced by larger boxes in the bin handling system, which are loaded and unloaded by the tractor operator using a hydraulic system.

Personal communication with farmers and harvester manufacturers indicate that wild blueberry harvesters are typically used for about 280-320 hrs in a production year (Swinkles 2018). The harvestable acreage using the small box and semi-automatic bin handling technologies in a berry production year were estimated using the following equation:

$$H_{ai} = \frac{T_h}{HR} \tag{4.1}$$

where H_{ai} represents the harvestable area (ha) using harvest handling technology, i=1 for harvester with small box handling (S), and i=2 for harvester with semi-automatic bin handling system (B). T_h represents the total number of hours each mechanical harvester is assumed to operate during full season, which is 300. HR denotes harvest rate (h ha^{-1}) for each of the two harvest handling technologies (Table 4.1). The harvest rates and harvestable area as summarized in Table 4.1, by year and harvest technology.

A field harvest rate study, conducted as part of a larger research project, indicates that the semi-automatic bin handling system is 22-29% more efficient than the small box handling system. The higher harvest efficiency of the semi-automatic bin handling system is due to the mechanical handling of the large boxes compared with the small box handling technology. Mechanical box handling allows the semi-automatic bin handling system to harvest additional area compared with the manual box loading and unloading using the small box handling technology. The increased harvest efficiency translates to extra 10 ha of harvested area in a production year, and ultimately into additional revenue for the semi-automated bin handling system with double head

Table 4.1: Harvest rate and harvestable area of alternative box handling system.

	Harvest rate (h ha^{-1})		Harvestable area in a production year (ha)[1]	
	Small box system	Bin handling system	Small box system	Bin handling system
(a) Year 2017				
Pessimistic	7.05 (0.55)	5.82 (0.01)	42.55 (0.55)	51.54 (0.01)
Average	7.22 (0.24)	5.90 (0.11)	41.57 (0.24)	50.85 (0.11)
Optimistic	7.39 (0.05)	5.98 (0.12)	40.59 (0.05)	50.16 (0.12)
(b) Year 2018				
Pessimistic	6.75 (0.15)	5.30 (0.02)	44.44 (0.15)	56.60 (0.02)
Average	6.89 (0.19)	5.33 (0.04)	43.55 (0.19)	56.28 (0.04)
Optimistic	7.03 (0.07)	5.36 (0.06)	42.67 (0.07)	55.60 (0.06)

[1]Harvestable area was obtained from dividing the total number of hours in a production year (300h) by harvest rate.

configuration. However, the additional revenue comes at additional investment and operating cost associated with upgrading to the semi-automatic bin handling technology. Partial budgeting is apt for evaluating the choice of harvester handling system faced by a farmer for a given blueberry enterprise. In this analysis, only those costs that will increase or decrease and benefits that increased or decreased due to the change in harvester handling system are evaluated; levels and costs of all unchanged production processes and inputs are not considered. The decision criterion in switching from the traditional small box handling system to the semi-automatic bin handling system is profitable (inferior) if positive effects are greater (lower) than negative effects.

The main types of positive effects were estimated as reduced costs and additional revenue, while the main aspects of negative effects are the additional costs and reduced returns associated with the switch (Kay et al 2016). Positive effects of the switch involved reduced costs associated with eliminating the small box handling technology, and additional revenue generated from adopting the semi-automatic bin handling technology (i.e., added returns). Additional revenue (AR_B) from the semi-automatic bin handling system arise from increased harvesting time efficiency; 89% for the semi-automatic bin handling system, compared with 73% for the small box system. Thus, additional revenue resulted from additional acreage harvested using the semi-automatic bin handling technology (Equation 4.2).

$$AR_B = Y_B * P_F \tag{4.2}$$

where AR_B represents additional revenue associated with using the semi-automatic bin handling system, the index B denotes harvesting with bin handling system. Y_B is the harvestable yield using the semi-automatic bin handling system, and P_F is the farm gate price received for wild blueberries.

Reduced costs stem from eliminating the small box handling technology and include cost savings from eliminating the small boxes, and labour cost savings from eliminating the small bin loader/worker. Reduced costs RC_S are linked to eliminating variable and operating costs VC_S (e.g., fuel, lube, and repair and maintenance) of the small box handling technology (Equation 4.3):

$$RC_B = VC_S \tag{4.3}$$

By comparison, negative effects of the change in harvesting technology arise from increases in the purchase and operating costs of the semi-automatic bin handling technology (additional cost), and reduction in revenue from eliminating use of the small box handling system (i.e., reduced revenue). Additional cost (AC_B) include cost of upgrading the harvester with the semi-automatic bin handling harvester, such as fixed cost FC_B (i.e., depreciation and interest on the associated added cost), and associated variable cost VC_B (e.g., additional fuel, lube, and repair and maintenance).

$$AC_B = FC_B + VC_B \tag{4.4}$$

Reduction in revenue is associated with eliminating the small box handling system (reduced revenue from eliminating use of the small box technology).

$$RR_S = Y_S * P_F \tag{4.5}$$

where RR_S represents reduced revenue associated with using the small box handling technology, the index S denotes harvesting with small box handling technology. Y_S is the harvest yield using small box handling technology and P_F is the farm gate price of wild blueberries. The decision criterion in terms of net change in profit (π_p):

$$\pi_P = (AR_B + RC_B) + (AC_B + RR_S) \begin{cases} > 0 \; profitable\ to\ switch\ bin\ handling\ sysytem \\ < 0 \; profitable not to switch bin handling system \end{cases} \tag{4.6}$$

Harvester price data for the small box and semi-automatic bin handling systems are summarized in Table 4.2. Fixed costs (including depreciation, interest on investment, and housing and insurance) do not vary with production. Depreciation was calculated using the diminishing balance method, based on 15% rate for powered machines and 10% for non-powered equipment (Yiridoe and Weersink 1994). Depreciation rate was applied to the new or list price of the bin handling technology upgrade. Interest on the $30,000 investment upgrade was estimated by assuming that 70% of depreciation value was equity and the remaining 30% was debt (Yiridoe et al 1993). Interest rate on equity was assumed as 3.64% based on average rate offered by commercial banks in 2017 on saving accounts (Statistics Canada 2018). Interest rate on the debt portion was based on prime rate of 3.7% (Bank of Canada 2018), plus 0.5 for a debt charge of 4.2%. As a result, the interest rate on investment used was 3.80% (= 3.64*0.7 + 4.2*0.3). Insurance and housing or storage costs of equipment were assumed to be 1.5% of the purchase price of the harvester (Kay et al 2016; Yiridoe et al 1993).

Variable cost consists of fuel, lubrication, repairs and maintenance cost, and directly related to hours to use the harvester technology. For both small box and semi-automatic bin handling technologies, average diesel fuel consumption was estimated as 4 L hr^{-1}. Retail price of diesel fuel (i.e., \$1.20 L^{-1}) was applied in the calculations. Total fuel cost was determined by multiplying fuel cost per hour by harvester operating hours. Lubrication cost was assumed to be 15% of total fuel cost (Kay et al 2016). Repair and maintenance costs were calculated using American Society of Agricultural and Biological Engineers (ASABE) standards (ASABE 2015):

$$C_{rm} = (RF_1)\,P\,[\frac{h}{1000}]^{RF_2} \tag{4.7}$$

where C_{rm} denotes accumulated repairs and maintenance cost (\$). RF_1 and RF_2 are repairs and maintenance factors respectively, obtained from ASABE standards. P is the harvester purchase price and h is the accumulated use of harvester in hours. Values for RF_1 and RF_2 were obtained from ASABE (2015) for each equipment considered in this study.

The annual cost of ownership of small box handling system and semi-automatic bin handling system were based on important assumptions. The harvesters with bin handling technology was assumed to be new. Annual ownership cost of the small box handling technology was \$13,807, and assumed to be purchased with a loan at 3.80% interest rate, compared with \$19,042 for the semi-automatic bin handling technology (Table 4.2). In this study, mechanical harvesters were assumed to be operated for 300 hrs in a production year, and used to estimate annual harvest cost. Wild blueberry price (\$0.55 kg) was based on 2017 farm gate price received by producers.

4.3.2 Sensitivity Analysis

Sensitivity analysis was conducted to assess the effects of selected variables on changes in net profit associated with switching from small box to semi-automatic bin handling technology. Net change in profit may be influenced by market and economic factors (e.g., farm gate price,

Table 4.2: Financial and harvest cost data when switching to bin handling system from small box system.

	Unit	Small box handling system	Bin handling system
(a) General information			
Purchase price	$	----	30000.00
Expected life of a harvester	yr	----	10.00
Harvester use	h yr^{-1}	280-320	280-320
Fuel consumption rate	L h^{-1}	4.00	4.00
Salvage value	$	----	7500.00
Interest rate	%	----	3.80
Fuel (Diesel) price	$	1.20	1.20
(b) Annual fixed costs			
Depreciation	$	0.00	2409.38
Interest on investment	$	0.00	712.50
Housing and storage	$	0.00	450.00
(c) Annual variable cost			
Fuel cost	$	1440.00	1560.00
Lubrication cost	$	216.00	234.00
Repairs and maintenance	$	3486.00	4543.00
Labour cost (operator)	$	4500.00	4500.00
Labour cost (support worker)	$	3600.00	----
Annual rental rate of loader tractor	$	----	4000.00
Interest on operating expenses		565.43	633.54
Total cost per year		13807.43	19042.42

interest rate on loans, and labour wages) and technology-induced production factors. In this study, sensitivity analysis was performed on wild blueberry production, interest rate and labour wages. All the variables investigated in this study due to the uncertainty associated with them.

Sensitivity analysis on wild blueberry production were based on three yield scenarios; i.e., optimistic scenario (high yield), average scenario (typical yield), and pessimistic scenario (low yield). Yield data were obtained from the field trials conducted in 2017 and 2018 in three different fields of Nova Scotia. Yield levels of scenarios were summarized in Table 4.3.

Interest rates in Canada are currently at a historically low range, around 3.5 to 5%. In contrast, interest rates during the 1980's were in the 16 to 18% range. Fluctuations in interest rate can affect net change in profit for wild blueberry farmers. For example, an increase in interest rate results in a decrease in net change in profit through increase in the annual ownership of cost of the

Table 4.3: Summary of yield scenarios used in partial budget analysis.

Yield scenario	Sample mean	Standard deviation	Maximum	Minimum	Replications
(a) 2017 data (kg ha^{-1})					
Optimistic	7561	465	8290	7088	6
Average	6517	1443	8290	3450	12
Pessimistic	5473	1323	6694	3450	6
(a) 2018 data (kg ha^{-1})					
Optimistic	1944	106	2053	1813	6
Average	1790	197	2053	1412	12
Pessimistic	1637	136	1803	1411	6

harvester and vice versa. Sensitivity analysis of the effect of interest rate involved varying the initial rate used in the base analysis by increments of 2%, ranging from 2-18%.

Early in 2019 the government of Nova Scotia announced a plan to increase minimum labour wage rate by $0.55 a year for the next three years upto 2022. Furthermore, the wage rate would be adjusted annually for inflation beyond 2022. Sensitivity analysis was conducted on labour wage rate considered in this study, to determine effects on net change in profit, for the different yield scenarios. In this analysis, both operator and support worker wages were adjusted by 10% increments and then used to evaluate the effect on net change in profit.

4.3.3 Stochastic Partial budgeting

A stochastic partial budgeting approach was used to account for uncertainty associated with several variables. In this analysis, output price, output levels, interest rate on loans, and labour wages were identified as stochastic variables. Stochastic features were introduced by specifying probability distributions of the selected variables in the deterministic budget analysis. Probability distributions were based on data from various sources. For example, yield distributions were generated from the field trial data conducted during 2017 and 2018. Distributions of the output price, interest rate and labour wages data were based on time series data (1981-2016) of the wild blueberry crop. Time series data (1981-2016) on output price were obtained from Wild Blueberry Producers Association of Nova Scotia (2018), while data on interest rate were obtained from Statistics Canada (2018). Time series data (1982-2016) on wage rate were obtained from Government of Canada (2018). Probability distributions based on historical time series approximate uncertainty about future scenarios in stochastic analysis (Milham 1998).

To quantify the uncertainties around the estimates associated with the key parameters used in the base analysis, were modelled by fitting the probability distributions. The methods of moments approach was used to estimate the alpha and beta parameter required for the distribution. Uncertainty associated with the cost items were modelled by using a log normal distribution, while uncertainties associated with the interest rate parameter is fitted to beta distribution, which is constrained to the interval [0, 1].

The stochastic partial budgeting used data on the means and standard errors of the selected parameters in this probability analysis. We assumed standard error $2 for the hourly labour wage, 1% for the annual interest rate, and $0.07 for the wild blueberry farm gate prices. For all other selected parameters in this multivariate probability sensitivity analysis, the optimistic values were considered as proxy for the standard errors. Key parameters associated with this analysis were summarized in Table 4.4a and 4.4b.

Monte Carlo simulations were used to generate cumulative distributions of net change in profit associated with switching from the small box to the semi-automatic bin handling technology. To obtain the net change in profit distributions, the Monte Carlo simulations was used repeatedly to draw 1000 random samples from the probability distributions from the budget items considered in this analysis. The keys components of the deterministic partial budgeting in this analysis includes additional cost and additional revenue of the semi-automated bin handling system, and the reduced cost and reduced revenue associated with the small box handling system. The net change in profit was estimated using 95% of the confidence interval, and the cumulative distributions functions (CDF) presented in graphical forms. In addition, the additional revenue and reduced cost and the reduced cost and additional revenue as a result of 1000 random samples using Monte Carlo simulations are also summarized using scatterplot.

4.4 Data

Berry production and harvest data were obtained from on-farm field trials conducted in Nova Scotia, using mechanical harvesters with the two handling systems during 2017 and 2018. In 2017, field trials were conducted in farms near Debert, Nova Scotia, while in 2018, the trials were conducted on farms near Portapique and Antigonish in Nova Scotia. In 2017, the farmer's own mechanical harvester with the small box handling system was used to harvest berries on the Debert fields, while the harvester with the semi-automatic bin handling system was provided by

Table 4.4a: Parameters used in the Stochastic Partial Budget for 2017.

