Decisions of Producer-Funded Agricultural Research and Development

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ABSTRACT

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Decisions of Producer-Funded Agricultural Research and Development

Supervisor: Dr. Murray E. Fulton

Agricultural research and development (R&D) investment is becoming an increasingly important policy issue as food prices push upwards and food security problems emerge. An important source of agricultural R&D funding is from producer check-offs, which are increasingly being used to fund applied agricultural research such as disease management, genetic improvement, and weed control. Existing studies of producer-funded agricultural R&D indicate that there are high private and social rates of return to agricultural R&D investment by farmers, and thus that farmers are under investing in R&D.

The focus of this thesis is at the producer level. This study examines one of the factors – the horizon problem – behind the apparent disincentive for farmers to invest in producer-funded R&D activities. It has been argued that given the long period of time over which the benefits of R&D investment occur, the increasing age of the farm population implies that the horizon problem could be indeed an important factor in producer underinvestment. Contrary to this widely acknowledged argument, this study shows the horizon problem is likely not a factor affecting farmers R&D investment decisions.

Two models are developed to examine the horizon problem. The first model consists of a framework for determining the marginal internal rate of return of investing in R&D. Specifically, the analysis compares the internal rate of return IRR_h associated with the farmers' planning horizon with the internal rate of return $\overline{\text{IRR}}$ associated with the benefit horizon of the R&D. The impact of the horizon problem is determined by examining the difference between IRR_h and $\overline{\text{IRR}}$. In this analysis the farmers are assumed to be located in a small country – i.e., a country whose collective output has no impact on world price – and produce a single product.

The results of the horizon problem model show how that, contrary to what some authors have argued, the horizon problem is likely not a disincentive for R&D investment, unless the time

horizon of farmers is very short. Given that the membership horizon for the average Canadian producer is 15 to 20 years, it is expected that the horizon problem is not an issue for Canadian producers. Furthermore, the analysis assumes farmers only are concerned with profit maximization. However, farmers may also consider other factors when making R&D investment decisions, such as future generations of agricultural producers and environment issues. The results of this study show that, even under the assumption of profit maximization, the horizon problem is not an issue for Canadian farmers, let alone in a more realistic model implemented by including factors other than profit. The results of the horizon problem model also show that the impact of the horizon problem is not affected by land tenure relationships.

In the second model, the assumption of a single-product small-country exporter is relaxed. The model consists of a multi-region, multi-product trade model that is used to examine the impact of Canadian pea R&D funding on consumers and producers in Canada and in various countries around the world that produce and consume pulses. To address the underinvestment issue, it is important to understand the question of who benefits from the research that is undertaken, and who bears the cost. Given that Canada is the largest pea exporter in the world an increase in R&D investment can be expected to have a significant impact on international trade and overseas producers and consumers. Given this impact, there is a need to develop a model of a large-country exporter. In addition, since R&D in the pulse industry affects the profitability of growing other crops such as canola and wheat, it is necessary to consider the multi-product case.

The model considers the lags that occur between R&D investment and increases in the research benefits. It explicitly specifies the linkage among the check-off ratio, the R&D investment, and the knowledge stock. This dynamic framework allows the calculation of the internal rate of return to Canadian producer-funded R&D and a re-examination of the horizon problem in the case of the multi-product large-country exporter. The model also fills a gap in our understanding of the manner in which the nature of the supply shifts affects R&D returns. This study examines the empirically relevant case where a pivotal supply shift generates the R&D cost and a parallel supply shift generates the R&D benefits. Contrary to what some authors find, the incentives to invest are not the same in the large country exporter case and in the small country exporter case, a situation that is particularly important for the Canadian pulse industry.

The simulation results from the second model illustrate that with increased pea R&D investment, Canadian producers, as well as consumers in all regions, are better off as a result of the R&D investment, while overseas producers are worse off.

The results of the sensitivity analysis indicate that the IRR to Canadian producers depends critically on how large an impact pea R&D has on the production of other crops (e.g., wheat and canola). The larger is this impact – i.e., the more that wheat and canola production falls as a result of higher yields/lower costs of pea production – the smaller is the IRR. The results also indicate that the elasticities of demand for peas and lentils in the importing countries do not have an impact on the IRR in the case where Canada is a large country exporter for peas only; however, they do have an impact on IRR in the case where Canada is a large exporter for both peas and lentils. In all cases, the more elastic is the demand, the higher is the IRR.

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Chapter 1

Introduction

1.1 Background

The recent increase in food prices raises important issues around the long term demand and supply of agricultural commodities. The worldwide demand for agricultural commodities has dramatically increased, driven by population expansion, per capita income growth, and the demand for biofuels.

The world population has more than doubled from around 3 billion in 1961 to 6.89 billion in 2010, and is projected to reach 9.49 billion in 2050 [Bremner et al., 2010]. This increase in population will cause a substantial growth in food demand, even without an increase in income. Increased incomes in the developing world are expected to significantly increase the per capita demand for foods such as meat, dairy products, fruits, and vegetable oils. Third, the newly emerged demand for biofuels, which is equivalent to a decade of worldwide grain production increase, further adds to the demand for agricultural products.

Future demand projections for agricultural commodities indicate that, even without biofuels, food supply must increase 70 percent by 2050 [Bremner et al., 2010]. However, agricultural production faces serious constraints of limited arable land and water. To meet the upcoming demand under these physical limitations, increases in the food supply have to be mainly driven by productivity growth [Alston et al., 2009a]. Therefore, productivity growth will be the pivotal determinant of the long term food supply.

However, productivity growth has slowed significantly around the world since 1990. As Table 1.1 shows, global land and labor productivity has been growing at a substantially slower pace in 1990-2005 than during the period 1961-1990. Land productivity is much lower in the period 1990-2005 than in the period 1961-1990 (1.19 percent per year versus 1.90 percent per year). Global labor productivity also slowed over the 1990-2005 time frame compared to the 1961-1990 period (0.42 percent per year versus 1.21 percent per year). If the slowdown in productivity growth continues, it is expected to put significant upward pressure on future food prices.

Table 1.1: Worldwide Growth in Agricultural Land and Labor Productivity, 1961-2005

	Land Productivity		Labor Productivity	
Group	1961-90	1990-05	1961-90	1990-05
	percentage			
World	2.03	1.82	1.12	1.36
Excl. China	1.90	1.19	1.21	0.42
Top 20 Producers	2.11	2.16	1.17	1.77
Excl. China	1.98	1.38	1.33	0.63

Source: Alston et al. [2009b].

Many factors have caused the slowdown in productivity growth. These factors include increased land degradation, continuing disease and insect infestations, frequent extreme climate events such as drought and flooding, and farmers' slow adoption of research outcomes [Alston et al., 2009a].

Reduced productivity growth is also the result of a decreasing growth rate of agricultural research and development (R&D) investment [Alston et al., 2009a]. R&D investment is undertaken by three key groups – government, the private sector, and agricultural producers. The rate of increase in public research funding in many countries has slowed considerably since the 1970s. Table 1.2 shows, the global average annual rates of growth in public agricultural R&D spending decreased from 2.02 percent in the 1980s to 1.72 percent in the 1990s. Although the overall growth rate in developing countries was faster in the 1990s than in the 1980s (3.31 percent vs 2.21 percent), OECD countries recorded a significant slower growth rate in the 1990s than in the 1980s (0.38 percent vs 1.89 percent).

Table 1.2: Average Annual Growth Rates of Public Agricultural R&D Spending

	1980s	1990s
	percentage	
World Total	2.02	1.72
Total OECD	1.89	0.38
United States	2.36	2.01
Canada	-0.15	-0.80
Total Developing	2.21	3.31
China	4.81	6.67
India	6.16	6.95

Source: Alston et al. [2010] p145.

Table 1.2 also indicates that Canadian public agricultural R&D funding is falling. Its annual growth rate was not only substantially lower than the OECD as a whole, but it has been negative for the past 30 years – the growth rate decreased from -0.15 percent per year in the 1980s to -0.80 percent per year in the 1990s. The result is that total real Canadian public spending in agricultural R&D declined from 520.7 million dollars in 1981 to 474.3 million dollars in 2000 (Table 1.3). This lower R&D investment, as Veeman and Gray [2010] concluded, has made a significant contribution to the slowdown of productivity growth of Canadian agriculture in the past 10 to 15 years. Consequently, Canadian agriculture has become less productive and less competitive relative to other regions such as China and Latin America.

In contrast to the reduced public funding, real private sector investment has dramatically increased in Canada since 1981. Table 1.3 shows that private sector funding in Canada increased from 109.2 million dollars in 1981 to 244.5 million dollars in 2000. This increase, combined with less public R&D, has resulted in the private sector share of agricultural R&D spending increasing from 17 percent in 1981 to 39 percent in 2007.

The third important source of agricultural R&D funding is from producer check-offs, which are increasingly being used to fund applied agricultural research such as disease management, genetic improvement, and weed control. It is argued that the producer check-off is a desirable way to fund agricultural R&D for two reasons: (1) producers, as the main beneficiaries, should bear the R&D costs rather than the general taxpayers; and (2) it is more efficient than general taxes.