Parameter	Mean	Standard error	Distribution	Alpha	Beta
Additional yield per hectare (kg per year)	1303.40	417.00	Log-Normal	7.17	0.38
Farm gate price received by producers (kg)	0.55	0.07	Log-Normal	-0.60	0.13
Labour cost (operator)	15.00	2.00	Log-Normal	2.71	0.14
Rental rate of loader tractor	12.00	2.00	Log-Normal	2.48	0.17
Small box handling system					
General Information					
Purchase price	0.00	0.00	Log-Normal	0.00	0.00
Expected life of a harvester	10.00	1.00	Log-Normal	2.30	0.10
Harvester use	300.00	40.00	Log-Normal	5.70	0.14
Fuel consumption rate	4.00	1.00	Log-Normal	1.39	0.27
Interest rate	0.04	0.01	Beta	17.41	390.36
Fuel (Diesel cost)	1.20	0.50	Log-Normal	0.18	0.59
Harvest rate	7.22	0.17	Log-Normal	1.98	0.02
Annual variable costs					
Fuel cost	1440.00	2.00	Log-Normal	7.27	0.00
Lubrication cost	216.00	2.00	Log-Normal	5.38	0.01
Repairs and maintenance	3486.00	2.00	Log-Normal	8.16	0.00
Operator cost	4500.00	150.00	Log-Normal	8.41	0.03
Labour cost	3600.00	150.00	Log-Normal	8.19	0.04
Hourly variable costs					
Fuel cost	4.80	0.01	Log-Normal	1.57	0.00
Lubrication cost	0.72	0.01	Log-Normal	-0.33	0.01
Repairs and maintenance	11.62	0.01	Log-Normal	2.45	0.00
Labour cost (operator)	15.00	0.50	Log-Normal	2.71	0.03
Rental rate of loader tractor	12.00	0.50	Log-Normal	2.48	0.04
Interest on operating expenses	1.88	0.01	Log-Normal	0.63	0.00

Table 4.4a: Parameters used in the Stochastic Partial Budget for 2017. (Continued)

Parameter	Mean	standard error	Distribution	Alpha	Beta
Bin handling system					
General Information					
Purchase price	30000.00	5.00	Log-Normal	10.31	0.00
Expected life of a harvester	10.00	1.00	Log-Normal	2.30	0.10
Harvester use	320.00	5.00	Log-Normal	5.77	0.02
Fuel consumption rate	4.00	1.00	Log-Normal	1.39	0.27
Salvage value	7500.00	1.00	Log-Normal	8.92	0.00
Interest rate	0.04	0.01	Beta	35.58	797.64
Fuel (Diesel cost)	1.20	0.01	Log-Normal	0.18	0.01
Harvest rate	5.90	0.08	Log-Normal	1.77	0.01
Annual fixed costs					
Depreciation	2409.38	29.00	Log-Normal	7.79	0.01
Interest on investment	712.50	29.00	Log-Normal	6.57	0.04
Housing and storage	450.00	1.01	Log-Normal	6.11	0.00
Hourly fixed costs					
Depreciation	8.03	1.00	Log-Normal	2.08	0.13
Interest cost on investment	2.38	1.00	Log-Normal	0.86	0.60
Taxes, Insurance and Housing	1.50	0.50	Log-Normal	0.41	0.40
Annual variable costs					
Fuel cost	1560.00	1.00	Log-Normal	7.35	0.00
Lubrication cost	234.00	1.00	Log-Normal	5.46	0.00
Repairs and maintenance	4543.00	1.00	Log-Normal	8.42	0.00
Labour cost (operator)	4500.00	1.00	Log-Normal	8.41	0.00
Annual rental rate of loader tractor	4000.00	1.00	Log-Normal	8.29	0.00
Interest on operating expenses	633.54	1.00	Log-Normal	6.45	0.00
Hourly variable costs					
Fuel cost	5.20	0.50	Log-Normal	1.65	0.10
Lubrication cost	0.78	0.01	Log-Normal	-0.25	0.01
Repairs and maintenance	15.14	0.50	Log-Normal	2.72	0.03
Labour cost (operator)	15.00	0.50	Log-Normal	2.71	0.03
Rental rate of loader tractor	13.33	0.50	Log-Normal	2.59	0.04
Interest on operating expenses	2.11	0.01	Log-Normal	0.75	0.00

Table 4.4b: Parameters used in the Stochastic Partial Budget for 2018.

Parameter	Mean	Standard error	Distribution	Alpha	Beta
Additional yield per hectare (kg per year)	358.00	61.40	Log-Normal	5.88	0.18
Farm gate price received by producers (kg)	0.55	0.07	Log-Normal	-0.60	0.13
Labour cost (operator)	15.00	2.00	Log-Normal	2.71	0.14
Rental rate of loader tractor	12.00	2.00	Log-Normal	2.48	0.17
Small box handling system					
General Information					
Expected life of a harvester	10.00	1.00	Log-Normal	2.30	0.10
Harvester use	300.00	40.00	Log-Normal	5.70	0.14
Fuel consumption rate	4.00	1.00	Log-Normal	1.39	0.27
Interest rate	0.04	0.01	Beta	17.41	390.36
Fuel (Diesel cost)	1.20	0.50	Log-Normal	0.18	0.59
Harvest rate	6.89	0.28	Log-Normal	1.93	0.04
Annual variable costs					
Fuel cost	1440.00	2.00	Log-Normal	7.27	0.00
Lubrication cost	216.00	2.00	Log-Normal	5.38	0.01
Repairs and maintenance	3486.00	2.00	Log-Normal	8.16	0.00
Operator cost	4500.00	150.00	Log-Normal	8.41	0.03
Labour cost	3600.00	150.00	Log-Normal	8.19	0.04
Hourly variable costs					
Fuel cost	4.80	0.50	Log-Normal	1.57	0.11
Lubrication cost	0.72	0.01	Log-Normal	-0.33	0.01
Repairs and maintenance	11.62	0.01	Log-Normal	2.45	0.00
Labour cost (operator)	15.00	0.50	Log-Normal	2.71	0.03
Rental rate of loader tractor	12.00	0.50	Log-Normal	2.48	0.04
Interest on operating expenses	1.88	0.01	Log-Normal	0.63	0.00

Table 4.4b: Parameters used in the Stochastic Partial Budget for 2018. (continued)

Parameter	Mean	Standard error	Distribution	Alpha	Beta
Bin handling system					
General Information					
Purchase price	30000.00	5.00	Log-Normal	10.31	0.00
Expected life of a harvester	10.00	1.00	Log-Normal	2.30	0.10
Harvester use	320.00	5.00	Log-Normal	5.77	0.02
Fuel consumption rate	4.00	1.00	Log-Normal	1.39	0.27
Salvage value	7500.00	1.00	Log-Normal	8.92	0.00
Interest rate	0.04	0.01	Beta	35.58	797.64
Fuel (Diesel cost)	1.20	0.01	Log-Normal	0.18	0.01
Harvest rate	5.33	0.06	Log-Normal	1.67	0.01
Annual fixed costs					
Depreciation	2409.38	29.00	Log-Normal	7.79	0.01
Interest on investment	712.50	29.00	Log-Normal	6.57	0.04
Housing and storage	450.00	1.01	Log-Normal	6.11	0.00
Hourly fixed costs					
Depreciation	8.03	1.00	Log-Normal	2.08	0.13
Interest cost on investment	2.38	1.00	Log-Normal	0.86	0.60
Taxes, Insurance and Housing	1.50	0.50	Log-Normal	0.41	0.40
Annual variable costs					
Fuel cost	1560.00	1.00	Log-Normal	7.35	0.00
Lubrication cost	234.00	1.00	Log-Normal	5.46	0.00
Repairs and maintenance	4543.00	1.00	Log-Normal	8.42	0.00
Labour cost (operator)	4500.00	1.00	Log-Normal	8.41	0.00
Annual rental rate of loader tractor	4000.00	1.00	Log-Normal	8.29	0.00
Interest on operating expenses	633.54	1.00	Log-Normal	6.45	0.00
Hourly variable costs					
Fuel cost	5.20	0.01	Log-Normal	1.65	0.00
Lubrication cost	0.78	0.01	Log-Normal	-0.25	0.01
Repairs and maintenance	15.14	0.01	Log-Normal	2.72	0.00
Labour cost (operator)	15.00	0.50	Log-Normal	2.71	0.03
Rental rate of loader tractor	13.33	0.01	Log-Normal	2.59	0.00
Interest on operating expenses	2.11	0.01	Log-Normal	0.75	0.00

the equipment manufacturer. In 2018, both the small box handling and semi-automatic bin handling systems in Portapique and Antigonish were provided by the farmers.

Primary data on harvest time and berry handling time were used to estimate harvest rate (measured in kg h^{-1} and h ha^{-1}) for the two harvesting technologies. Yield data were collected for both harvester technologies on per hour basis. Harvestable yield per ha was estimated using the following relationship:

$$Y_i = Y * H_r \tag{4.7}$$

where Y_i is the harvestable yield using harvest handling technology, i=1 for harvester with small box handling (S), and i=2 for harvester with semi-automatic bin handling system (B). Y denotes yield harvested per hour and H_r is the number of hours required to complete harvesting one ha. Harvestable yield was classified as; i) optimistic (i.e., high) yield; ii) average (or typical) yield; and iii) pessimistic (or low yield), and are summarized in Table 4.3.

Financial and other economic data were obtained from various sources (Table 4.2). For example, wild blueberry harvester price data and harvest handling technology were obtained from Doug Bragg Enterprises Ltd., the main manufacturer of mechanical harvesters in the region. Wild blueberry prices were obtained from Statistics Canada (2018), and Wild Blueberry Producers Association of Nova Scotia. Interest rate was based on Bank of Canada and commercial banking rates (Statistics Canada 2018). In addition, labour wage rate and harvester usage data (i.e., fuel consumption rate, harvester use) were obtained from local wild blueberry farmers, and wild blueberry harvester manufacturers.

4.5 Results and Discussion

4.5.1 Economic Viability of Bin Handling Technology

Net change in profit using point estimates of variables in the deterministic model are presented separately for 2017 and 2018 (Table 4.5 and 4.6). Net change in profit was \$674.69 ha^{-1} (or \$0.52 kg^{-1}) in 2017, and implies that switching from the small box technology to semi-automated bin handling technology was financially viable (Table 4.5). The bin handling system has capacity to harvest same acreage in less time (354 minutes per ha for bin handling compared with 433 minutes per ha for small box handling system), and allows for generating extra revenue from harvesting extra area. The breakeven yield associated with switching from the small box to bin handling technology was 77 kg ha^{-1}.

Additional revenue from additional area harvested using the more efficient semi-automatic bin handling technology was \$716.87, while reduced cost (RC_S) associated with eliminating use of the small box harvesting technology was \$332.30.

The total additional cost (AC_B) of \$374.48 includes the variable cost (fuel, lubrication, repairs and maintenance cost) and fixed cost (depreciation, interest rate, insurance and housing) of bin handling technology. The combined reduced revenue and total additional cost was \$374.48 (Table 4.5).

Net change in profit for 2018 are summarized in Table 4.6. Net change in profit in the deterministic model was \$175.71 ha^{-1} (or 0.49 kg^{-1}) in 2018 and indicates that upgrading from small box to bin handling technology was also profitable. Efficient bin handling system takes less time to cover one ha compared to small box system. For example, on average, semi-automatic bin handling system takes 319.8 minutes to complete one ha compared to 413.4 minutes of small box technology. The breakeven yield associated with upgrading from small box to semi-automatic bin handling system technology was 38 kg ha^{-1}.

Additional revenue generated from additional area harvested using semi-automated bin handling technology was $196.90, while reduced cost associated with eliminating use of the small box system was $317.11. The total additional cost associated with the use of semi-automatic bin handling technology was $338.30. The combined total additional cost and reduced revenue was also $317.11.

While comparing net change in profit of 2017 and 2018. The result highlighted that net change in profit decreased by 75% in typical field condition from $674.69 ha^{-1} in 2017 and $175.71 ha^{-1} in 2018. In 2018, berry production was adversely affected by frost, and wiped out 70-80% of blueberry yield in Nova Scotia. The variability in yield and increased harvest efficiency is significant factor in generating additional revenues to farmers.

In summary upgrading from a small box handling to bin handling technology is profitable, and consistent for both years. Production levels varies depending on the use of inputs, harvesting method and weather, while interest rate and labour wages depending on economic and market factors. Sensitivity analysis was conducted to access the uncertainty associated with the selected variables associated with production and economic factors.

4.5.2 Sensitivity Analysis

Production of wild blueberry

Net change in profit for the three yield scenarios are summarized in Table 4.5 and 4.6. Net change in profit was highest under the optimistic yield scenario and lowest for the pessimistic yield scenario, consistent for both years. For 2017, switching from the small box technology to bin handling technology was profitable for all three yield scenarios. As expected, on average, net change in profit was highest under the optimistic yield condition (\$792.23 ha^{-1}) lowest under the pessimistic yield conditions with \$557.10 ha^{-1}.

Table 4.5: Net change in profit (CAD$), 2017 data.

(a) Additional costs (Bin handling system)	Amount ($ ha^{-1})			(c) Reduced costs (Small box handling system)	Amount ($ ha^{-1})		
	Yield scenarios				Yield scenarios		
	Pessimistic	Average	Optimistic		Pessimistic	Average	Optimistic
Fixed costs				Fixed costs			
Depreciation	46.73	47.38	48.02	Depreciation	---	---	---
Interest on investment	13.85	14.04	14.23	Interest on investment	---	---	---
Insurance and Storage	8.73	8.85	8.97	Insurance and Storage	---	---	---
Variable costs				Variable costs			
Fuel cost	30.26	30.68	31.10	Fuel cost	33.84	34.66	35.47
Lubrication cost	4.54	4.60	4.66	Lubrication cost	5.08	5.20	5.32
Repairs and maintenance	88.11	89.33	90.54	Repairs and maintenance	81.92	83.90	85.87
Labour cost (operator)	87.30	88.50	89.70	Labour cost (operator)	105.75	108.30	110.85
Rental rate of loader tractor	77.58	78.65	79.71	Labour cost (support worker)	84.60	86.64	88.68
Interest on operating expenses	12.29	12.46	12.63	Interest on operating expenses	13.29	13.61	13.93
Total for (a)	369.40	374.48	379.56	Total for (c)	324.47	332.30	340.12
(b) Reduced revenue				(d) Additional revenue			
Revenue for harvest using small box system	0.00	0.00	0.00	Revenue for harvest using bin handling system	602.03	716.87	831.67
Total for (b)	0.00	0.00	0.00	Total for (d)	602.03	716.87	831.67
(e) Total additional cost and reduced revenue	369.40	374.48	379.56	(f) Total additional revenue and reduced costs	926.50	1049.17	1171.79
				Net change in profit ($ ha^{-1}) (f-e)	557.10	674.69	792.23
				Net change in profit ($ kg^{-1})	0.51	0.52	0.52

Table 4.6: Net change in profit (CAD$), 2018 data.

(a) Additional costs (Bin handling system)	Amount ($ ha^{-1})			(c) Reduced costs (Small box handling system)	Amount ($ ha^{-1})		
	Yield scenarios				Yield scenarios		
	Pessimistic	Average	Optimistic		Pessimistic	Average	Optimistic
Fixed costs				Fixed costs			
Depreciation	42.56	42.80	43.04	Depreciation	---	---	---
Interest cost on investment	12.61	12.69	12.76	Interest cost on investment	---	---	---
Insurance and Storage	7.95	8.00	8.04	Insurance and Storage	---	---	---
Variable costs				Variable costs			
Fuel cost	27.56	27.72	27.87	Fuel cost	32.40	33.07	33.74
Lubrication cost	4.13	4.16	4.18	Lubrication cost	4.86	4.96	5.06
Repairs and maintenance	80.24	80.70	81.15	Repairs and maintenance	78.44	80.06	81.69
Labour cost (operator)	79.50	79.95	80.40	Labour cost (operator)	101.25	103.35	105.45
Rental rate of loader tractor	70.65	71.05	71.45	Labour cost (support worker)	81.00	82.68	84.36
Interest on operating expenses	11.19	11.25	11.32	Interest on operating expenses	12.72	12.99	13.25
Total for (c)	383.41	385.58	387.75	Total for (c)	310.67	317.11	323.55
(d) Reduced revenue				(d) Additional revenue			
Revenue for harvest using small box system	0.00	0.00	0.00	Revenue for harvest using bin handling system	180.07	196.90	213.88
Total for (d)	0.00	0.00	0.00	Total for (d)	180.07	196.90	213.88
(e) Total additional cost and reduced revenue	336.40	338.30	340.21	(f) Total additional revenue and reduced costs	490.74	514.01	537.44
				Net change in profit ($ ha^{-1}) (f-e)	154.34	175.71	197.23
				Net change in profit ($ kg^{-1})	0.47	0.49	0.51

Net change in profit increased as wild blueberry production increased, as expected. For example, net change in profit increased from \$674.69 to \$792.23 ha^{-1}, when the blueberry yield increased from typical yield condition (1303 kg ha^{-1}) to optimistic yield condition (1512 kg ha^{-1}). Similarly, net change in profit was decreased from \$792.23 to \$557.10 ha^{-1}, representing 29.67% decline, when the berry yield decreased from typical (1095 kg ha^{-1}) to pessimistic yield condition (1303 kg ha^{-1}). The result implies that the effect of an increase in output level, increased the net change in profit for high production field (optimistic scenario) compared with low production fields (pessimistic scenario) and typical field.

In 2018, frost also influenced the blueberry yield up to 70%. The net change in profit was comparatively less in 2018 than 2017, when switching from a small box to semi-automatic bin handling technology. Net change in profit increased from \$175.71 to \$197.23 ha^{-1} (representing 12.22% increases), when berry production increased from typical field to optimistic field condition. Switching from small box handling to semi-automatic bin handling system was also financially viable when the berry yield decreased from typical to pessimistic yield condition. Net change in profit decreased from \$175.71 to \$154.34 ha^{-1} representing 12.16% decline.

On average, the net change in profit was higher for 2017 than 2018 due to crop damage in following year. For example, net change in profit was \$792.23 in 2017 and \$197.23 ha^{-1} in 2018 in optimistic field conditions, representing 75% decline. On average, net change in profit was also low in 2018 for typical yield condition (74% decline) and pessimistic field condition (72%) compared with 2017.

The trend of the partial budgeting results indicates that an increase in wild blueberry production generate high profit for the farmers (Table 4.5 and 4.6). Switching from small box system to semi-automatic bin handling technology becomes more profitable with an increase in production of wild blueberry. Semi-automatic bin handling system increases the harvest time and decreases the handling time during wild blueberry harvesting allows extra area coverage. Extra area coverage with semi-automatic bin handling system will generate additional revenue and additional profit for the farmers.

Interest rate:

As expected, net change in profit decreased as interest rate increased (Figure 4.1a). For example, for an optimistic yield scenario, when interest rate doubled from 4 to 8%, net change in profit decreased by less than proportionate rate of 1.89% from \$792 ha^{-1}to \$777 ha^{-1}. By comparison, under pessimistic yield conditions, a 100% increase in interest rate from 4% to 8%, resulted in a 2.5% reduction in net change in from \$556 to \$542. This implies that the effect of an increase in interest rate on reduction in net change in profit is higher for low production fields (pessimistic scenario), compared with high production field (optimistic scenario).

The effect of changes in interest rate on net change in profit results for 2018 were generally similar to the findings for 2017. However, the actual differences are due to low yield in year 2018. For example, for an optimistic yield scenario, when interest rate doubled from 4 to 8%, net change in profit decreased by 7.11% from \$197 ha^{-1}to \$183 ha^{-1}. Under pessimistic yield conditions, a 100% increase in interest rate from 4% to 8%, reduced by 9.09% from \$154 ha^{-1} to \$140 ha^{-1}. The impact of interest rate on net change in profit was higher on 2018 due to low production compared to 2017.

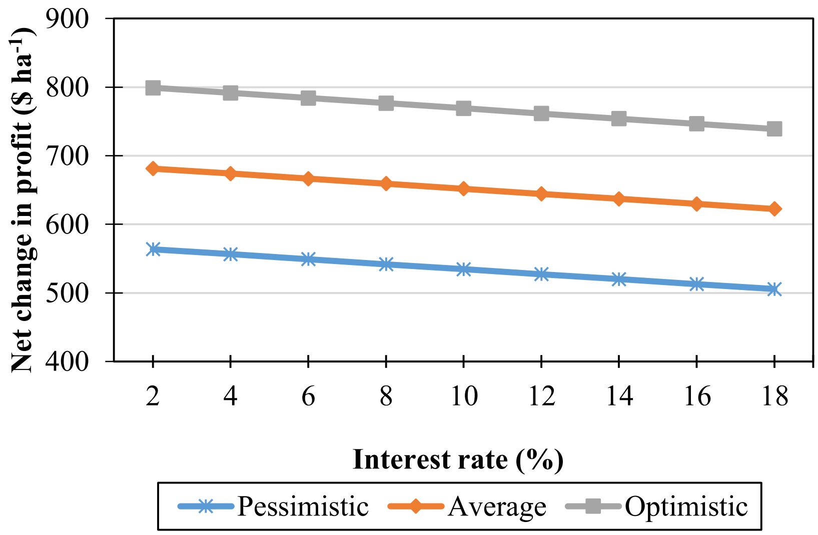

Figure 4.1a: Effect of changes in interest rate on net change in profit ($ ha^{-1}) for 2017.

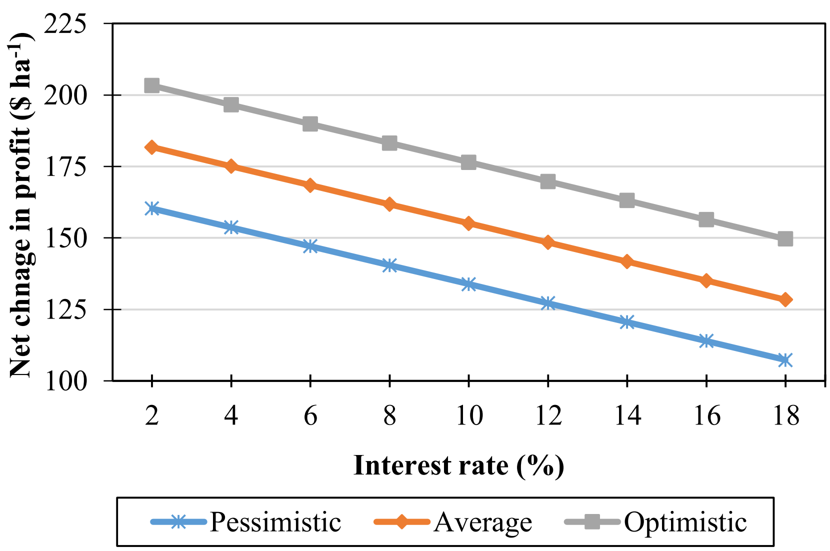

Figure 4.1b: Effect of changes in interest rate on net change in profit ($ ha^{-1}) for 2018.

The effect of interest rate was higher on 2018 compared to 2017 (Figure 4.1a and 4.1b). For example, when interest rate increased by 50% in 2017, net change in profit increased from $792 to $784 ha^{-1}, resulted in reduction of 1.01% (Figure 4.1a), compared to 3.55% ($197 to $190 ha^{-1}) reduction in 2018 in optimistic yield scenario (Figure 4.1b). Similarly, in pessimistic yield scenario net change in profit decrease by 1.25% in 2017 compared to 4.54% decrease in 2018, when interest rate increased by 50%.

Labour wage:

An increase in labour wages increases net profit for the farmers associated with switching from small box to semi-automatic bin handling technology, as expected. An increase in wage rate disproportionately increases the cost of harvesting for small box system, as it requires extra farm worker to load and unload the berry boxes. For example, in optimistic yield scenario, when the labour wage increased by 50% (i.e., for both operator and support worker), resulted the net change

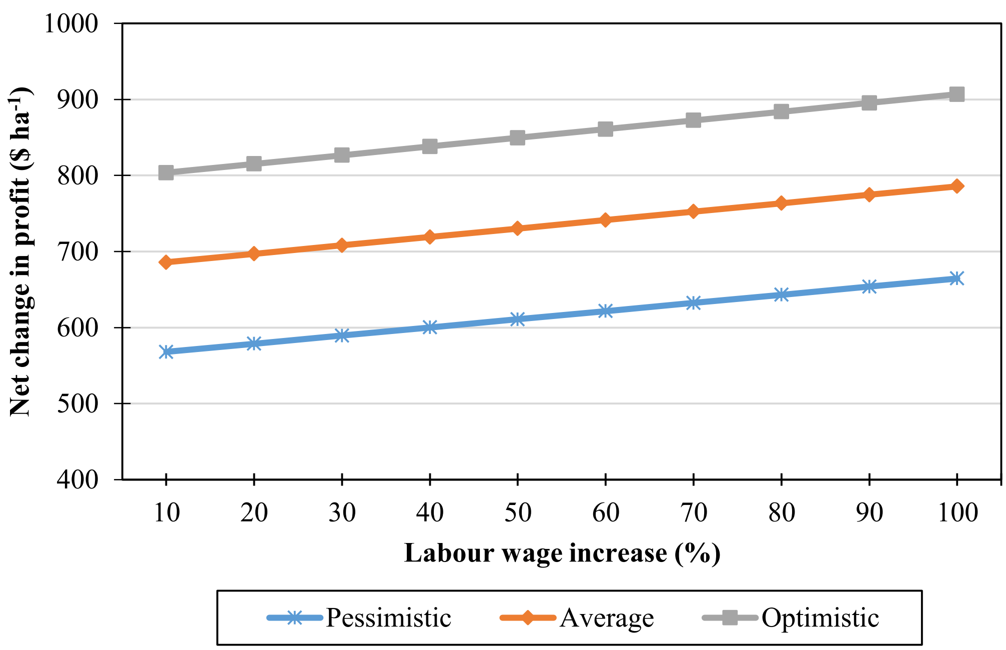

Figure 4.2a: Effect of changes in labour wage on net change in profit ($ ha^{-1}) for 2017.

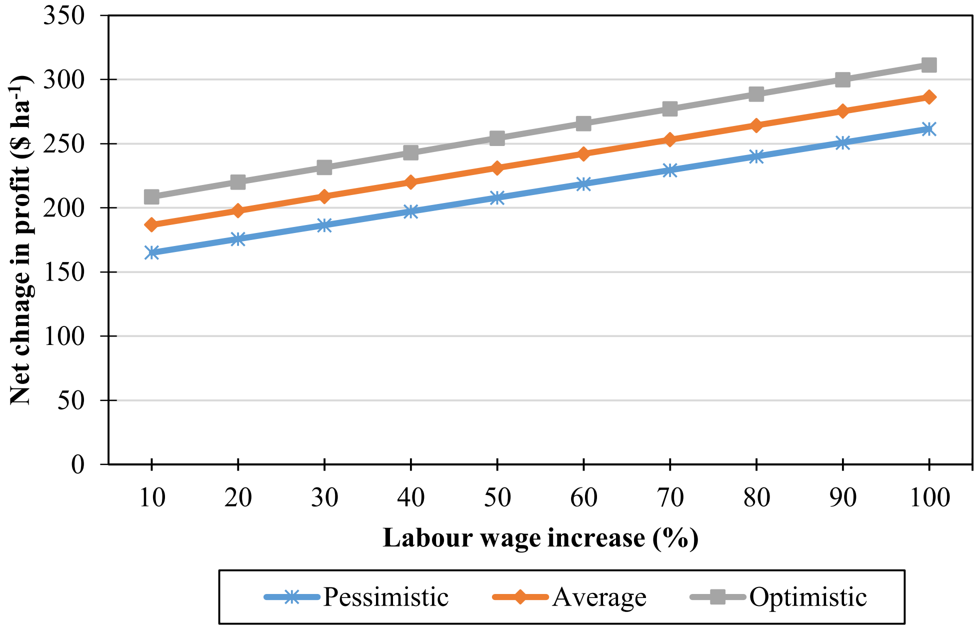

Figure 4.2b: Effect of changes in labour wage on net change in profit ($ ha^{-1}) for 2018.

in profit increased by 7.19% in optimistic yield scenario, compared to 9.69% increase in pessimistic yield scenario (Figure 4.2a), makes the switch profitable.

As expected in 2018, net change in profit increased as labour wage increased (Figure 4.2b). For example, net change in profit increased by 35.06% (from $154 to $208 ha^{-1}) when the labour wage increased by 50% in optimistic yield scenario compared to 28.93% in pessimistic yield scenario. Small box system requires extra labour to carry out the farm operation compared to bin handling technology. So, increase in labour wage will make the bin handling technology more profitable.