Table 1.3: Public and Private Agricultural R&D Spending in Canada

Year	Public Spending	Private Spending	Private Share Total
	Millions of international dollars (2000 prices)		*percentage*
1981	520.7	109.2	17
2000	474.3	244.5	34
2007			39[1]

Source: Alston et al. [2010];
[1]Gray and Weseen [2008].

First, farmers are the primary beneficiaries of agricultural R&D in Canada. Previous research, which is summarized by Brinkman [2004], shows that for internationally traded commodities, Canadian producers receive 85 to 96 percent of the benefit from public research. The reason for this large percentage is that Canada is typically a price taker on international markets. Hence productivity improvements simply lower the cost of production without lowering the price, thus providing the benefits to producers. Based on the philosophy that those who benefit should pay, farmers should undertake the R&D investment.

The second reason that farmers should fund R&D is that producer funding avoids some of the efficiency losses compared to public funding. Levying farmers directly, rather than taxing the general taxpayers, costs the society less for raising the same amount of R&D funding. As Alston et al. [2003] argued, in the absence of other market distortions, the marginal social cost of check-off revenue is less than the marginal social cost of general tax revenue.

Among hundreds of existing studies of agricultural R&D, only a few have been done on producer-funded R&D. This research falls into two general categories. One category discusses distribution issues, while the other provides estimates of the rate of return to producer-funded agricultural R&D.

In the first category, Alston et al. [2003] argue that the distribution of benefits and costs of levy-funded R&D is determined by the magnitude and the nature (parallel or pivotal) of the supply shift. Alston et al. [2004] formally model the producers' optimal check-off ratio versus the optimal check-off ratio for society as a whole and theoretically determine the distribution of benefits and costs of producer-funded R&D. Zhao [2003] discusses the welfare distribution of levy-funded R&D combined with government funding for the Australian grape and wine industry. She concludes that grape producers, wine makers and overseas consumers receive a larger share of R&D benefits relative to their costs; the government and the domestic parties (domestic consumers and mobile factor providers and marketers) have costs that are greater than their corresponding benefits.

In the second category, researchers have estimated the rates of return to producer-funded R&D [Gray and Weseen, 2008; Gray et al., 2008; Scott et al., 2005; Thirtle, 1999]. For instance, Scott et al. [2005] estimate the benefit/cost ratio (B/C) for the Western Canadian Wheat producer check-off to be 4.4 to 1 (every one dollar check-off investment in R&D generates 4.4 dollars in increased producer surplus) and 12.4 to 1 for barley grower check-offs. Gray et al. [2008] show that the benefit/cost ratio for the Saskatchewan Pulse Growers (SPG) is 15.8 to 1, the internal rate of return (IRR) is 39.0 percent from 1984 to 2012; the benefit/cost ratio is 20.2 to 1 and the IRR is 39.5 per cent over the period 1984 to 2024.

Existing studies of producer-funded agricultural R&D indicate that there are high private and social rates of return to agricultural R&D investment by farmers, and thus that farmers are under investing in R&D. Faced with such high rates of return, rational farmers should invest more, according to standard economic theory, which will bring down the research returns. The persistent high rates of return imply farmers have not made these additional investments.

A critical question for producer-funded R&D is "Why do farmers not invest more money in agricultural R&D?" Are there any other factors that could affect farmers' decisions which are missing in the existing explanations? How do farmers really make their investment decisions? These are important questions and to answer them it is necessary to understand the factors that may affect farmers' decision making process when it comes to R&D investment.

There are a number of explanations as to why farmer organizations would underinvest in R&D. These problems include the free-rider problem, the portfolio problem, the control problem, the heterogeneity problem, and the horizon problem [Olson, 1971; Jensen and Meckling, 1979; Cook, 1995; Alston and Fulton, 2012; Vitaliano, 1983]. These problems emerge because of the individual incentives facing producers in a collective organization and because of the manner in which decisions are made within the organization.

• The Free-Rider Problem

The public good nature of agricultural R&D means there is a free rider problem – each member in the group can obtain the benefits of the R&D without making the investment, thus reducing the incentive to invest. This lack of incentive to invest – effectively a prisoners' dilemma – leads to insufficient R&D funding and the lack of the resulting benefits (see [Olson, 1971] for an in-depth examination of the free-rider problem).

• The Portfolio Problem

The portfolio problem [Jensen and Meckling, 1979; Cook, 1995; Vitaliano, 1983] emerges when individuals in a group are forced to contribute to a collective investment, which in turn limits the individual's ability to diversify their assets. Collective investments, such as group check-offs and the subsequent investment in R&D, can be seen as part of a farmers' investment portfolio. Although more investment in the collective investment would increase returns, farmers would not wish to make this investment if doing so adversely affected their diversification opportunities.

• The Control Problem

The control problem – or principal-agent problem – arises when the members of a commodity group, through their board of directors (the principal), are unable to perfectly monitor the actions of the group's manager (the agent) [Jensen and Meckling, 1979; Cook, 1995]. Although the members might like to see additional R&D undertaken, doing so might not be in the interests of the manager, who might find this additional R&D to be too time consuming or overly risky. If this is the case, then underinvestment might be the outcome.

• The Heterogeneity Problem

The heterogeneity problem recognizes that the benefit of R&D is not the same across all producers, even though all producers pay the same levy. In such a situation, the identity of the member that effectively makes the R&D investment decision is critical. If decisions are made on the basis of majority rule and the median producer is someone that finds the R&D benefits to be particularly small (e.g., because of a skewed distribution of the productivity gains across producers), then the resulting decision is one that would result in underinvestment. Requirements for supermajorities (e.g., in order to satisfy political demands for substantial agreement) will further exacerbate the problem [Alston and Fulton, 2012].

• Proportionate Distribution of Benefits and Costs

This problem is similar to the heterogeneity problem in that it involves different groups receiving disproportionate benefits relative to the costs that they incur. In this case the groups are the different agents in the supply chain. For instance, farmers will not gain proportionately to their costs – their share of the benefits is less than their share of the costs – if R&D results in a rotation of the industry supply curve and the demand curve is downward sloping. In such instances, the optimal amount of R&D funding from the perspective of producers can be expected to be less than the social optimum [Alston et al., 2004]. This result occurs because the non-proportionate allocation of costs and benefits directly influences producers' R&D incentives. As well, a non-proportionate allocation of costs and benefits may not be perceived as being fair, thus further affecting R&D decisions.

• The Horizon Problem

The horizon problem is also believed to be an important explanation for underinvestment by members in a group. As Jensen and Meckling [1979]; Cook [1995] and Vitaliano [1983] argue, the horizon problem occurs when people's individual time horizon of staying in the group (their planning horizon) is shorter than the expected payback time of the investment. Since agricultural R&D is a long-term investment, the horizon problem may have particular importance for R&D investment decisions. Cook [1995] (p.1157) argues that for cooperatives "the severity of the horizon problem intensifies when considering investment in research and development, advertisement, and other intangible assets." Featherstone and Goodwin [1993] empirically conclude that older farmers in the United States have a lower level of investment in conservation technologies. In contrast, Fulton and Giannakas [2012] argue that in cooperatives, the horizon problem is less severe than believed because of a different objective function (cooperative members are interested in consumer surplus plus profit, while investor-owned firms are interested only in profits). Olesen [2007] claims that the horizon problem is likely to cause over-investment rather than underinvestment, while Fahlbeck [2007] finds no empirical support for the horizon problem in Swedish agricultural co-operatives.

1.2 Research Objectives

The objective of this thesis is to examine the impact of one of the above problems, namely the horizon problem, on the rate of return to agricultural R&D undertaken by producer organizations, and hence on the incentive for farmers to undertake R&D. The specific question that will be examined is the impact of the horizon problem on the internal rate of return of agricultural R&D.

Among the factors listed above that are expected to affect investment decisions, a number of them – specifically the free-rider problem, the control problem, the heterogeneity problem and the proportionality issue – are concerned about the manner in which individual members interact in a group/organization or the rules by which decisions are made. The other two – the portfolio problem and the horizon problem – require an in-depth understanding of the goals and objectives of the individual member. Since this understanding of the goals and objectives of the individual member is required before the other issues can be examined, it seems appropriate to begin with an analysis of them.

The choice of the horizon problem was made because there is evidence that this problem might be empirically relevant. The average age of farmers has been increasing – it is now 54 years. Given that the benefits to agricultural R&D can take a considerable time to occur – as Alston et al. [2010] argue, the maximum benefits often do not occur until 25 years after the investment is made – there is *a priori* expectation that the horizon problem may be influential in determining farmers' R&D decisions.

The analysis of the horizon problem is conducted in two parts. In the first part, the analysis compares the internal rate of return IRR_h associated with the farmers' planning horizon with the internal rate of return $\overline{\mathrm{IRR}}$ associated with the benefit horizon of the R&D. The impact of the horizon problem is determined by examining the difference between IRR_h and $\overline{\mathrm{IRR}}$. In this analysis the farmers are assumed to be located in a small country – i.e., a country whose collective output has no impact on world price – and produce a single product. An important part of the analysis in this section is an examination of the role of land tenure relationships on the internal rate of return and hence on the horizon problem.