The effect of labour wage was higher on 2018 compared to 2017 (Figure 4.2a and 4.2b). For example, when labour wage increased by 20% in 2017, net change in profit increased from $792 to $827 ha^{-1}, resulted in 4.41% (Figure 4.2a), compared to 11.67% ($197 to $220 ha^{-1}) reduction in 2018 in optimistic yield scenario (Figure 4.2b). Similarly, in pessimistic yield scenario net change in profit increased by 3.94% in 2017 compared to 14.28% in 2018, when labour wage increased by 20%.

4.5.3 Stochastic partial budgeting

Stochastic partial budgeting results of year 2017 are summarized in Table 4.7. The results of stochastic partial budgeting were consistent with the deterministic partial budgeting. In 2017, the average net change in profit was $729.96 at 95% confidence interval, ranges between $235.77 and $2,285.25. The net change in profit for the deterministic base analysis was $674.67 was also lies in this range. The total additional revenue and reduced cost for the 1000 randomly simulated cases were greater than the total additional cost and reduced revenue. The joint distribution of the additional revenue and reduced costs, and the total additional cost and reduced revenue on the simulated sample for the 2017 data was presented in Figure 4.3a.

Probability distribution functions for the net change in profits, for 2017-based data are presented in figure 4.3b. For example, if we select a net change in profit of $236 from the figure

Table 4.7: Results of the stochastic partial budgeting analysis.

Budget item		Deterministic results	Stochastic Results				
		Mean	Mean	2.5th percentile	97.5th percentile	Minimum	Maximum
2017							
	a) Additional costs (Bin handling system)	374.50	374.50	366.42	383.57	359.75	389.51
	b) Revenue for harvest using small box system	0.00	0.00	0.00	0.00	0.00	0.00
	c) Reduced costs (Small box handling system)	332.30	332.37	316.88	348.56	307.88	359.06
	d) Additional revenue for harvesting using bin handling system	716.87	772.09	355.55	1495.92	290.80	2336.29
	e) Total additional cost and reduced revenue (a+b)	374.50	374.50	366.42	1598.76	359.75	389.51
	f) (Total additional revenue and reduced costs (c+d)	1049.17	1104.46	692.90	1832.50	613.04	2661.38
	Net change in profit (f-e), ($ per ha)	674.67	729.96	314.78	1458.54	235.77	2285.25
2018							
	a) Additional costs (Bin handling system)	338.32	338.31	335.18	341.48	333.74	343.85
	b) Revenue for harvest using small box system	0.00	0.00	0.00	0.00	0.00	0.00
	c) Reduced costs (Small box handling system)	317.11	317.81	305.29	330.75	300.09	340.65
	d) Additional revenue for harvesting using bin handling system	196.90	200.62	137.77	282.79	106.87	351.80
	e) Total additional cost and reduced revenue (a+b)	338.32	338.31	335.18	341.48	333.74	343.85
	f) Total additional revenue and reduced costs (c+d)	514.01	518.43	455.32	599.20	419.60	665.40
	Net change in profit (f-e), ($ per ha)	175.69	180.11	117.62	261.32	80.01	327.46

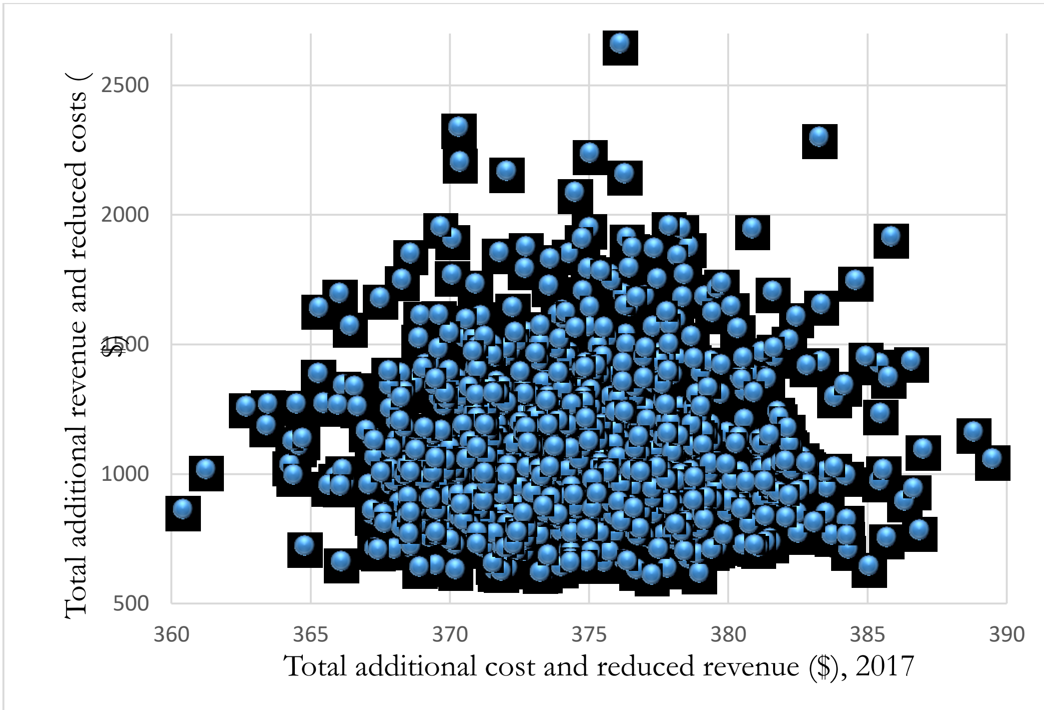

Figure 4.3a: Joint distribution of the additional revenue and reduced costs, and the total additional cost and reduced revenue for 2017 based on the simulated sample.

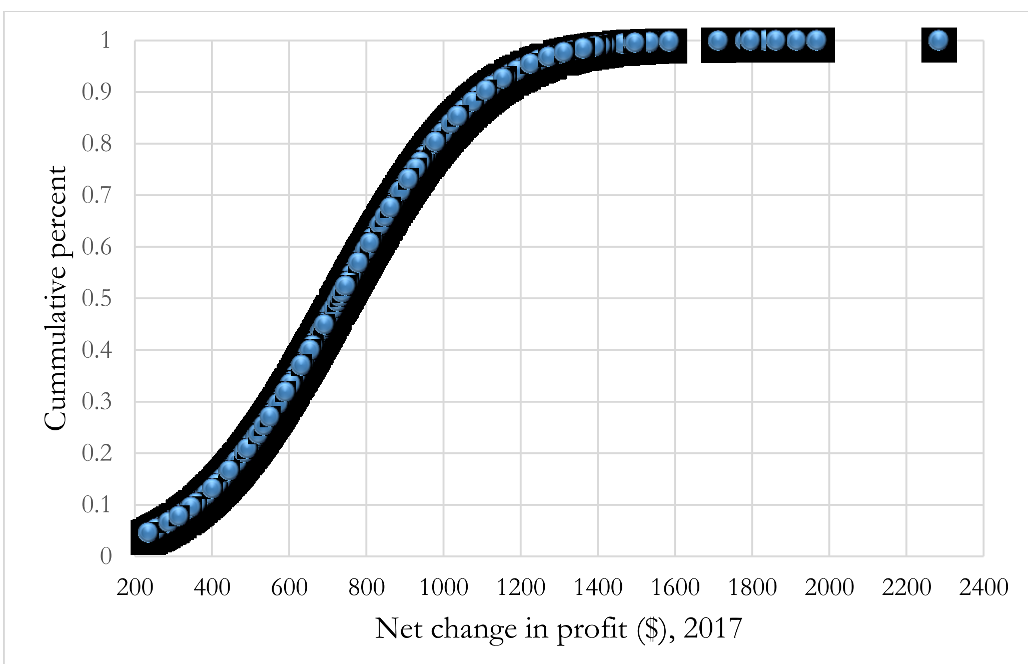

Figure 4.3b: Cumulative distribution function for net change in profit, 2017 data.

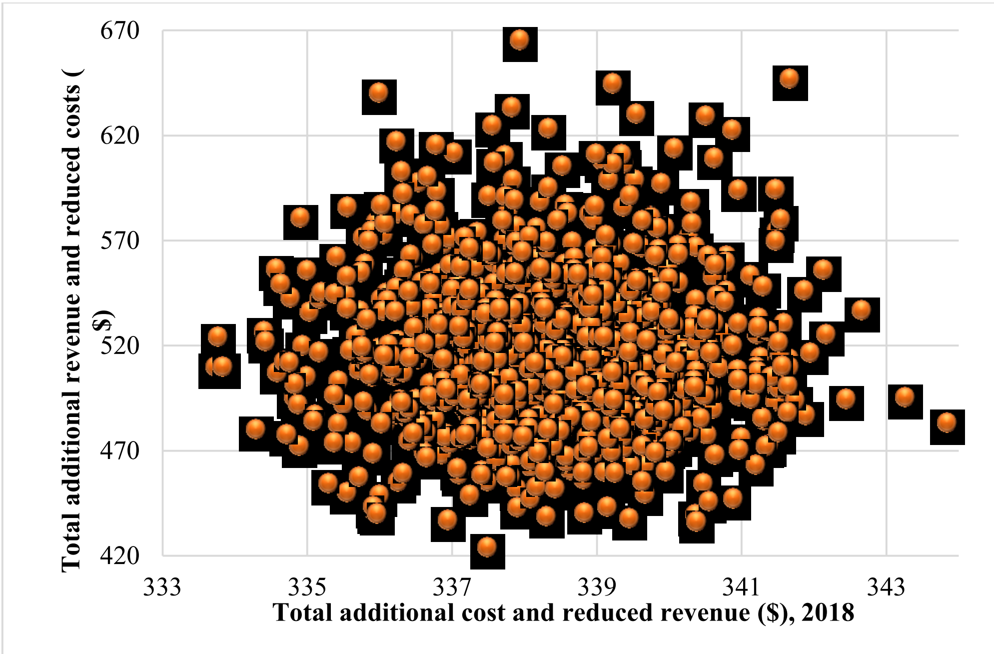

Figure 4.4a: Joint distribution of the additional revenue and reduced costs, and the total additional cost and reduced revenue for 2018 based on the simulated sample.

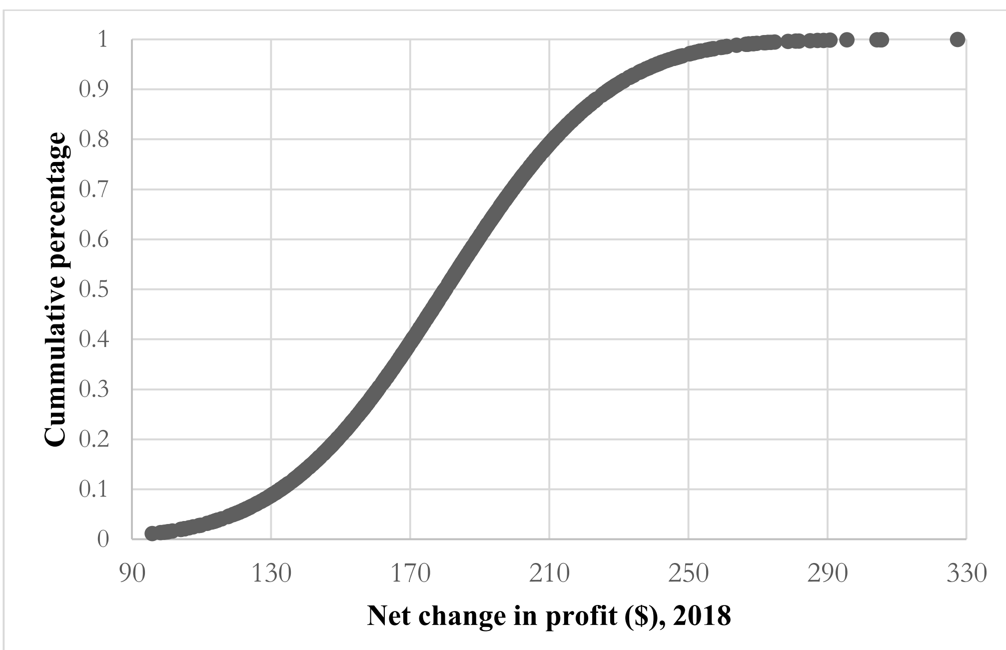

Figure 4.4b: **Cumulative distribution function for net change in profit, 2018 data.**

4.3b, the percentage of the simulated cases with net change in profit less than or equal to that value is 4.6%. Alternatively, 95.4% of the 1000 simulated cases had more than $236 in net change in profit. The probability is 60%, if $800 was to be selected from the figure (or 40% of the simulated cases make more than $800 in profit).

The results for the year 2018 are presented in Table 4.7. In 2018, the average net change in profit of randomly drew 1000 simulations was $180.11 at 95% confidence interval, ranges between $80.01 and $327.46. The net change in profit reported for the deterministic base analysis was $175.69 was also lies between the range suggesting consistent results. The total additional revenue and reduced cost for the 1000 randomly simulated cases were also greater than the total additional cost and reduced revenue for 2018 data. The joint distribution of the additional revenue and reduced costs, and the total additional cost and reduced revenue on the simulated sample for the 2018 data is summarized in figure 4.4a.

Probability distribution functions for the net change in profits, for 2018-based data are presented in figure 4.4b. For example, if we select a net change in profit of $96 from the figure 4.4b, 1.1% of the values in 1000 simulated cases have the net change in profit less than or equal to that value, while 98.9% had more than $96 net change in profit. The stochastic partial budgeting results for both years are in consistent with deterministic partial budgeting.

4.6 Summary and Conclusions

In general, the wild blueberry crop is mechanically harvested by mechanical harvester with a small box and semi-automated bin handling technology in Atlantic Canada. Economic performance of the wild blueberry mechanical harvesters with small box and semi-automated bin handling technologies were investigated and compared. The new more efficient semi-automatic bin handling technologies are developed in Atlantic Canada, especially given declining availability of labour and high harvesting and production cost. Deterministic partial budgeting model, which accounts for the economic impact of switching from small box to semi-automated bin handling technology was used. Parametric partial budget and stochastic partial budget was also developed and used to accounts uncertainty associated with wild blueberry output levels, output price, interest rates on loan purchasing new mechanical harvesters and labour wages.

Net change in profit was \$674.69 ha^{-1} in 2017 and \$175.71 ha^{-1} in 2018 and indicate that upgrading from the traditional small box handling system to the semi-automated bin handling technology is financially economically viable. Stochastic partial budgeting results were also consistent with the deterministic partial budgeting results. Sensitivity analysis results indicated that switching from small box system to bin handling technology becomes more profitable with an increase in wild blueberry production and labour wage. While increased interest rate had negative effect on net change in profit. The findings of this study provide new insights for wild blueberry farmers contemplating choice of cost- effective and labour-saving harvesting technology.

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CHAPTER 5: PROFITABLITY OF WILD BLUEBERRY PRODUCTION USING ALTERNATIVE HARVESTING TECHNOLOGIES

5.0 Abstract

Profits to wild blueberry farmers are squeezed due to a significant increase in berry production and reduction in farm gate price. Harvesting costs, labour scarcity and low farm gate price prompted farmers to seek options to reduce the overall cost of production in wild blueberry operation. Efficient cost-effective and labour saving mechanical harvesters have the potentials to reduce the harvest cost, and ultimately overall cost of production. This study evaluated the profitability of wild blueberry production using alternative harvesters managed under three different harvester ownership arrangements. Production data for the economic analysis were obtained from field trials conducted in Nova Scotia, Canada. Financial and economic data were obtained from wild blueberry producers, manufacturers, and government and private database. The results indicated that net returns were maximum for both the harvesters managed under the outright purchase and rental ownership scenario, compared to custom harvesting services. Net returns were \$323 ha^{-1} using semi-automatic bin handling system compared to \$281 ha^{-1} of small box handling system in an outright purchase scenario. By comparison, net returns were \$90 ha^{-1} using semi-automatic bin handling system and \$63 ha^{-1} using small box system using rental harvesting services. Currently, net returns were negative (-\$75.71 ha^{-1}) using custom harvesting services for both the harvesters. Sensitivity analysis was also performed to assess the changes in berry production and price on net returns. Sensitivity analysis results suggest that an increase in wild blueberry production and price, increased the total net returns.

5.1 Introduction

Farm-level profitability is the greatest threat to the long-term viability of Canadian agriculture (Blank 2014; Yiridoe 2018). Profits to wild blueberry farmers are squeezed because berry markets and prices are global in scope, while productions costs are location-specific. The variability of production costs according to location influences net returns to wild blueberry producers, and prompts farmers to seek options to increase output per unit area and lower production cost. Dhuyvetter and Smith (2010) noted that differences between the range of income-risk efficient farm businesses can be traced to farm machinery cost advantages, more so than other drivers of farm profitability. Wild blueberry farmers in Atlantic Canada are seeking options to reduce average cost using innovative harvesting methods and technologies.

In Atlantic Canada, a significant increase in berry production during the last two decades (Yarborough 2004) have resulted in substantial reduction in farm-gate price from $0.60 in 2015 to $0.30 in 2018 (i.e., 50% decline) (Statistics Canada 2018). Production and acreage of wild blueberries increased with introduction of mechanical harvesters, and increased consumer demand and awareness of multiple nutritional and health benefits of the berries (Brazelton and Strik 2007).

Harvesting cost accounts for a significant proportion of total wild blueberry production cost (Yarborough 2000; Gallardo and Zilberman 2016; Esau 2017), and declining availability of labour is a key challenge for wild blueberry producers. Cost-efficient harvesting technology has the capacity to generate additional revenue by expanding total harvest area, reducing harvest cost and providing cost-effective substitute for labour (Blank 2014). Increasing global competitiveness has prompted wild blueberry producers to look for cost-effective and labour-saving harvesting technologies. Innovations in mechanical harvesters have the potential to help wild blueberry growers become competitive.

Although farmers' choice of harvesting technology is based on consideration of complex factors, most account for important costs and returns associated with the investment. Several studies have evaluated the profitability of highbush blueberries especially for production conditions in the USA (e.g., Fonsah et al 2007, 2008; Gallardo and Zilberman 2016). However, the profitability of wild blueberry production using alternative harvest handling technologies has not been investigated for Atlantic Canada farming conditions. A semi-automated bin handling harvester was introduced in Atlantic Canada in response to farm labour constraints, and cost-inefficiency complications. Depending on size of the farm operation and other farmer considerations, the mechanical harvesting equipment may be leased or rented or purchased outright. Other options for harvesting wild blueberries in Atlantic Canada include custom harvesting. Wild blueberry growers need information about the production and harvesting costs, and potential profitability associated with use of the two mechanical harvest handling technologies, managed under the alternative ownership arrangements.

The purpose of this study was to compare the farm-level profitability of wild blueberry production for the two harvest handling technologies, each managed under three harvester equipment use/acquisition scenarios. Farm returns associated with the semi-automatic bin handling technology was compared with the small box handling technology. The harvester ownership and use arrangements considered include: i) ownership or outright purchase; ii) rental agreement; and iii) custom harvesting. A first objective was to estimate and compare net returns assuming a representative 40 ha wild blueberry operation for the [2 × 3 = 6] harvester technology and ownership scenarios. The second objective was to compare net returns for three berry yield conditions (i.e., pessimistic, average, and optimistic yield) managed under different ownerships arrangements.

5.2 Research Methods

5.2.1 Harvester acquisition and service scenarios

Alternative mechanical harvester acquisition and harvester services available to wild blueberry farmers in Atlantic Canada include ownership from outright purchase, harvester rental services, and custom hiring of harvesting services. The alternative chosen for providing the use of mechanical harvester depend on factors such as size of the farm investment cost, and government cost-share support programs, labour scarcity and risk associated with a harvesting operation (Kay et al 2016).

Custom harvesting and ownership through purchase are the most common options for acquiring the use of wild blueberry mechanical harvesters in Atlantic Canada. Farmers who have limited time and labour during the critical berry harvest season, and limited investment capital to acquire the latest harvester technology tend to prefer custom hiring. Custom harvesting services also provide supplemental income to wild blueberry farmers with excess machinery capacity. Personal communication with farmers and harvester manufacturers indicate that the price paid to custom hire contractors is based on sliding pricing scale according to berry volume harvested. For example, in 2018 farmers paid \$0.26 kg^{-1} to contractors for their harvesting services for berry yield of 4300 $kg\ ha^{-1}$ or above. The summary of price paid to contractors based on sliding price scale is attached as Appendix.

Some wild blueberry farmers in Atlantic Canada rent harvesters for a relatively short period of time, depending on size of harvestable area (i.e., ranging from a few days at a time to an entire harvesting season). The harvester rental rate depends on the type of the harvesting system service. For example, in Nova Scotia the 2018 average monthly rental rate of the small box handling harvester translates to $150 per hour, compared with $180 per hour for the semi-automatic bin handling system (Swinkles 2018). Rental harvesting cost includes only the tractor and harvesting machine, while the berry farmer pays the fuel cost, operator and labour cost, and minor repair and maintenance costs. The rental agency is responsible for transportation cost of the harvester to the farm, but the farmer is responsible for providing the empty boxes and transporting the filled berry boxes to the produce receiving shed.

Farmers in Atlantic Canada who own large wild blueberry fields prefer to buy the harvesting equipment. Wild blueberry farmers can optimize use of their harvesters by renting or providing custom services for other farmers. In 2018, the government of Nova Scotia provided a cost-share program, the "Wild blueberry Harvest Efficiency program 2019-2020" which allows farmers to upgrade their harvesters with 75% funding assistance up to $20,000 per harvester. Details of the cost-share program, and eligibility requirement described in (Government of Nova Scotia 2019).

5.2.2 Wild Blueberry Production System costs

Wild blueberries are managed as biennials. Vegetative growth occurs during the first year, followed by berry fruit production in the second year (Kinsman 1993). Typical operations for a two-year wild blueberry cropping cycle are summarized in Table 2.1. Costs for fertilizer, insecticide, fungicide, and herbicide for the wild blueberry cropping systems were obtained from local farm input retailers. Application rate for inputs assumed to be used were based on official recommended label rates (Esau et al 2016; Esau 2017). Inputs costs were obtained by multiplying

Table 5.1: Fertilizer and Herbicide Prices, and Input Application Rates and Costs

Fertilizer type (granular)	Unit Price[a] ($ kg^{-1})	Application Rate[b] (kg ha^{-1})	Input Cost[c] (kg ha^{-1})
9-30-11 (Mesz)	0.76	224.07	170.29
12-22-15 (Mesz)	0.71	224.07	159.09
11-52-0 (MAP)[d]	0.70	168.05	117.64
18-46-0 (DAP)[e]	0.68	168.05	114.28
Fertilizer type (foliar)	**Unit Price ($ L^{-1})**	**Application Rate (L ha^{-1})**	**Input Cost (L ha^{-1})**
Calcium	10.00	4.94	49.40
Zinc	10.00	4.94	49.40
Boron	13.00	1.23	16.05
Iron	10.00	4.94	49.40
Magnesium	10.00	3.70	37.05
Herbicide type (granular)	**Unit Price[a] ($ kg^{-1})**	**Application Rate[b] (kg ha^{-1})**	**Input Cost[c] (kg ha^{-1})**
Velpar DF	85.00	1.97	167.96
Spartan 75 DF	2037.00	0.04	81.51
Ultim DF	1165.00	0.03	39.13
Chateau WDG	364.00	0.41	152.84
Herbicide type (foliar)	**Unit Price ($ L^{-1})**	**Application Rate (L ha^{-1})**	**Input Cost (L ha^{-1})**
Sinbar WDG	145.00	2.00	290.10
Venture L	42.50	1.97	83.98
Poast Ultra	73.00	1.12	82.04
Merge	6.70	1.97	13.24
Option 2.25 OD	36.35	1.55	56.56
UAN	3.00	1.55	4.67
Callisto 480 SC	105.00	0.29	31.12
Kerb SC	93.00	4.44	413.48
Ignite 15 SN	17.50	4.94	86.45
Authority 480	159.00	0.29	46.42

[a]Price data for fertilizers and herbicides obtained from local farm input retailers.
[b]Application rates are based on recommended label rates.
[c]Input cost obtained by multiplying unit price by application rate.
[d](MAP) denotes *Monoammonium phosphate*
[e](DAP) denotes *Diammonium phosphate*

Table 5.2: Fungicide and Insecticide Prices and Input Application Rates and Costs

Fungicide type (granular)	Unit Price[a] ($ kg^{-1})	Application Rate[b] (kg ha^{-1})	Input Cost[c] (kg ha^{-1})
Switch 62.5 WG	235.00	0.86	203.15
Pristine WG	131.50	1.39	183.83
Captan Supra 80 WDG	27.00	2.24	60.68
Fungicide type (foliar)	**Unit Price ($ L^{-1})**	**Application Rate (L ha^{-1})**	**Input Cost (L ha^{-1})**
Bravo Zn	18.50	4.94	91.39
Proline 480 SC	153.00	0.35	54.79
Tilt 250 E	50.50	0.49	24.94
Allegro 500 F	114.00	2.23	255.11
Pivot 418	75.00	0.29	22.23
Fontellis	76.50	1.72	132.26
Quilt	33.00	1.00	33.01
Insecticide type (granular)	**Unit Price[a] ($ kg^{-1})**	**Application Rate[b] (kg ha^{-1})**	**Input Cost[c] (kg ha^{-1})**
Immidan 70 WP	53.00	1.58	83.78
Assail 70 WP	817.50	0.16	131.25
Delegate WG	415.00	0.19	82.93
Insecticide type (foliar)	**Unit Price ($ L^{-1})**	**Application Rate (L ha^{-1})**	**Input Cost (L ha^{-1})**
Decis 5 EC	89.00	0.12	11.21
Success 480 SC	212.00	0.18	38.54
Sevin XLR	26.25	4.00	105.04

[a]Price data for fungicides and insecticides obtained from local farm input retailers.
[b]Application rates are based on recommended label rates.
[c]Input cost obtained by multiplying unit price by application rate.

the input rates by 2018 input prices obtained from local farm input retailers. The cost for fertilizer and herbicides are summarized in Table 5.1 and fungicides and insecticides in Table 5.2.

Wild blueberry fields can be pruned using different methods, such as oil burning, straw burning, flail mowers, etc. Before 1980, wild blueberry fields were commonly pruned using straw and oil burning. Flail mowing is now widely practiced, in part because it is more cost-efficient and more environmentally-friendly compared to the other alternatives (Yarborough 2004). Honey bees colonies are often placed on wild blueberry fields to improve pollination and increase fruit sets and, ultimately, berry yield (Yarborough 2004). Pruning and pollination cost were obtained from Colbert Farmers Cooperatives, Joe Slack Limited and Bragg Lumber Company (Table 5.3).

Application of specific agronomic and management practices (such as fertilizer, insecticide, fungicide, herbicide, pruning and supplemental pollination) often depend on existing field conditions. In Nova Scotia, a single fertilizer application of *Mitteleuropaische sommerzeit* (Mesz) is recommended, and was assumed to be applied in early May (during the 1st year of vegetative growth). Herbicide application involved Velpar and a tank mix of Callisto and Venture. Fungicides recommendation includes one application of Bravo and Proline, and two applications of Tilt and Pristine during the vegetative year. Imidian is commonly used as an insecticide in wild blueberry fields in Nova Scotia.

In order to determine machinery fixed costs and variable costs, it was assumed that wild blueberry crop was grown on 40 ha farm, which is the average size farm for wild blueberry in Nova Scotia (Statistics Canada 2018). In this analysis, half of the crop was assumed to be managed during the vegetative growth year, and the remaining half managed in the fruit production year. Net returns associated with wild blueberry systems using the two harvest handling systems were calculated by subtracting the total production cost from the associated gross returns.

5.2.3 Machinery fixed cost

Fixed costs such as annual depreciation, interest on investment loans, and housing and insurance do not vary with machinery and equipment usage. The diminishing balance method was used to calculate annual depreciation of machinery and equipment, with a rate of 15% applied to powered machines (e.g., tractor and harvester) and 10% for non-powered equipment (Yiridoe and Weersink 1994). All the machinery used in this study were assumed to be five years old. Interest on investment (i.e., both tractor and harvester) was based on the assumption that 70% of

Table 5.3: Pollination and Pruning methods and Costs

Pollination	Cost ($ ha^{-1})
Honey bee hives	321.1
Bumble bee quads	864.5
Pruning Method	**Cost ($ ha^{-1})**
Flail mower	172.90
Rotary mower	172.90
Rotary and flail mower	345.80
Sickle bar and burning	296.40
Straw burning	642.20
Oil burning	642.20

Data source: Pruning and pollination costs were obtained from Colbert Farmers Cooperatives, Joe Slack Limited and Bragg Lumber Company.