In the second part of the analysis, the assumption of a single-product small-country exporter is relaxed and a model for a multi-product large-country exporter is developed. To undertake the IRR analysis, it is necessary to choose a particular crop, since the impact of R&D investment depends on the characteristics of the crop in question (e.g., degree of export exposure, importance in the world market, elasticities of demand and supply). Pulse crops were selected for the analysis because they are major crops in western Canada. Canada is the largest exporter of pulses in the world. As a consequence, the added production from agricultural R&D investment will necessarily affect the world price and thus the welfare of both domestic and foreign consumers and producers. Given this impact, there is a need to develop a model of a large-country exporter. In addition, since R&D in the pulse industry affects the profitability of growing other crops such as canola and wheat, it is necessary to consider the multi-product case.

The analysis empirically examines how the R&D benefits and costs generated by Canadian producer-funded R&D are distributed between overseas producers and consumers and domestic producers and consumers. The model considers the lags that occur between R&D investment and increases in the research benefits. This dynamic framework allows the calculation of the internal rate of return to Canadian producer-funded R&D and a re-examination of the horizon problem in the case of the multi-product large-country exporter.

1.3 Contributions of The Thesis

The thesis makes three contributions to the literature. First, contrary to the view that the horizon problem may be an important disincentive for investment, this study shows that the horizon problem is unlikely to be the reason for the underinvestment of producer-funded R&D, unless farmers' time horizon is very short (e.g., under 10 years). Given that the membership horizon for the average Canadian producer is 15 to 20 years, the horizon problem is thus likely not an issue for Canadian producers.

The second contribution involves filling a gap in our understanding of the manner in which the nature of the supply shifts affects R&D returns. The literature to date (e.g., see Alston et al. [2004]), assumes that both R&D costs and benefits are generated by the same type of supply shift, i.e., both shift in a parallel manner or both shift in a pivotal manner. This study examines the empirically relevant case where a pivotal supply shift generates the R&D cost and a parallel supply shift generates the R&D benefits. Contrary to what Alston et al. [2004] find, the incentives to invest are not the same in the large country exporter case and in the small country exporter case, a situation that is particularly important for the Canadian pulse industry.

The third contribution of the thesis is that it introduces a dynamic pattern of lagged R&D benefits over a number of periods into a partial equilibrium model. The thesis explicitly specifies the linkage among the check-off ratio, the R&D investment, and knowledge stock.

1.4 Organization of The Thesis

The rest of the thesis is organized as follows. Since a significant portion of the analysis in the thesis focuses on the pulse market, Chapter 2 provides an overview of the world pulse industry and the Canadian pulse check-off mechanism. Chapter 3 develops a theoretical model that can be used to examine the severity and the existence of the horizon problem, and then empirically calibrates this model to examine the extent of the horizon problem. Chapter 4 derives a partial equilibrium model (PEM) to measure the interaction between the peas, lentils, wheat, and canola markets in Canada and in major pulse import and export countries. Chapter 5 uses the PEM to empirically examine the global impact of the Canadian pea R&D activity. The thesis concludes in Chapter 6 with a summary of the key findings, policy implications, and a discussion of the areas for further exploration.

Chapter 2

An Overview of Pulse Industry

2.1 Introduction

The growing worldwide demand for agricultural commodities, driven by population expansion, per capita income growth, and the demand for biofuels, raises concerns around food security. The major challenge for food and agricultural sector is to provide enough food in both quantity and quality to meet nutritional needs [FAO, 2013].

Pulse products – crops such as peas, lentils and beans – have the potential to assist in meeting these food consumption demands. Pulses provide a wide variety of health benefits such as high fibre, protein, and iron. They are low in fat and sodium, are free of saturated fats and are cholesterol free [SPG, 2009]. On the supply side, pulses are environmentally friendly because they take less inputs (such as fertilizer) than other crops and they produce less greenhouse gases [SPG, 2009]. Pulse crops can fix nitrogen and they can break the disease cycle to improve land quality and protect water resources. In large part because of these advantages, pulses have become an important component in crop rotations in countries such as Canada.

2.2 Research Objectives

The objective of this chapter is to provide an overview of the pulse industry in Canada and the world. The chapter starts with an introduction of the world pulse industry in which Canada is the largest pulse exporter. The study then moves to a review of the supply and demand sides of the Canadian pulse industry. Section 2.5 examines the administration of the Canadian pulse check-off system and the mechanism of R&D investment decision making.

2.3 World Pulse Industry

World pulse products consist of four major crops: dry peas, lentils, dry beans, and chickpeas. Pulse products are increasingly traded in the world market, with more than ten million tonnes of pulses traded annually since 2005 (FAOSTAT). As it will be shown below, Canada is the largest exporter of pulse products. Since dry peas and lentils are particularly important in Canada, the focus of the thesis and this chapter is on these two crops.

As panel (a) in Figure 2.1 shows, the major dry pea exporters are Canada, the United States, France, EU, and Australia. On average, over the period 2006 to 2010, Canada exported 59 percent of the dry peas traded internationally, compared to 12 percent for the United States, 8 percent for France, 7 percent for the Europe Union, 4 percent for Australia, and 9 percent for the rest of the world.

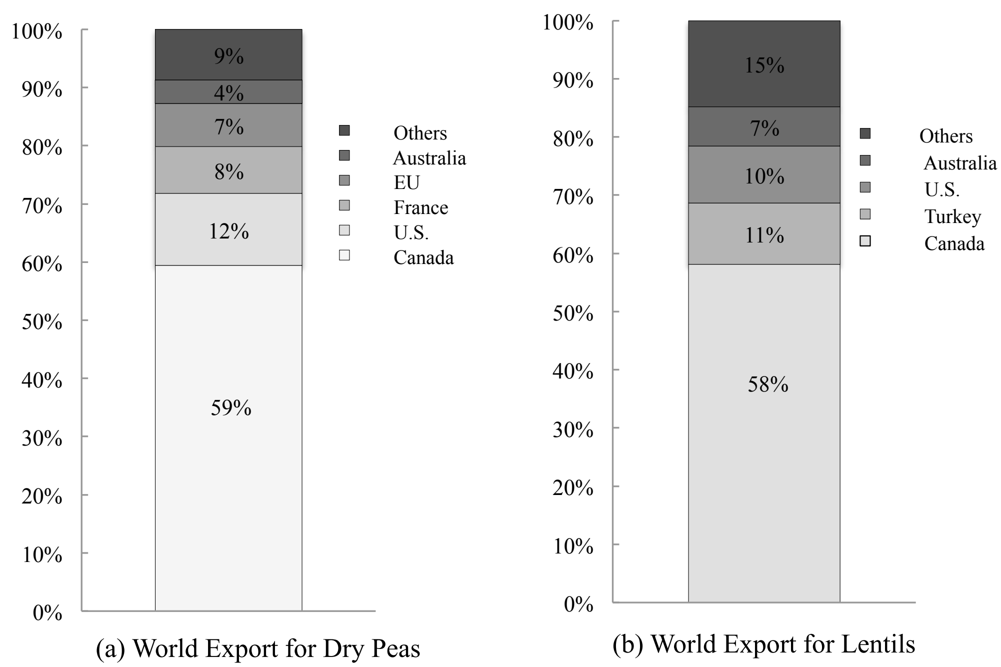


Figure 2.1: World Exports of Pulses, 2006 – 2010 Average

Source: FAOSTAT.

The major exporting countries in the world lentil market are Canada, the United States, Turkey, and Australia (see panel (b) in Figure 2.1). Canadian lentils occupied 58 percent of the

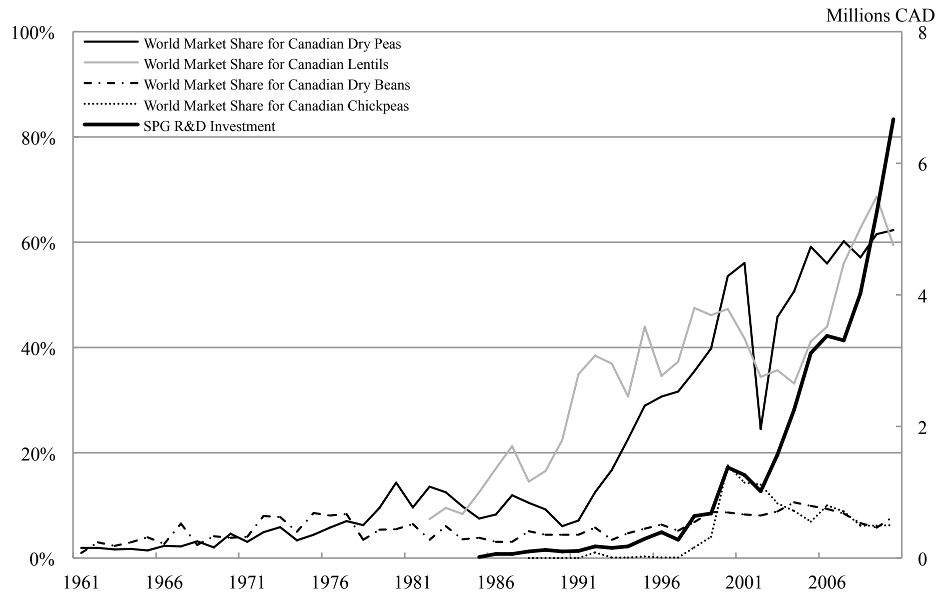


Figure 2.2: World Market Share for Canadian Pulse Crops and SPG R&D Investment

Source: FAOSTAT and Saskatchewan Pulse Growers.

world export market (using the average value of sales over the period 2006 to 2010). The market shares for the other exporters are 10 percent for the United States, 11 percent for Turkey, 7 percent for Australia, and 15 percent for the rest of the world. Canada is thus the largest exporter in both the dry pea market and the lentil market.