Table 5.4: Machinery fixed cost for a 40 ha representative wild blueberry farm.

Machine/Harvester	Machinery fixed cost		
	Depreciation	Interest cost	Housing and Tractor
Small box handling system	3750.04	1137.45	718.39
Tractor	4899.55	1486.11	938.60
Bin handling system	3988.39	1209.74	764.05
Tractor	4003.79	1214.41	767.00

Table 5.5: Machinery and variable cost for a 40 ha representative wild blueberry farm.

Machinery variable costs	Small box handling system (40 ha)		Semi-automatic bin handling system (40 ha)	
	Harvester	Tractor	Harvester	Tractor
Fuel cost	693.12	779.76	613.6	637.2
Lubrication cost	103.97	116.96	92.04	95.58
Repairs and maintenance	1677.93	675.79	1786.6	552.24
Labour cost (operator)	2166	---	1770	---
Labour cost (second farm worker)	1732.8	---	---	---
Rental rate of loader tractor	---	---	4000	---

Inputs[a]	Recommended rate/method	Price (kg ha^{-1})	Total cost (40 ha)
9-30-11 (Mesz)	1	170.29	3405.80
Velpar DF	1	167.96	3359.20
Callisto + Venture	1	115.10	2302.00
Bravo Zn	1	91.39	1827.80
Proline 480 SC	1	54.79	1095.80
Pristine WG	2	367.66	7353.20
Tilt 250 E	2	49.88	997.60
Immidan 70 WP	1	83.78	1675.60
Pruning	Flail mowing	172.90	3458.00
Pollination	2.48 hives	321.10	6422.00

depreciation value was equity and the remaining 30% was debt (Yiridoe et al 1993). Insurance and housing cost were assumed to be 1.5% of the purchase price of the equipment (Kay et al 2016). Annual fixed costs of the machines and equipment are summarized in Table 5.4.

5.2.4 Machinery variable cost

Machinery variable costs include fuel consumption, oil and lubrication, repairs and maintenance cost, and based on equipment usage. Fuel cost was calculated by multiplying average hourly fuel consumption by operating hours. Oil and lubrication costs were assumed to be 15% of total fuel costs (Kay et al 2016). Repair and maintenance costs were estimated using American Society of Agricultural and Biological Engineers (ASABE) standards (ASABE 2017) and estimated life of the tractors and harvesters. The wage rate of the tractor operator was $15 per hour, and based on 2018 Nova Scotia labour market prices, and $12 per hour for the second farm worker. Annual variable costs are summarized in Table 5.5.

5.2.5 Net return

Net returns were compared under three alternative ownership scenarios for both small box and semi-automatic bin handling systems. Net returns associated with the alternative harvesting systems and harvester acquisition scenarios were calculated by subtracting the total production cost from the total revenues. Total revenue was obtained by multiplying wild blueberry yield obtained from the field trails by the farm gate prices received by Nova Scotia farmers and then by the assumed 40 ha representative farm.

The total cost includes input costs (i.e., fertilizer, herbicide, fungicide, and insecticide costs), cost of management practices (i.e., pruning, pollination), harvesting costs (i.e., fixed and variable costs) and costs associating with transporting berries from field to receiving shed. Details on the total cost and recommended applications rates of different agronomic and management practices on the representative farm are summarized in Table 5.5. A more efficient wild blueberry harvesting technology will allow for harvesting a given area in a shorter time period, which may translate into cost savings, and, ultimately, higher net returns.

5.2.6 Sensitivity analysis

Sensitivity analysis was performed to assess the effects of selected variables on net returns for the small box and semi-automatic bin handling technology. Net returns in wild blueberry production mainly influenced by wild blueberry yield and price. Sensitivity analysis on wild blueberry output were based on three yield scenarios; i.e., optimistic scenario, average scenario, and pessimistic scenario. Yield levels of the scenarios are reported in Table 4.3.

The 2017 farm gate price of wild blueberries in Atlantic Canada was \$0.55 kg^{-1}, which low compared with \$2.30 kg^{-1} in 2008. Sensitivity of the effect of wild blueberry price on net returns was investigated using a price range from \$0.55 to \$2.30 kg^{-1}.

5.3 Data

The average size of a representative blueberry farm was obtained by dividing total berry area (ha) in Nova Scotia by total number of farms, according to 2016 census Canada data. Wild blueberry production data were obtained from on-farm trials conducted in selected sites in Nova Scotia using the two mechanical harvesters. In this study, wild blueberry yields net of harvester-induced losses were determined by weighing at a receiving shed.

Costs of production and output price associated with the wild blueberry systems were based on local Nova Scotia market prices. Financial and other economic data were gained from various sources. For example, agronomic cost data were obtained from local farm input retailers. Wild blueberry tractor and harvester price data and usage data (i.e., fuel consumption data) were obtained from Doug Bragg Enterprises Ltd., located in Collingwood, Nova Scotia. Rental and custom berry harvesting rates were 2018 industry rates obtained from local wild blueberry farmers. Wild blueberry prices were obtained from Statistics Canada (2018), and Wild Blueberry Producers

Association of Nova Scotia. Interest rate on loans were based on Bank of Canada and commercial banking rates (Statistics Canada 2018).

5.4 Results and Discussion

5.4.1 Effect of Harvest Handling Technology Type on Profitability

Net returns using alternative harvester acquisition/ownership scenarios are presented in Figure 5.1a. Net returns were \$280.62 ha^{-1} with the outright purchase of harvester with small box handling system. The main proportion of the total cost comes from using various chemical inputs in the vegetative year and harvesting cost from the production year. Total variable costs including chemical inputs, pruning, and pollination account for about 55% of the total costs, while harvesting cost including total fixed costs and total variable costs accounts for 45% of the total costs using small box handling system managed under outright purchase scenario.

The high harvesting cost of small box handling system includes total fixed costs (i.e., depreciation, interest cost on investment, and housing and insurance) and total variable costs (fuel cost, lubrication cost, repairs and maintenance costs and labour costs). The breakeven yield associated with using small box system was 5496 kg ha^{-1}. While the breakeven farm gate price using small box system was \$0.46 kg^{-1}.

Net returns were \$322.23 ha^{-1} with the outright purchase of harvester with semi-automatic bin handling system in wild blueberry production (Figure 5.1a). High efficiency increased the net returns despite an additional \$30,000 costs of the semi-automatic bin handling system, compared to the small box handling system. The semi-automatic bin handling system has the capacity to harvest the same acreage in less time (354 minutes per ha for semi-automatic bin handling system compared with 433 minutes per ha for small box handling system) and allows to offset the additional cost of semi-automatic bin handling system by generating additional revenues.

Harvesting cost accounts for 44% of the total costs using semi-automatic bin handling system operated under outright purchase scenario. The higher proportion of harvest cost of semi-automatic bin handling systems includes total fixed cost (i.e., depreciation, the interest cost on investment and housing and insurance), which is approximately 40% of total harvest cost. The breakeven yield associated with using small box system was 5345 kg ha^{-1}. While the breakeven farm gate price using small box system was \$0.45 kg^{-1}.

Mechanical handling of semi-automatic bin handling system makes the semi-automatic bin handling more profitable by saving time and labour managed under outright purchase scenario,

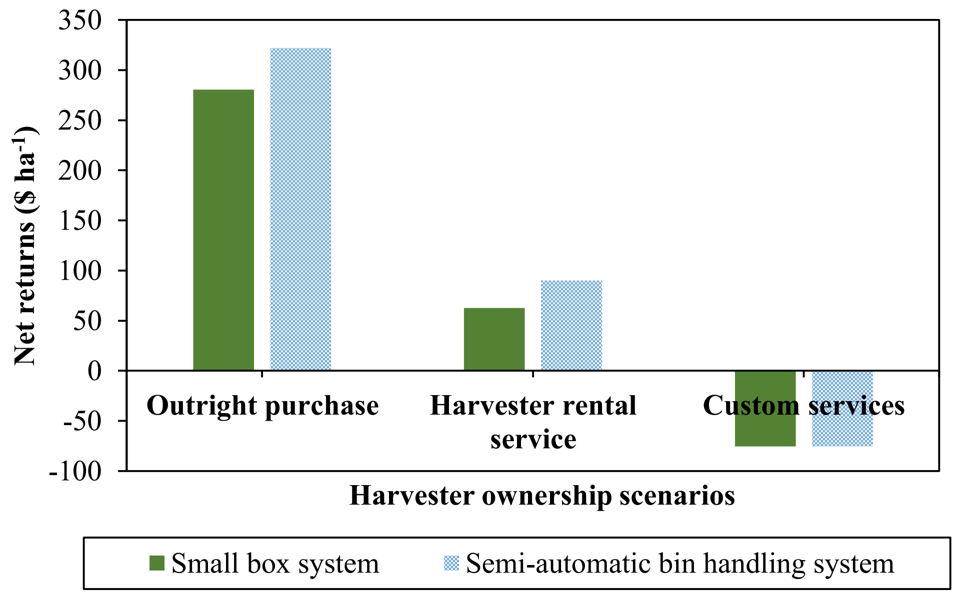

Figure 5.1a: Effects of alternative harvester acquisition/ownership scenarios on net returns (\$ ha^{-1}).
Note: Net returns were calculated from 40 ha representative wild blueberry field.

compared with small box handling system. Semi-automatic bin handling system increased the net returns \$322.23 ha^{-1} from \$280.62 ha^{-1} using small box handling system, representing a 15% increase in net returns (Figure 5.1a).

5.4.2 Effect of Alternative Harvester Ownership/Use Arrangements

Net returns using alternative harvester acquisition/ownership scenarios are presented in Figure 5.1a. Net returns were \$62.53 ha^{-1} using small box handling system managed under harvester rental services. Low net returns using rental services compared to small box handling system ownership by purchase was mainly due to high rental cost of harvesting machinery. The high rental cost of harvesting equipment includes total rental cost, fuel cost, lubrication cost, repair and maintenance cost, and labor cost. Net returns were decreased by 78% from \$280.62 to \$62.53 ha^{-1} when harvester with small box handling system managed under rental services from outright purchase. The breakeven farm gate price in average yield field (6517 kg ha^{-1}) using small box system was \$0.53 kg^{-1}, while the breakeven yield associated with using small box system was 6290 kg ha^{-1}.

Net returns were lowest when small box handling system was managed using custom harvesting services, compared to other ownership arrangements (i.e., outright purchase and rental services). Net returns were -\$75.71 ha^{-1} and implies that harvesting using custom services was not profitable (Figure 5.1a). The high custom harvesting cost and low farm gate price were the leading factors that make this arrangement not profitable. In custom harvesting services, the breakeven farm gate price in average yield field (6517 kg ha^{-1}) was \$0.57 kg^{-1}, for both small box and semi-automatic bin handling technology. While, the breakeven yield associated with custom harvesting services was 6792 kg ha^{-1} (using \$0.55 kg^{-1} farm gate price). The harvesting cost paid by the farmer to contractors were the same for a small box and semi-automatic bin handling technologies, according to the sliding price scale. Generally, it depends upon the contractor to use harvester with small box and semi-automatic bin handling system for the wild blueberry harvesting.

For the semi-automatic bin handling system, net returns were \$89.92 ha^{-1} when managed rental ownership scenario The low profit in rental ownership scenario compared to outright purchase scenario were due to the high rental cost of the harvesting equipment. Net returns were decreased by 72% from \$322.23 to \$89.92 ha^{-1} when harvester semi-automatic bin handling technology managed under rental services scenario. The breakeven farm gate price in average yield field (6517 kg ha^{-1}) using semi-automatic bin handling technology was \$0.52 kg^{-1}, while the breakeven yield associated with using semi-automatic bin handling technology was 6190 kg ha^{-1}. Net returns were lowest when semi-automatic bin handling technology was managed using custom harvesting services (\$75.71 ha^{-1}), compared to other ownership arrangements, similar to small box system.

In summary, net returns were maximum (\$322.23 ha^{-1}) when semi-automatic bin handling system was managed under outright purchase scenario compared to other ownership arrangements considered in this study. Harvester using semi-automatic bin handling system was more profitable than small box system both in the outright purchase and rental ownership scenarios.

5.4.3 Effect of Cost-share Harvest Efficiency Program on Profitability

Cost-share Harvest Efficiency Program allows farmers to upgrade their harvesters with 75% funding assistance up to \$20,000 per harvester. Net returns were \$368.27 ha^{-1} and indicate that harvesting under outright purchase scenario using cost-share harvest efficiency program was more profitable (compared to all other scenarios). Net returns increased from \$280.62 to \$368.27

ha^{-1} by 31% when upgraded from small box to semi-automatic bin handling system (Figure 5.1b). Whereas, net returns increased from \$322.23 to \$368.27 ha^{-1} by 14% when semi-automatic bin handling system managed under outright purchasing using cost-share harvest efficiency program (Figure 5.1b). The high net returns were due to extra \$20,000 funding assistance outright purchase ownership. Cost-share harvest efficiency program decreases the total harvest cost from 44% to 29% in wild blueberry production. The low harvest cost increased the overall net returns in wild blueberry production.

5.4.4 Sensitivity analysis

5.4.4.1 Sensitivity of Yield on Net returns

As expected, net returns were highest under the optimistic yield scenario and lowest for the pessimistic yield scenario, consistent for both small box and bin handling system (Figure 5.2). For example, when blueberry production increased from typical yield condition (6517 kg ha^{-1}) to

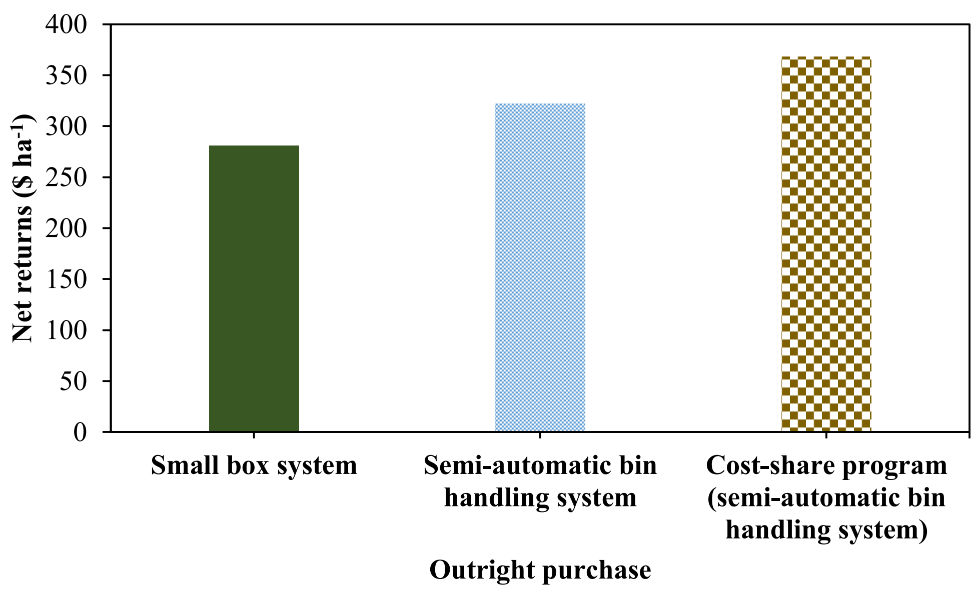

Figure 5.1b: Effects of alternative harvester on net returns (\$ ha^{-1}), with outright purchase of harvester.