Canada has not always had such a major presence in the world pulse market. As Figure 2.2 shows, the world market share for Canadian dry peas and lentils was less than 15 percent before the 1980s. Since 1984, however, Canada's market share has increased dramatically – specifically, from 10 percent in 1984 to over 60 percent in 2010. This rise in market share corresponds to the establishment and development of the SPG over this period.

Figure 2.2 also depicts the pulse R&D investment from producer check-offs. As is illustrated, a positive relation exists between the SPG R&D investment and the world market share for Canadian peas and lentils. The reason behind the relationship is the positive feedback effect that exists between R&D investment and pulse production. With the increase in R&D investment, the world market share for Canadian pulses increases because of the improved competitiveness caused by the innovation. The higher pulse production, in turn, results in more R&D investment and more pulse research. Higher R&D investments generates a higher industry knowledge stock which in turn drives up pulse production.

2.4 Pulse Industry in Canada

History of Canadian Pulse Production

To understand the development of the pulse industry in Canada, it is necessary to understand the agricultural policy environment in Western Canada in the 1960s and 1970s. To ensure individual producers had an equal opportunity to access the export grain market, the Canadian Wheat Board (CWB) implemented a delivery quota system. In addition to ensuring equal access to the international market, the quota system regulated wheat production from Western Canada. Given restrictions on the amount of wheat they could grow, Prairie grain farmers looked for other opportunities to increase farm income. Among these opportunities were the growing of crops such as pulses and canola.

Before these new crops could be grown, however, significant R&D was required. Agricultural R&D activities have played a critical role in the crop development and production improvement in Canada since the1960s. These research activities led to significant changes in the structure of crop production. As Figure 2.3 shows, the share for the harvested acreage of canola and pulses has been increasing while the acreage devoted to wheat has been falling over the last 50 years. With the increased acreage, farm revenue of canola and pulses also increase, as Figure 2.4 shows. The increased acreage and farm revenue of both pulses and canola is the result of the extensive R&D that was undertaken on these crops.

In the canola sector, canola oil was not the major source of edible oil prior to the 1970s due to its high erucic acid and glucosinolate content, both of which had adverse effects on animals when fed to them as feed. As a result of R&D efforts, new canola varieties with low erucic acid content were developed starting in the late 1960s, followed by low glucosinolate in 1974 [Phillips and Khachatourians, 2001]. These variety improvements led to the wide acceptance of canola meal and oil in the feed and the food system.

The rise of pulse acreage and production was influenced by a variety of technological changes, including the rise of continuous cropping and direct seeding (and with this a reduction in summer

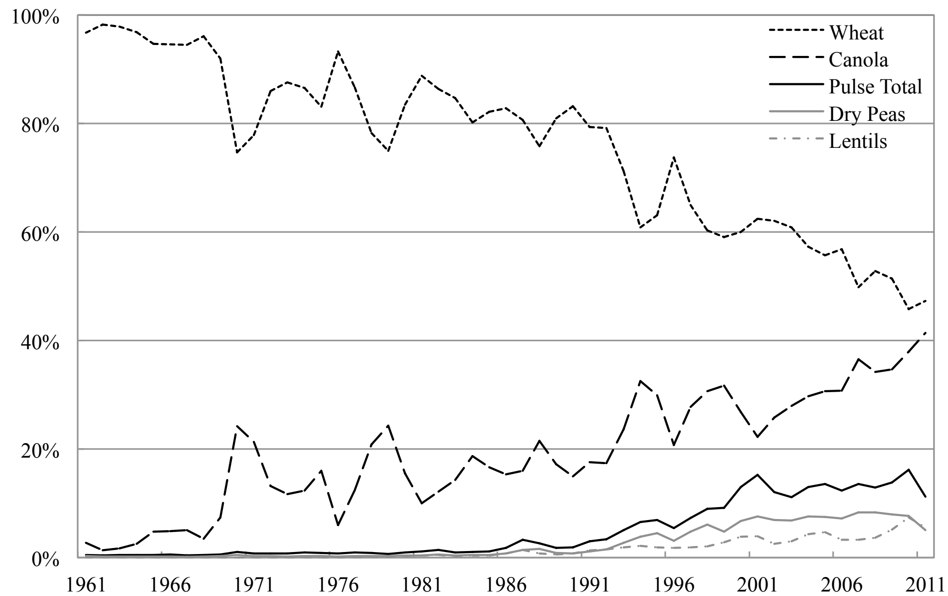


Figure 2.3: Crop Harvested Acreage in Canada

Source: FAOSTAT.

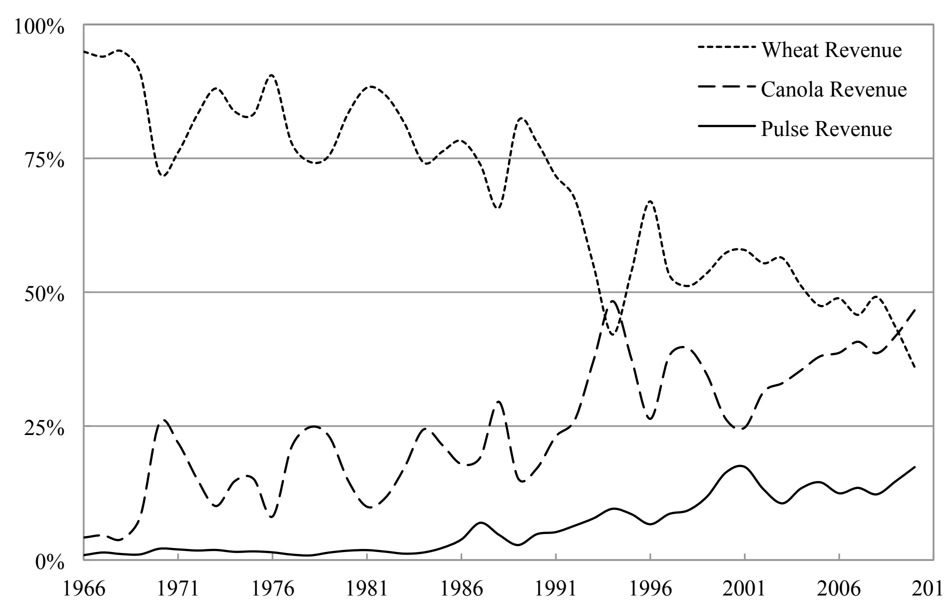


Figure 2.4: Crop Revenue Share in Canada

Source: FAOSTAT.

fallow acreage) [Awada, 2012]. The nitrogen-fixing ability of pulses lowers input costs, and the inclusion of pulses in a crop rotation improves disease management and weed control. As Figure 2.5 shows, there was an increase in the yield of pulse crops from the late 1970s/early 1980s to the period since 2005. This increase in yield appears to coincide with the establishment of SPG in 1984 and resulting increase in R&D activity. In addition, the demand for pulses, in both Canada and the world market, has been increasing due to pulses' high protein and low-glycemic content.

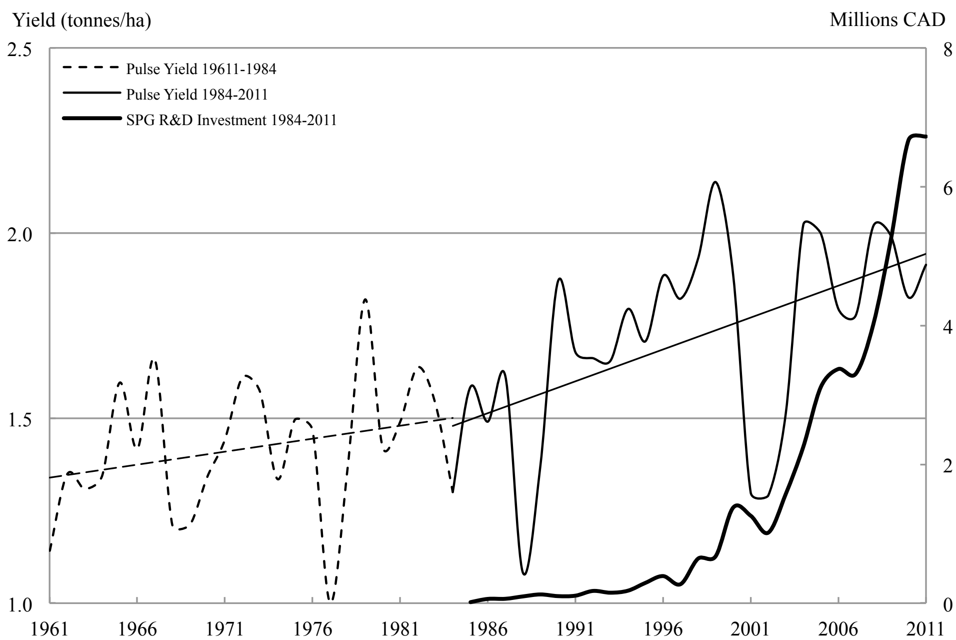


Figure 2.5: Canadian Pulse Crop Yield and SPG R&D Investment

Source: FAOSTAT and Saskatchewan Pulse Growers.