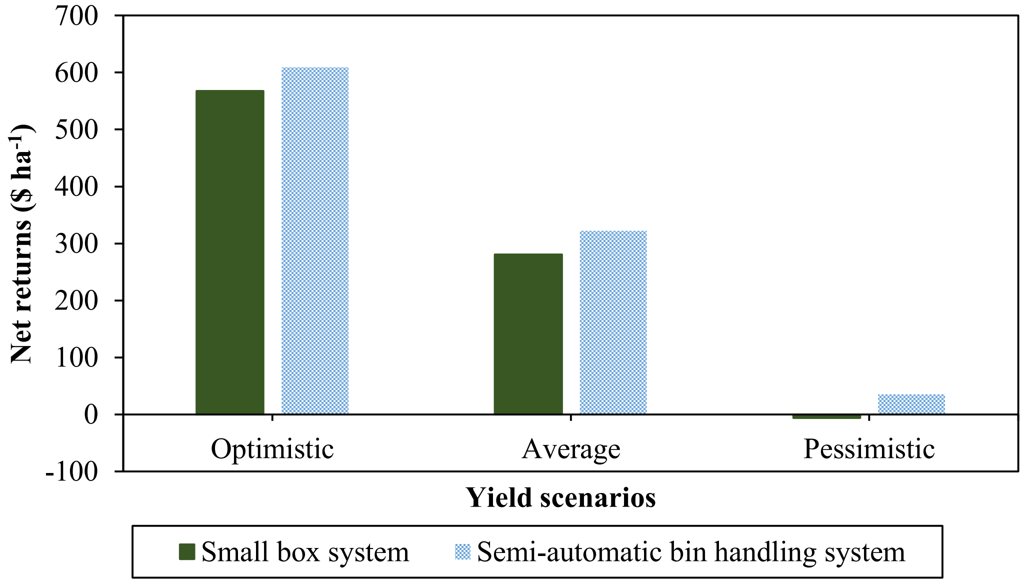

Figure 5.2: Effects of alternative yield scenarios on net returns ($ ha^{-1}), with outright purchase of harvester.

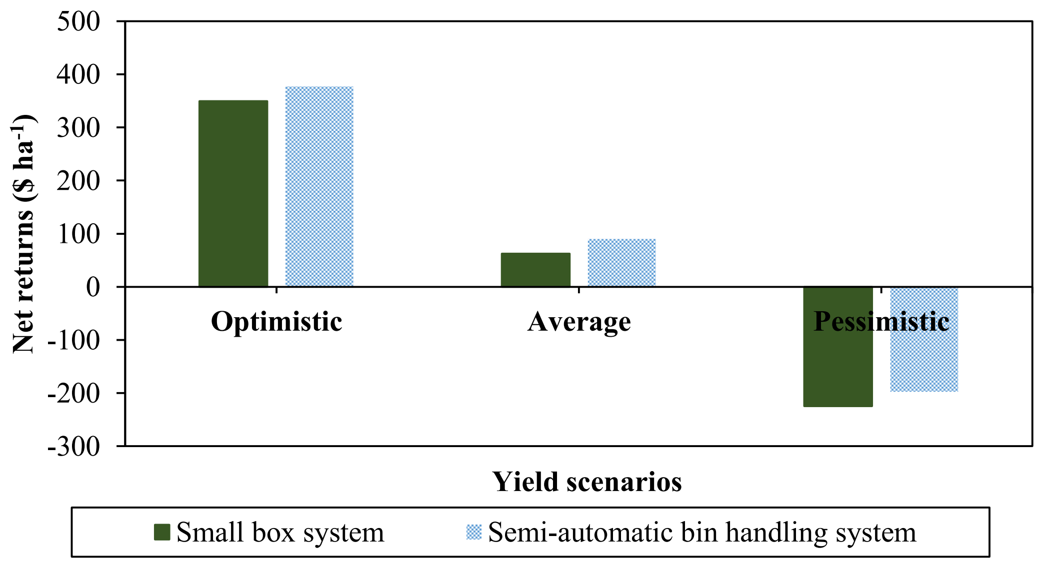

Figure 5.3: Effects of alternative yield scenarios on net returns ($ ha^{-1}), using harvester rental services.

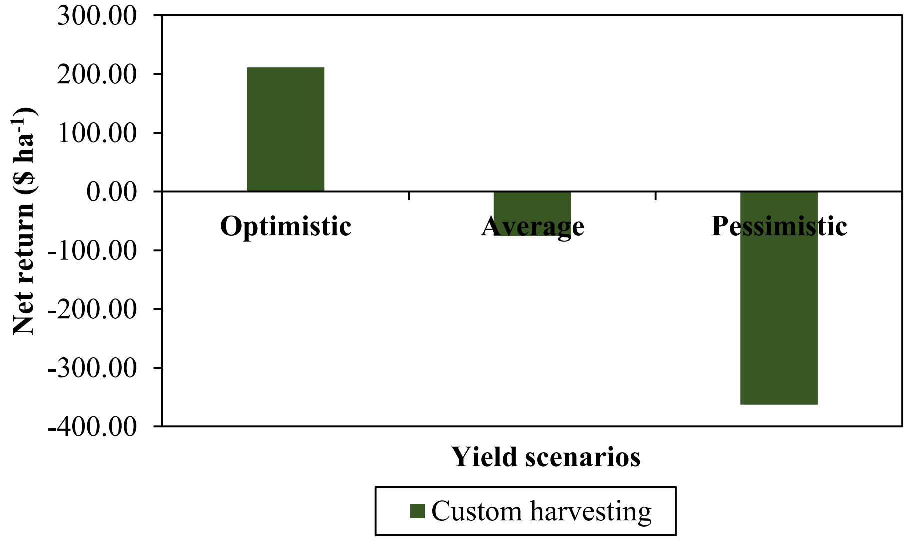

Figure 5.4: Effects of alternative yield scenarios on net returns ($ ha^{-1}), using custom harvesting services.

optimistic yield condition (7561 kg ha^{-1}) net returns increased by 89% from $322 to $609 ha^{-1} using semi-automatic bin handling system. By comparison, net returns increased by 102% from $281 to $568 ha^{-1} using small box handling system under the two yield scenarios. Similarly, when blueberry production decreased from typical yield condition (6517 kg ha^{-1}) to pessimistic yield condition (5473 kg ha^{-1}) net returns decreased by 89% from $322 to $35 ha^{-1} using semi-automatic bin handling system (Figure 5.2). By comparison, net returns decreased by 102% from $281 to -$6 ha^{-1} using small box handling system under the two yield scenarios.

The effects of alternative yield scenarios on net returns ($ ha^{-1}), using harvester rental services are illustrated in Figure 5.3. Net returns increased by 318% from $90 to $377 ha^{-1}, when blueberry production increased from typical yield condition to optimistic yield condition using semi-automatic bin handling system, compared to 456% increased using small box handling system. When blueberry production decreased from typical yield condition to pessimistic yield condition net returns decreased by 319% from $90 to -$197 ha^{-1} using semi-automatic bin handling system (Figure 5.3). By comparison, net returns decreased by 457% from \$63 to -\$225 ha^{-1} using small box handling system under the two yield scenarios.

The effects of alternative yield scenarios on net returns (\$ ha^{-1}), using custom harvesting services are presented in Figure 5.4. In custom harvesting services, net returns were only profitable in optimistic yield scenarios compared to typical and pessimistic yield scenarios. For example, when blueberry production increased from typical yield condition to optimistic yield condition net returns increased by 379% from -\$76 to \$212 ha^{-1} for alternative handling systems. Similarly, net returns decreased by 378% from -\$76 to -363 ha^{-1}, when blueberry production decreased from typical yield condition to pessimistic yield condition

5.4.4.2 Sensitivity of Berry Prices on Net returns

As expected, net returns were highest for maximum wild blueberry price considered in this study and was lowest for minimum wild blueberry price, for both small box and bin handling technologies. An increase in wild blueberry price increases net profit for the farmers. As expected, increased in wild blueberry price increased the net returns for a small box and semi-automatic bin handling systems. For example, when blueberry price increased from \$0.55 to \$0.99 kg^{-1} net returns increased by 448% from \$322 to \$1763 ha^{-1} using semi-automatic bin handling system (Figure 5.5). By comparison, net returns for small box handling system increased from \$281 to \$1722 ha^{-1}, representing 513% increase.

In rental harvester ownership scenario, when the blueberry price increased from \$0.55 to \$0.99 kg^{-1} net returns increased by 1601% from \$90 to \$1531 ha^{-1} using semi-automatic bin handling system (Figure 5.6). By comparison, net returns for small box handling system increased by 2287% from \$63 to \$1504 ha^{-1}. Similarly, for custom harvesting scenario, net returns were highest for maximum wild blueberry price and was lowest for minimum wild blueberry price, as expected. For example, when blueberry price increased from \$0.55 to \$0.99 kg^{-1} net returns increased by 1837% from -\$76 to \$1366 ha^{-1} for both small box and semi-automatic bin handling technologies.

5.5 Summary and Conclusions

Wild blueberry production has been increased significantly during the last two decades have resulted in a substantial reduction in farm-gate price affects the profitability of berry operation. Currently, mechanical harvesters with a small box and semi-automatic bin handling technology were commonly used for wild blueberry harvesting in Atlantic Canada. The farm-level profitability of two alternative harvesters using different ownership arrangement has never taken

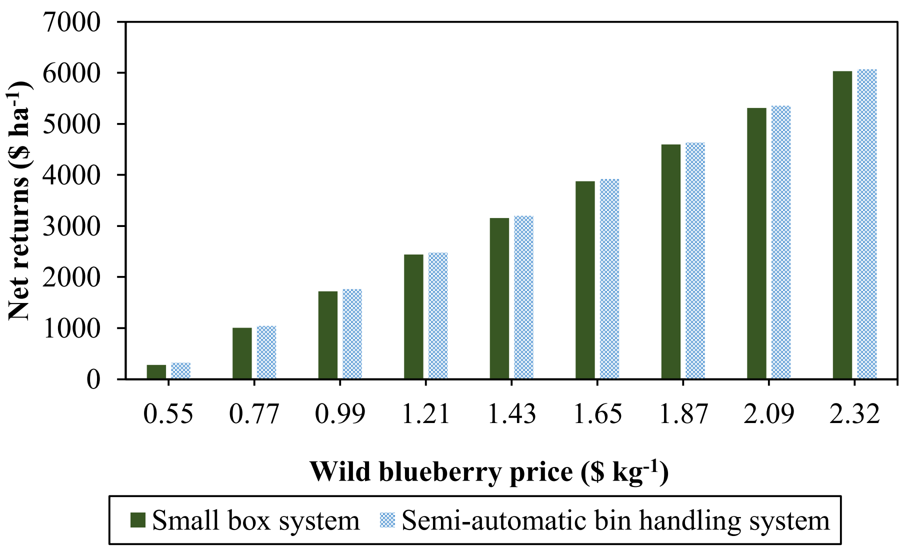

Figure 5.5: Sensitivity of wild blueberry price on net returns (\$ ha^{-1}), with outright purchase of harvester.

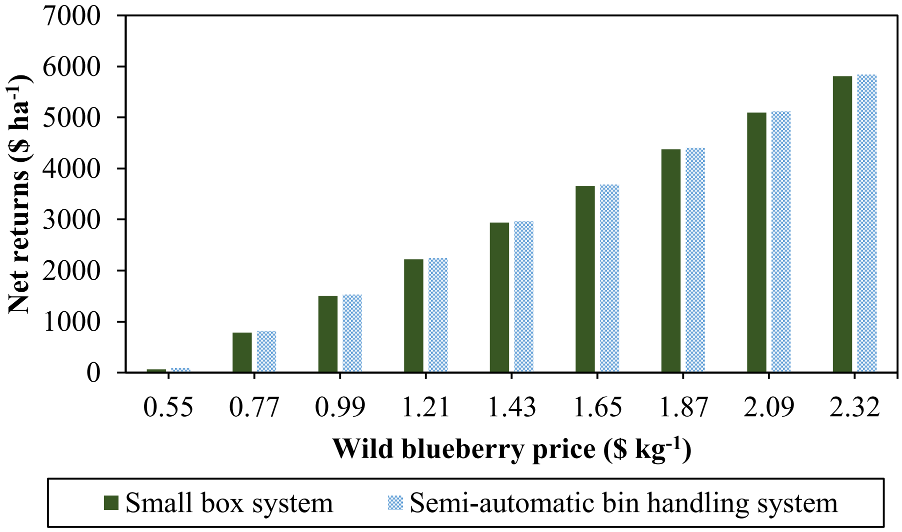

Figure 5.6: Sensitivity of wild blueberry price on net returns ($ ha^{-1}), using harvester rental services.

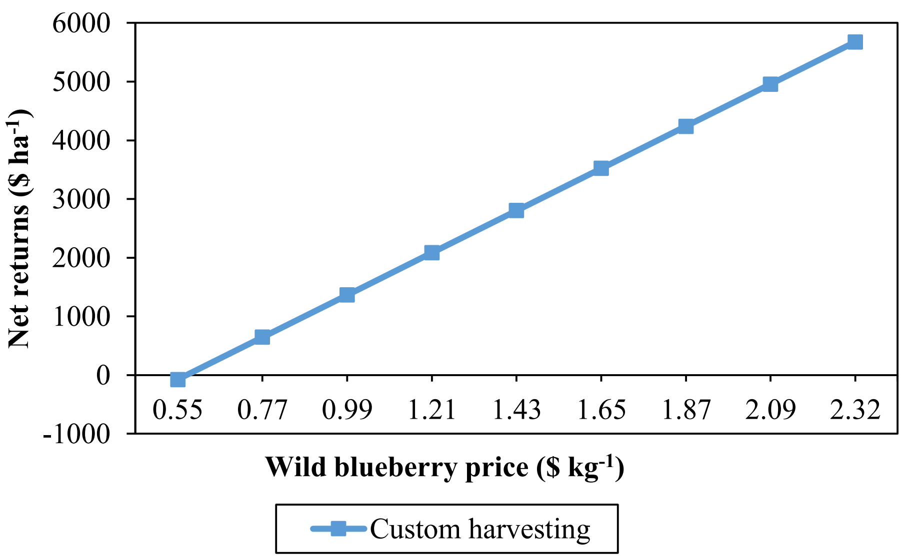

Figure 5.7: Sensitivity of wild blueberry price on net returns ($ ha^{-1}), using custom harvesting services.

into investigated. This study evaluated the profitability of wild blueberry production for the alternative harvesters, managed under three ownership scenarios for a 40 ha representative farm. Data for this study were obtained from on-farm trials, local farm inputs retailers, farmers, and various other sources.

It was found that net returns were maximum for semi-automatic bin handling system ($368 ha^{-1}) under the government support cost-share program. Net returns were positive in ownership through purchase and harvester rental services, while net returns were negative using custom harvesting services. In an outright purchase scenario, net returns were $322.23 ha^{-1} using semi-automatic bin handling system, compared to $280.62 ha^{-1} for small box system. Similarly, semi-automatic bin handling system was more profitable using rental harvesting services in wild blueberry production than the small box system. While net returns were -$75.71 ha^{-1} for both small box and semi-automatic bin handling systems using custom harvesting services.

Sensitivity analysis was also conducted to assess the effect of wild blueberry yield and price on net returns. The results suggest that an increase in production and price positively influenced the results under all harvester ownership arrangements.

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CHAPTER 6: SUMMARY AND CONCLUSIONS

6.1 Background

Wild blueberry is a unique and major cash crop of Atlantic Canada. Improved agronomic and management practices have contributed to an increase in the production of wild blueberry crop, prompted a need for the economically viable mechanical harvester. Wild blueberry mechanical harvesters with small box handling system and semi-automatic bin handling technology are commonly used to harvest the wild blueberry crop. An important problem involves the availability of skilled labour for wild blueberry harvesting, especially for the small box handling system which requires an extra farm worker to manually handle the boxes compared to mechanical handling of boxes for the semi-automated box handling system.

Rising harvesting costs and other production cost, and declining blueberry price due to high berry supply have squeezed the profit margins for the wild blueberry producers. Several engineering studies in Atlantic Canada have resulted in engineering improvements in wild blueberry mechanical harvesters. There is no specific study regarding the comparison of harvest efficiency and economic returns associated with the use of alternative mechanical harvest handling systems in Atlantic Canada.

In this study, the economic problem was to provide the required technical information of wild blueberry crop to the farmers and manufacturers regarding how they could harvest the crop using cost-effective and labour-saving technologies. The research problem of the study was to provide technical knowledge on production cost and economic returns comparison of the alternative mechanical harvesters. The main purpose was to compare the harvest efficiency, net change in profit and farm returns and to understand the economic viability of using small box and semi-automated bin handling technologies in Nova Scotia.

6.2 Summary of Major Results

In this section, a brief summary of the major findings are presented according to specific objectives of the study.

Objective 1: To decompose and compare total harvest time, and harvest rate of small box and semi-automatic bin handling systems for wild blueberries.

Harvest efficiency and harvest rate of the small box and semi-automatic bin handling technologies have been quantified and compared in this study using field trials data. Different mathematical equations have been used to determine the harvest time and berry handling time of the two box-handling systems. Harvest rate was measured in alternative ways including; i) tonnes per hour; and ii) hours per hectares. Both mechanical harvesters were operated side by side during field harvesting trials with double-head and similar engineering configurations.

Paired *t*-test and two sample student *t*-test were used to compare the harvest efficiency of the small box and semi-automated bin handling system. Regression modelling were also used to check the effect of weed coverage and harvester type on wild blueberry yield. For 2017 and 2018 data, the parameter estimate for weed coverage dummy variable was significantly different. The parameter estimate for harvester type was not significantly different, although yield associated with semi-automated bin handling technology was higher than the small box system.

Results also indicated that semi-automated bin handling system had high harvest rate then small box system. Bin handling system harvested 1.20 tonnes of berries, compared with 1.01

tonnes per hour for the small box system. Results also suggested that, harvest efficiency of the semi-automatic bin handling system was significantly higher by 22% in 2017 and 29% in 2018 from small box handling system.

Objective 2: To determine the economic impacts of switching from the small box to semi-automatic bin handling technology.

Economic performance of alternative mechanical harvesting technologies involving a small box handling technology and a semi-automatic bin handling technology was determined using important economic and harvest efficiency data. Deterministic partial budgeting methods allowed to estimate the net change in profit, when switching to small box system to semi-automated bin handling technology. Parametric partial budgeting and stochastic partial budgeting methods were used to determine uncertainty associated with selected economic parameters that effect the net change in profit.

Results indicated that the net change in profit was \$674.69 ha^{-1} in 2017 and \$175.71 ha^{-1} in 2018, and suggests that switching from small box to bin handling system was profitable. Parametric partial budgeting results suggested that wild blueberry production and labour wages have a positive effect on net change in profit, while interest rate on investment loans has a negative effect on net change in profit. Increase in interest rate increased the total additional cost, negatively influenced the profits. The main findings of stochastic partial budgeting were consistent with the deterministic partial budgeting. The total additional revenue and reduced costs were greater than the total additional cost and reduced revenue for 1000 randomly drew simulations. The average net change in profit was \$729.96 in 2017 and was \$180.11 at 95% confidence interval.

Objective 3: To estimate and compare profitability of wild blueberry production using mechanical harvesters with two berry handling systems.

The profitability of wild blueberry production was investigated for the small box and semi-automatic bin handling systems, managed under alternative asset ownership arrangements. Furthermore, the profitability was also estimated with a Nova Scotia government cost-share harvest efficiency program. Sensitivity of the yield and price were also assessed on net returns managed under alternative ownership arrangements.

Results suggest that mechanical harvesters with two box handling system were profitable, with the outright purchase of harvesters and rental services, compared to custom harvesting services. Semi-automatic bin handling system was more profitable in wild blueberry production operation than the small box handling system when managed under the outright purchase and rental harvesting services. For example, net returns were \$323 ha^{-1} for the semi-automatic bin handling technology with the outright purchase of harvester, compared to \$281 ha^{-1} for the small box handling system. Similarly, in harvester rental services, net returns were highest for semi-automatic bin handling technology (\$90 ha^{-1}), compared to the small box system (\$63 ha^{-1}). Custom harvesting services were not profitable in wild blueberry production, using mechanical harvesters with two berry handling systems.

Net returns were maximum (\$368 ha^{-1}) with a Nova Scotia government cost-share harvest efficiency program using semi-automatic bin handling system. The \$20,000 funding assistance helped wild blueberry farmers to reduced overall total harvesting cost. Sensitivity analyses suggest that wild blueberry price and yield were positively influenced profitability of wild blueberry production. Increase in price and yield increased net returns for both harvesters under all ownership arrangements.

6.3 Contributions of the Study

6.3.1 Empirical Contributions

There are several applications of partial budgeting and enterprise budgeting in crop production. But there are no previous studies that used this application to estimate the farm returns in wild blueberry production in Atlantic Canada. This is a first study that used partial budgeting and enterprise budgeting in wild blueberry production in Atlantic Canada.

6.4 Recommendations for the Further research

Further studies can evaluate the long-term impact of socioeconomic factors on the adoption of the alternative wild blueberry mechanical harvesters.

The further research can consider to evaluate the long-term nature of harvester investments that will help to determine the financial feasibility of new harvester purchase decisions. Economic decision criteria including net present value (NPV), benefit-cost ratio (BCR), pay-back period, and internal rate of return (IRR) will further investigate the long term impact of harvester investments.

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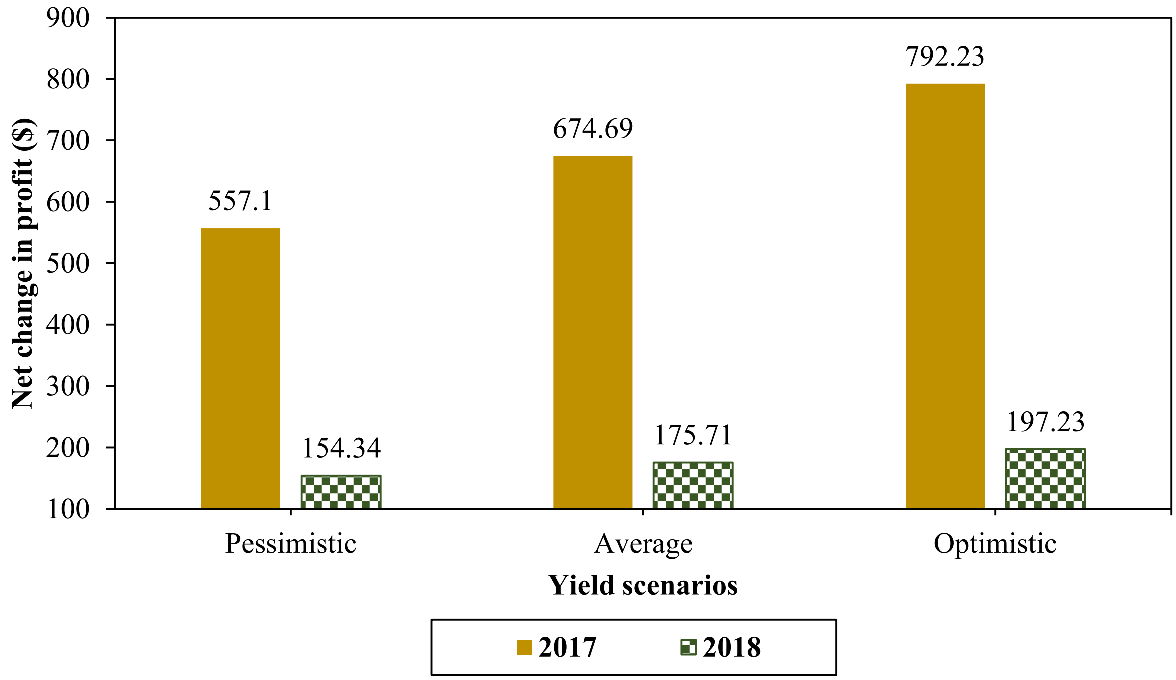
APPENDIX

Appendix a: Net change in profit (CAD$) for 2017 and 2108 data, when switching from small box to semi-automatic bin handling technology.



Appendix b: Net returns of wild blueberry production managed under alternative harvester ownership scenarios.

	SB[a] Outright purchase	**BHS[b] Outright purchase**	**SB[a] Rental services**	**BHS[b] Rental services**	**SB[a] Custom harvesting**	**BHS[b] Custom harvesting**
Chemical inputs[a]	22017.00	22017.00	22017.00	22017.00	22017.00	22017.00
Pruning	3458.00	3458.00	3458.00	3458.00	3458.00	3458.00
Pollination	6422.00	6422.00	6422.00	6422.00	6422.00	6422.00
Spraying cost	1102.40	1102.40	1102.40	1102.40	1102.40	1102.40
Transportation cost	5747.80	5747.80	5747.80	5747.80	5747.80	5747.80
Fuel cost	693.20	613.60	693.20	613.60	NA	NA
Lubrication cost	104.00	92.00	104.00	92.00	NA	NA
Repairs and maintenance	2353.40	2339.00	2353.40	2339.00	NA	NA
Labour cost (operator)	2166.00	1770.00	2160.00	1770.00	NA	NA
Labour cost (second farm worker)	1728.00	NA	1728.00	NA	NA	NA
Rental rate of loader tractor	NA	1573.40	NA	1573.40	NA	NA
Interest on operating expenses	1740.09	1715.14	1739.86	1715.14	1472.39	1472.39
Total Variable costs	**47531.89**	**46850.34**	**47525.66**	**46850.34**	**40219.59**	**40219.59**
Fixed costs						
Depreciation	8649.60	6760.24	NA	NA	NA	NA
Interest cost	2623.60	2050.51	NA	NA	NA	NA
Housing and Insurance	1657.00	1295.05	NA	NA	NA	NA
Rent	NA	NA	21660.00	21240.00	NA	NA
Custom harvesting	NA	NA	NA	NA	34487.96	34487.96
Total fixed costs	**12930.20**	**10105.80**	**21660.00**	**21240.00**	**34487.96**	**34487.96**
Total costs	60462.09	56956.13	69185.66	68090.34	74707.56	74707.56
Net revenue	71687.00	71687.00	71687.00	71687.00	71687.00	71687.00
Net returns ($ 40ha^{-1})	**11224.91**	**14730.87**	**2501.34**	**3596.66**	**-3020.56**	**-3020.56**
Net returns ($ ha^{-1})	**280.62**	**368.27**	**62.53**	**89.92**	**-75.51**	**-75.51**

[a]SB denotes small box handling system; [b]BHS denotes semi-automatic bin handling system; [c]Chemical inputs includes fertilizer, herbicides, fungicides and insecticides

Appendix c: Wild blueberry price sliding scale.

Yield (kg ha^{-1})	Wild blueberry price ($ kg^{-1})	Yield (kg ha^{-1})	Wild blueberry price ($ kg^{-1})
784-896	0.816	2914-3025	0.331
897-1008	0.772	3026-3137	0.324
1009-1120	0.728	3138-3249	0.320
1121-1232	0.684	3250-3361	0.313
1233-1344	0.639	3362-3474	0.309
1345-1456	0.595	3475-3586	0.302
1457-1568	0.551	3587-3698	0.298
1569-1680	0.507	3699-3810	0.291
1681-1793	0.463	3811-3922	0.287
1794-1904	0.452	3923-4034	0.280
1905-2016	0.408	4035-4146	0.276
2017-2128	0.386	4147-4258	0.269
2129-2241	0.375	4300+	0.265
2242-2353	0.364		
2354-2465	0.357		
2466-2577	0.353		
2578-2689	0.346		
2690-2801	0.342		
2802-2913	0.335		