The establishment of the Crop Development Centre (CDC), a major research unit funded by SPG for Canadian pulse crops, in 1971 at the University of Saskatchewan contributed to new variety development and the commercial acceptance of pulse crops. As Figure 2.6 shows, pulse production is positively correlated with SPG's R&D investment. In part because of the CDC, Saskatchewan has become the major producer of pulses in Canada. In 2012, Saskatchewan farmers grew 96 percent of Canada's lentil crops, 90 percent of Canada's chickpea crops, and 70 percent of Canada's dry pea crops [SPG, 2013].

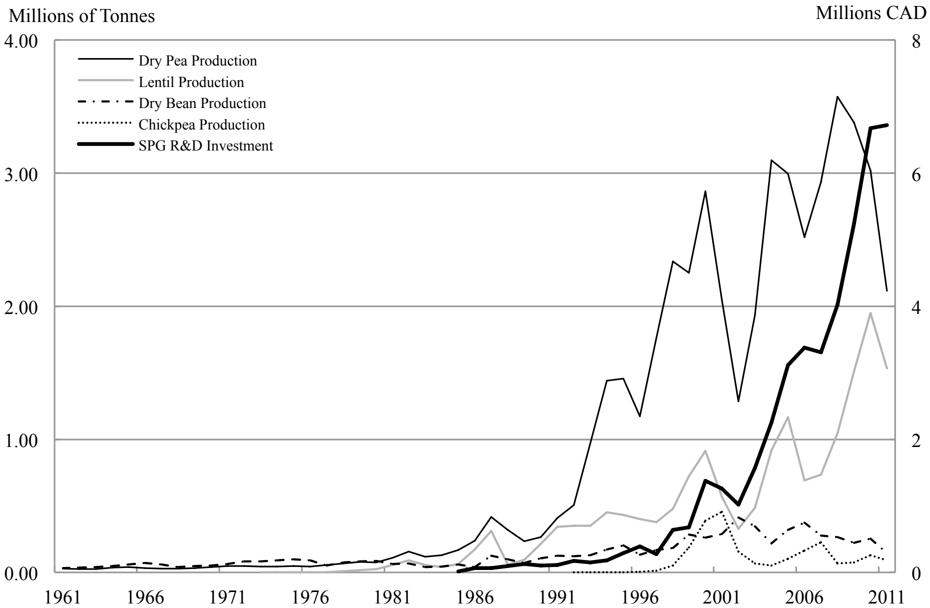


Figure 2.6: Canadian Pulse Production and SPG R&D Investment

Source: FAOSTAT and Saskatchewan Pulse Growers.

Current Canadian Pulse Production

Canadian pulse production consists of four closely related crops: dry peas, lentils, dry beans, and chickpeas. The crop shares for the different pulse crops are depicted in Figure 2.7. Since 2000, more than 80 percent of Canadian pulse production has been made up of peas and lentils. In 2011, pea production accounted for over 50 percent and lentils for about 40 percent of pulse production. The production of dry beans and chickpeas together is less than 10 percent.

Major Consumers of Canadian Pulses

The demand for Canadian peas and lentils in the world market is depicted in Figure 2.8. The major importers of Canadian dry peas, as panel (a) shows, are India, China, Bangladesh, and the European Union. Of Canada's total pea exports, on average from 2008 to 2012, 49 percent were exported to India, 19 percent to China, 11 percent to Bangladesh, three percent to EU, and 18 percent to the rest of the world (ROW).

The major importing countries for Canadian lentils are, as Figure 2.8 panel (b) shows, Turkey, India, the Europe Union, and Bangladesh. Specifically, 17 percent of the exported Canadian

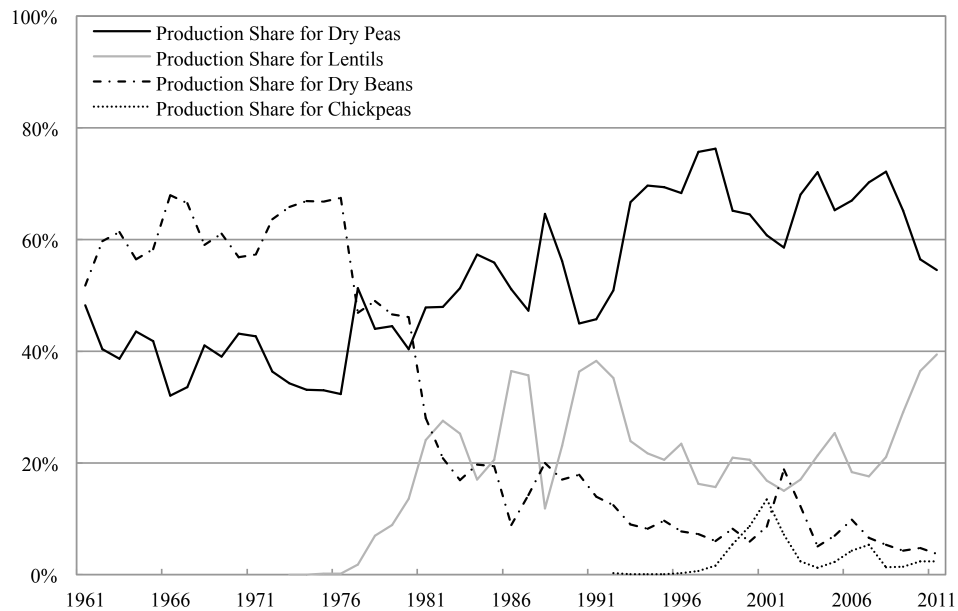
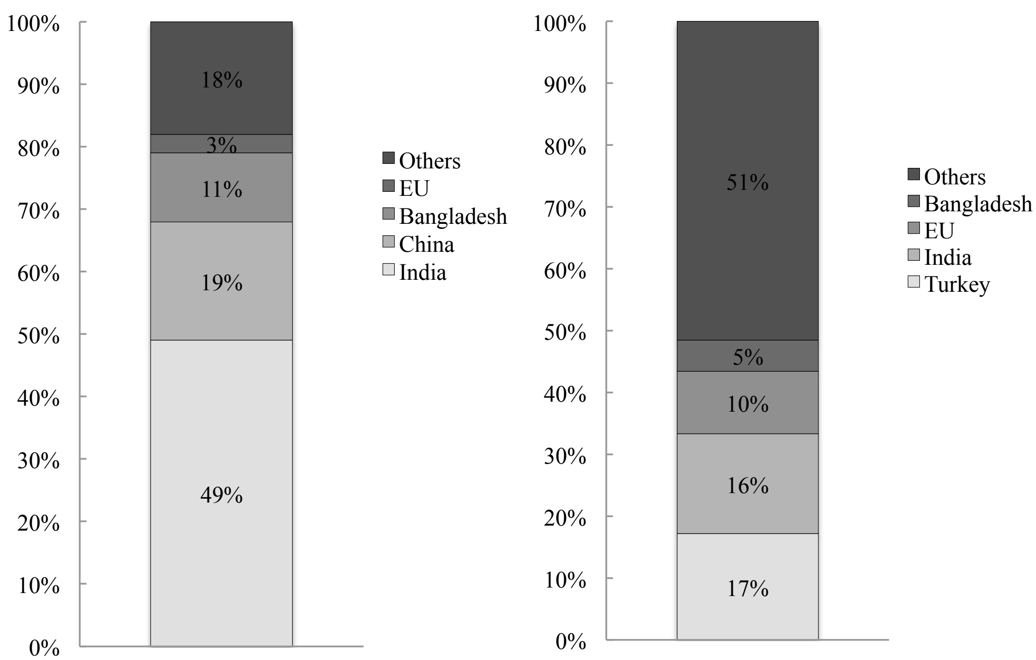


Figure 2.7: Production Share for Canadian Pulse Crops

Source: FAOSTAT.



(a) Import Share for Canadian Dry Peas

(b) Import Share for Canadian Lentils

Figure 2.8: Import Share for Canadian Pulses, 2008 – 2012 Average

Source: Statistics Canada, CATSNET Analytics.

lentils were sold to Turkey, 16 percent to India, 10 percent to the European Union, and 5 percent to Bangladesh. The remaining 51 percent is spread over more than 100 countries and regions, with the share for any specific jurisdiction being very small. This remainder is treated as the rest of the world (ROW).

It is important to note that Turkey is a major importer of Canadian lentils (see Figure 2.8) as well as a major lentil exporter (see Figure 2.1). This trade pattern is a result of Turkey importing lentils from Canada and then selling them to neighbouring countries. As Table 2.1 shows, in 2009, Turkey domestic lentil utilization and domestic supply were both just over 300,000 tonnes – i.e., domestic supply roughly equaled domestic demand. Table 2.1 also shows that Turkey imported 142,000 tonnes of lentils and exported 130,000 tonnes to other countries.

Based on the above evidence, the trade model that is developed in Chapter 4 and empirically examined in Chapter 5 focuses on dry peas and lentils in the context of a seven-region model. In this model, the world is divided into: Canada (c), India (i), China (h), Bangladesh (b), Turkey (t), the European Union (e), and the ROW (r). With this regional division, the impact of an increase in Canadian pea R&D investment can be determined on a region-by-region basis.

To construct the spatial trade model, it is necessary to have an overview of the distribution of production and imports/exports for pulse crops for the seven regions. Tables 2.1 and 2.2 report the data on the value and the percentage share of production, exports, imports, and domestic usage for dry peas, lentils, wheat and canola for each region in the model. Among the six major pulse importing countries, India is the biggest pulse importer. It occupies over 40 percent of world imports of peas and 17 percent of world imports of lentils in 2009.

Table 2.1: Regional Production and Utilization

	World	Canada	India	China	Bangladesh	Turkey	EU	ROW
					Thousands of Tonnes			
Production								
Dry Peas	10,527	3,379	750	960	12	4	1,399	4,023
Lentils	3,906	1,510	953	120	61	302	32	928
Wheat	680,102	26,848	80,686	115,115	849	20,600	138,255	297,755
Canola	62,705	12,626	7,201	3,675	203	114	21,483	17,403
Import								
Dry Peas	4,015	50	1,656	394	488	2	514	911
Lentils	1,680	10	288	3.6	178	142	188	871
Wheat	161,365	883	180	2,712	2,415	3,420	44,593	107,162
Canola	18,732	166	0	3,291	172	158	9,851	5,094
Export								
Dry Peas	4,272	2,618	1	6	5	0	349	1,298
Lentils	1,807	1,241	0.6	18	0	130	28	390
Wheat	180,625	20,126	146	672	0	3,161	62,454	94,061
Canola	17,006	7,809	35	2	0	0	5,250	3,910
Stock Variation[1]								
Dry Peas	117	0	-	0	-	0	264	-147
Lentils	-	-	-	-	-	-	-	-
Wheat	-26,241	-285	4,880	-5,972	-661	-1,308	547	-13,682
Canola	-2,681	-45	-	-1,000	-	-	-1,962	326
Utilization								
Dry Peas	10,387	811	2,405	1,349	501	6	1,827	3,489
Lentils	3,779	280	1,241	106	239	314	192	1,409
Wheat	634,602	7,320	75,834	111,183	2,598	19,550	120,941	297,174
Canola	61,751	4,938	7,166	15,963	375	272	24,122	18,913

Source: FAOSTAT 2009.

[1]The stock carried from the previous year plus the inflow minus the outflow in the current year.

2.5 Administration of Canadian Pulse Check-Offs

2.5.1 Producer Organizations

Under *The Agri-Food Act*, there are three general types of producer associations: development boards, development commissions, and marketing boards [Saskatchewan-Government, 2004]. Table 2.3 describes the activities of these three general types. The major mission of the development boards and commissions is to promote and develop the production and/or marketing for

Table 2.2: Production Share, Export/Import Share in the World Market

	Canada	India	China	Bangladesh	Turkey	EU	ROW
				percentage			
Production							
Peas	32.1	7.1	9.1	0.1	0.0	13.3	38.2
Lentils	38.7	24.4	3.1	1.5	7.7	0.8	23.7
Wheat	3.9	11.9	16.9	0.1	3.0	20.3	43.8
Canola	20.1	11.5	5.9	0.3	0.2	34.3	27.8
Imports							
Peas	1.2	41.2	9.8	12.2	0.0	12.8	22.7
Lentils	0.6	17.1	0.0	10.6	8.4	11.2	51.8
Wheat	0.5	0.1	1.7	1.5	2.1	27.6	66.4
Canola	0.9	0.0	17.6	0.9	0.8	52.6	27.2
Exports							
Peas	61.3	0.0	0.1	0.0	0.0	8.2	30.4
Lentils	68.7	0.0	1.0	0.0	7.2	1.5	21.6
Wheat	11.1	0.1	0.4	0.0	1.8	34.6	52.1
Canola	45.9	0.2	0.0	0.0	0.0	30.9	23.0

Source: FAOSTAT 2009.

a particular agricultural product by collecting a levy from producers that can be used for R&D and/or market development. The only difference between the development board and the development commission is that the former collects mandatory non-refundable check-offs, while the latter collects a mandatory refundable levy.

According to *The Agri-Food Act*, “The Agri-Food Council co-ordinates the process of the regulatory review by incorporating input from the plan proponents and legal and drafting services by the Ministry of Justice. Plans proposing non-refundable levies and/or compulsory powers can be established only after a vote of producers. If a producer vote is conducted, at least 60 per cent of all voting producers in the case of a Development Board plan must vote in favour before the Lieutenant Governor in Council can proceed to establishment” [Saskatchewan-Government, 2004].

The commodity groups that fall under each of the producer organizations are shown in Figure 2.9. The development board group includes three producer associations that collect mandatory non-refundable check-offs; one of these is the Saskatchewan Pulse Growers. The development

Table 2.3: General Types of Producer Organizations in Saskatchewan

	Purpose	Initiator	Duties	Director	Establishment	Check-Off
Development Board	To promote and develop the production and/or marketing	Producers	Collect levy that will be used for R&D	Elected and appointed	60% producers vote in favour	Mandatory Non-refundable
Development Commission	To promote and develop the production and/or marketing	Producers or Lieutenant Governor in Council	Collect levy that will be used for R&D	Elected and appointed	60% producers vote in favour or Discretion of Cabinet	Mandatory Refundable
Marketing Board	To promote and develop the production and/or marketing	Producers	Compulsory marketing powers including supply management	Elected and appointed	80% producers vote in favour	Mandatory Non-refundable

Source: Government of Saskatchewan documents.

commission group contains ten producer organizations that collect mandatory refundable check-offs. The largest and most important of the commissions is the Saskatchewan Canola Development Commission.

In 1976, the Saskatchewan Pulse Crop Growers Association (SPGCA) was formed by a group of nine pulse growers. In 1983, the pulse growers voted to establish a mandatory, non-refundable check-off to fund programs to develop the pulse industry and to create worldwide demand for Saskatchewan pulse crops. In the same year, the Saskatchewan Pulse Crop Development Board (SPCDB) was created. This board later became known as the Saskatchewan Pulse Growers (SPG). Currently, more than 20,000 registered pulse producers are growing pulses across Saskatchewan.

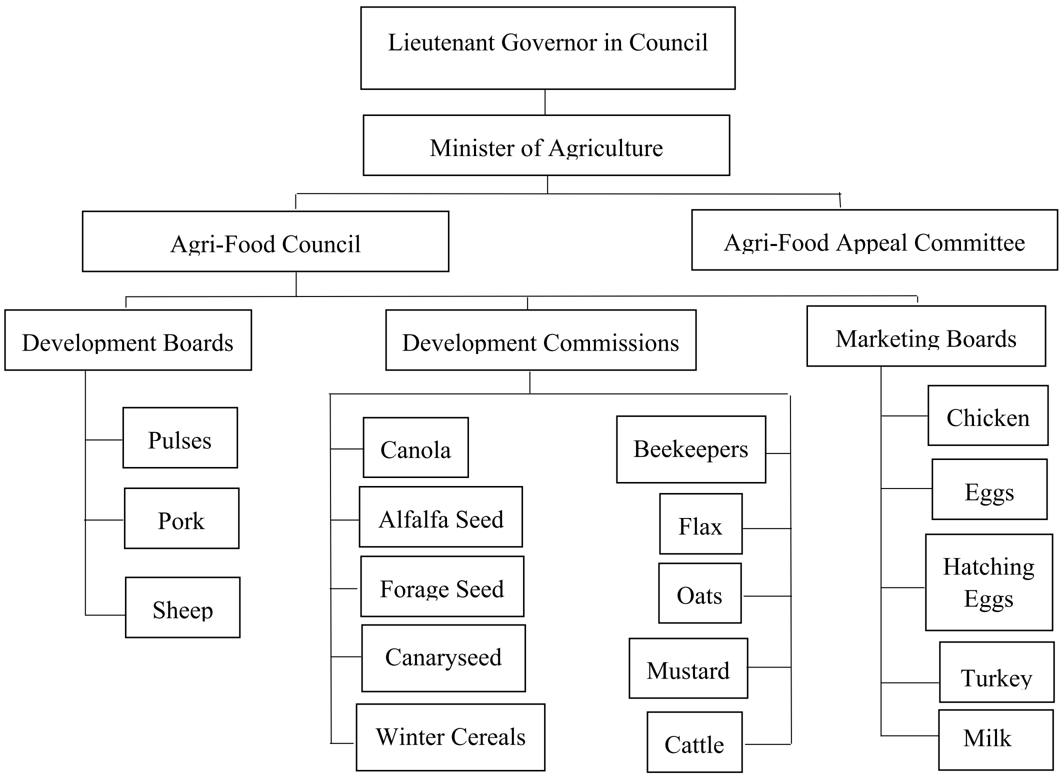


Figure 2.9: Organizational Structure of Saskatchewan Producer Organizations

Source: Government of Saskatchewan documents.

2.5.2 Check-Off Mechanisms

The check-off system of Canadian producer groups can be categorized into two forms. One is a mandatory refundable check-off, in which farmers have the right to request a refund after paying the check-off. The other one is a mandatory non-refundable check-off, in which farmers do not have the right to request a refund. In this latter group, farmers who pay the check-off are automatically enrolled as registered group members and are given the right to vote for the board of directors. The board of directors makes decisions about R&D investment.

The Saskatchewan Pulse Growers operates a mandatory non-refundable check-off. The check-off ratio was set at 0.5 percent at the time the Saskatchewan Pulse Development Board (SPDB) was established in 1984. In 2001, Pulse Canada Research released a report demonstrating that there was an underinvestment in R&D for pulse crops and an increased check-off ratio was needed. To address this underinvestment issue, SPDB proposed to increase the check-off ratio from 0.5 percent to one percent. After discussions with producers, the decision was made to increase the check-off ratio by using a two-step approach – the check-off ratio increased from 0.5 percent to 0.75 percent in 2002, and then in 2003 it was increased from 0.75 percent to the current one percent.

Table 2.4 summarizes the pulse check-off systems in Canada, the United States, and Australia. The Saskatchewan Pulse Growers, along with Idaho, Washington, and Australia, operate a non-refundable system. Alberta, Manitoba, and North Dakota have a refundable levy system.

Table 2.4: Comparison of Pulse Check-off Systems

Region	Check-off Ratio	Refundable or Non-refundable
	percentage	
Canada		
Saskatchewan	1.0	Non-refundable
Alberta	1.0	Refundable
Manitoba	0.5	Refundable
The United States		
North Dakota	1.0	Refundable
Idaho	1.0	Non-refundable
Washington	1.0	Non-refundable
Australia (all crops)	1.0	Non-refundable

Source: Saskatchewan Pulse Growers documents.

2.5.3 Administration of R&D Investment

Allocation of Check-Off Revenue

The pulse check-off revenue has been used for a number of activities, including R&D expenditures, market promotion, communication, and general operations. Figure 2.10 depicts SPG's expenditure pattern during the last ten years. R&D investment is the major expenditure of the pulse producer group, with SPG spending 50 percent, on average, of its levy revenue to fund research activities.

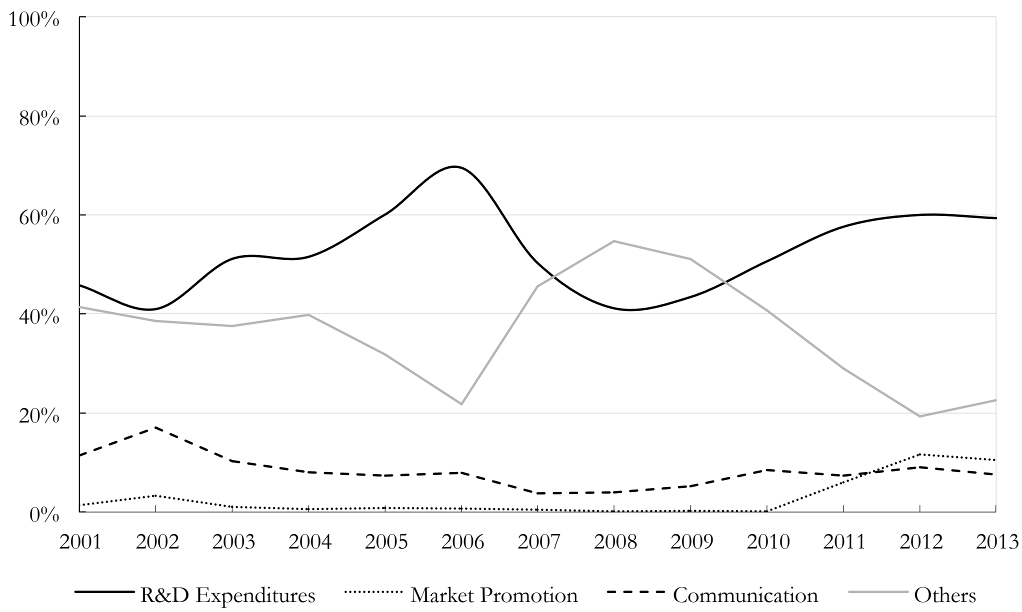


Figure 2.10: SPG Expenditure Trends

Source: Saskatchewan Pulse Growers Annual Report 2001 – 2013.

The major proportion of SPG's R&D investment is used to support the pulse breeding programs at the Crop Development Centre (CDC) at the University of Saskatchewan. The principal role of the CDC is to increase the diversification of crops by improving existing crops, creating new uses for traditional crops, and introducing new crops. The major output of the CDC is new seed varieties with higher yield and improved quality such as disease resistance, chemical tolerance, drought tolerance and cold tolerance.

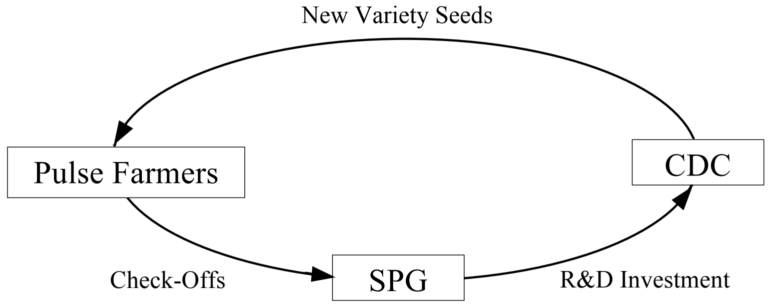


Figure 2.11: Innovation Flow for Saskatchewan Pulse Industry

Source: Developed by the author.

Figure 2.11 illustrates how R&D funding is generated in the Canadian pulse industry and how the innovation results get back to pulse farmers. First, pulse farmers in Saskatchewan pay the check-off to their producer association, the Saskatchewan Pulse Growers. SPG then uses the check-off money to fund research projects conducted by the CDC. Innovations take the form of new and improved seed varieties. After the new variety seeds have been successfully developed, CDC sells the seed directly to farmers at a royalty-free price that covers the cost of replicating the seed.

However, Gray et al. [2008] show that the B/C ratio for the Saskatchewan Pulse Growers is 15.8 to 1, the internal rate of return (IRR) is 39.0 per cent from 1984 to 2012; the B/C is 20.2 to 1 and the IRR is 39.5 per cent over the period 1984 to 2024. The empirical evidence suggests that despite a rise in the check-off ratio to one percent in 2003, there is still underinvestment in pulse crops.

2.6 Summary

The evidence presented in this chapter shows that pulses have become an important crop in Western Canada. An important factor in the rise of pulse crop production is R&D funding carried out largely by the Saskatchewan Pulse Growers through a producer levy. Although this levy was increased to one percent in 2003, estimates of the rate of return to pulse R&D suggest that underinvestment is still an issue.

It was suggested in the chapter 1 that farmers' investment decisions might be affected by the so-called horizon problem – i.e., the farmers' membership horizon is shorter than the R&D payback time horizon. To address how the horizon problem influences the R&D investment decisions of a producer group, an analysis of this issue is conducted in the next chapter.

To allow the analysis to focus first on the horizon problem, the analysis in chapter 3 assumes Canada is a small country – i.e., Canadian production has no impact on the world price. However, this assumption is not realistic. As the data in this chapter show, Canada is the largest exporter of pulses in the world, which means that the added production from agricultural R&D investment will affect the world price and thus the welfare of both domestic and foreign consumers and producers. The more realistic situation where Canada is assumed to be a large country exporter is examined in Chapters 4 and 5.

Chapter 3

The Horizon Problem

3.1 Introduction

Agricultural R&D investment is becoming an increasingly important policy issue as food prices push upwards and food security problems emerge [Alston et al., 2009a]. Understanding the factors that determine R&D investment is an important element in addressing these issues and problems.

R&D investment is undertaken by three key groups – government, the private sector, and agricultural producers. In spite of its high rate of return, the growth rate of public research funding in the developed countries has fallen over the last 40 years [Alston et al., 2010]. As Alston et al. [2010] conclude, since the 1990s the growth in public research funding in OECD countries has dropped below that of the developing countries. In Canada, the total real public agricultural R&D funding has fallen from $Cdn 520.7 million in 1981 to $Cdn 474.3 million in 2000 [Alston et al., 2010].

While public funding has fallen in Canada, private investment has increased dramatically since 1981, particularly in industries such as canola which have well-developed systems that can restrict the use of new varieties (e.g., hybrids, patents on genes). Consequently, private funding has become a larger component of total agricultural R&D investment; its share in total research funding has increased from 17 percent in 1981 [Alston et al., 2010] to 39 percent in 2007 [Gray and Weseen, 2008].

The third important source of agricultural R&D funding is from producer check-offs, which are increasingly being used to fund applied agricultural research such as disease management, genetic improvement, and weed control. It is argued that the producer check-off is a desirable way to fund agricultural R&D because taxing producers directly is more efficient than taxing the general population [Alston et al., 2003]. As well, the pricing of varieties produced by producer check-offs is often different from the pricing of varieties produced by investor-owned firms. While investor-owned firms will typically price varieties to maximize the returns to the investors (to do so they often rely on strong intellectual property rights), varieties produced by producer-funded organizations are often priced to cover the cost of seed production (the cost of the R&D has already been paid for through the check-off). The higher prices by investor-owned firms can generate efficiency losses compared to the average cost pricing practiced by producer organizations. Therefore, producer check-offs often represent the most efficient way of raising money and carrying out R&Ds among the three major funding models [Alston, 2007].

Existing studies of producer-funded agricultural R&D indicate that there are high private and social rates of return to agricultural R&D investment by farmers, and thus that farmers are under investing in R&D. For example, Table 3.1 shows that western Canadian wheat producers receive 4.40 dollars for every one dollar they invest in R&D through producer check-offs, while barley producers receive 12.40 dollars for every one dollar they invest [Scott et al., 2005]. In the pulse area, Saskatchewan pulse growers obtain 15.80 dollars for every one dollar they invest in R&D through producer check-offs; the internal rates of return (IRR) are 39.0 percent and 39.5 percent in the short-run and long-run, respectively [Gray et al., 2008]. Since these B/C ratios and IRRs are high compared to what would be expected if R&D investments were being made to maximize producer welfare, the implication is that farmers do not invest enough in agricultural R&D.

There are a number of explanations as to why farmer organizations would underinvest in R&D. These problems include the free-rider problem, the portfolio problem, the control problem, the heterogeneity problem, and the horizon problem [Olson, 1971; Jensen and Meckling, 1979; Cook, 1995; Alston and Fulton, 2012; Vitaliano, 1983]. These problems emerge because of the

Table 3.1: Benefit-Cost Ratio and IRR for Canadian Producers

Producers	Benefit-Cost Ratio and IRR	
West Canadian Wheat Producers[1]	4.4 to 1	
Barley Producers[1]	12.4 to 1	
Saskatchewan Pulse Producers[2]	15.8 to 1	IRR= 39% (Short-Run)
	20.2 to 1	IRR=39.5% (Long-Run)

Source: [1]Scott et al. [2005].
[2]Gray et al. [2008].

individual incentives facing producers in a collective organization and because of the manner in which decisions are made within the organization.

Given the long period of time over which the benefits of R&D investment occur, the horizon problem would appear to be of particular interest. For instance, Alston et al. [2010] argue that the benefits of agricultural R&D may occur for as long as 50 years, with the maximum benefits occurring at approximately 25 years on average. Since the average age of Canadian farmers is 54 years (Statistics Canada) and their membership horizons are about 15 to 20 years (assuming their retirement age is 69 to 74), farmers' planning horizons are much shorter than the benefit horizon associated with the R&D – in short, farmers will not collect the entire benefits of the R&D investment during the time horizon of their membership. Since estimates of the rates of return to research have used the longer benefit horizon rather than the shorter planning horizon, the empirical estimates of the rate of return to research may have overstated the rate of return that farmers believe they will obtain. If this is the case, then the incentive for farmers to make an investment in R&D may not be as high as has been believed.

3.2 Research Objectives

The purpose of this chapter is to examine the impact of the horizon problem on the rate of return to agricultural R&D undertaken by producer organizations. Specifically, the analysis in this chapter calculates the internal rate of return – i.e., IRR_h – associated with the farmers' planning horizon and compares this to the internal rate of return – i.e., $\overline{\text{IRR}}$ – associated with the benefit horizon of the R&D. The impact of the horizon problem is determined by examining the difference between IRR_h and $\overline{\text{IRR}}$.

The organization of this chapter is as follows. The analysis begins with the development of a framework that can be used to examine the impact of the horizon problem. The analysis then moves to the development of a theoretical model for determining IRR_h in the case of a constant returns to scale Cobb-Douglas (C-D) production function. Section 3.6 introduces an empirical examination of the horizon problem, while section 3.7 examines the sensitivity of the results via a Monte Carlo simulation. Section 3.8 discusses the impact of land tenure on the horizon prblem.

3.3 Literature Review

There are a number of explanations as to why farmer organizations would underinvest in R&D. These explanations generally focus on the collective nature of farmer organizations and the difficulties that collective organizations have in raising capital for investment. The typical problems that are highlighted include the free-rider problem, the portfolio problem, the control problem, the heterogeneity problem, and the horizon problem [Olson, 1971; Jensen and Meckling, 1979; Cook, 1995; Alston and Fulton, 2012; Vitaliano, 1983].

• The Free-Rider Problem

The public good nature of agricultural R&D means that farmers face a free rider problem – since each member in the group can obtain the benefits without making the investment, individual producers have no incentive to invest, which in turn leads to insufficient R&D funding and the lack of the resulting benefits [Olson, 1971]. In short, the public good nature of R&D creates a Prisoners' Dilemma – although the whole group would be better off if each producer were to invest, there is no incentive for producers to make this investment.

One way to address the free-rider problem is to introduce legislation that requires farmers to pay a levy on sales. Although many check-off schemes allow farmers to request a refund (the so-called mandatory refundable schemes), the transaction cost to farmers of doing so is typically substantial enough that most farmers do not request refunds; the result is that mandatory refundable check-off schemes can raise funds for R&D. However, there is a limit to the amount of funds that can be raised through such schemes because as the levy rate is increased, the incentive to request a refund rises, thus limiting the increase in funds that is attainable. Therefore, in effect, the free rider problem becomes more and more important as the levy rate rises.

Another form of check-off scheme to address the free-rider problem is so-called mandatory non-refundable check-off system – farmers pay the check-off at the first point of sale, but not allowed to ask for refunds. Producers who pay the check-off are automatically enrolled in the producer association, hence pay the funds for R&D activities. Under this mechanism, each individual farmer in the association pays for R&D, and the free-rider problem is addressed.

• The Portfolio Problem

The portfolio problem emerges when farmers are forced to contribute to group interests that constrain their diversification across assets [Jensen and Meckling, 1979; Cook, 1995; Vitaliano, 1983]. Collective investments, such as group check-offs and the subsequent investment in R&D, can be seen as part of farmers' investment portfolio. Given that R&D investment is highly risky (only about 10% of the research experiments will succeed), risk averse farmers may wish to direct their investment away from R&D towards other assets, thereby reducing their willingness to invest in R&D. At a collective level, this desire to shift investment away from R&D will manifest itself in reduced checkoff levies.

• The Control Problem

The control problem is effectively the principal-agent problem. It arises when the board of directors (the principal) is not able to monitor fully the actions of the manager (the agent); as a consequence the manager is able to pursue his or her own interests rather than those of the board [Jensen and Meckling, 1979; Cook, 1995]. The goals of the principal and the agent may diverge for a number of reasons. One important reason is that although R&D is a long term investment, the manager's performance is typically evaluated in the short run. As a result, the manager has an incentive to engage in short term investments rather than long-term investments. If short term investments generate lower rates of return, the result is an underinvestment in R&D. Fulton and Larson [2009] provide an analysis of the problems associated with the control problem in the Saskatchewan Wheat Pool, a producer-owned enterprise operating in the grains industry in western Canada.

• The Heterogeneity Problem

The heterogeneity problem argues that the benefit of R&D is not the same across producers. If decisions are made on the basis of majority rule and the median producer – i.e., the producer that is pivotal in deciding the outcome – is someone who finds the R&D benefits to be particularly small, then the resulting decision is one that would result in underinvestment. Requirements for supermajorities (e.g., in order to satisfy political demands for substantial agreement) will further exacerbate the problem. [Alston and Fulton, 2012].

• The Horizon Problem

The horizon problem is also believed to be an important explanation for underinvestment by members in a group. As Jensen and Meckling [1979]; Cook [1995] and Vitaliano [1983] argue, the horizon problem occurs when people's individual time horizon (T) of staying in the group (their planning horizon) is shorter than the expected payback time (L_R) of the investment (see Figure 3.1).

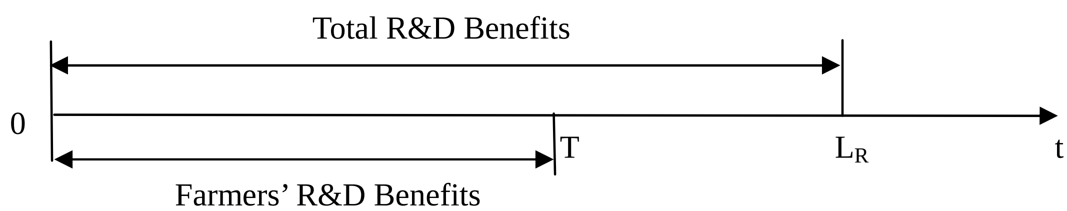


Figure 3.1: The Horizon Problem

Since agricultural R&D is a long-term investment, the horizon problem may have particular importance for R&D investment decisions. Moreover, it is likely to become increasingly important to producer-funded R&D as the average age of farmers increases. For instance, in Canada, the average age of Canadian farmers has risen from 49 in 2001 to 54 in 2011. As well, the proportion of farm operators that are age 55 or over has increased from 32.1 percent in 1991 to 34.9 percent in 2006 to 48.3 percent in 2011 (Statistics Canada). Such a increasing trend of aging farm population calls for a deeper economic analysis of the decision-horizon related consequences of producer-funded R&D. This study is an effort in this direction.

The severity, and even the existence, of the horizon problem has long been debated. Cook [1995] argues that for cooperatives "the severity of the horizon problem intensifies when considering investment in research and development, advertisement, and other intangible assets." Featherstone and Goodwin [1993] empirically conclude that older farmers in the United States have a lower level of investment in conservation technologies. In contrast, Fulton and Giannakas [2012] argue that in cooperatives, the horizon problem is less severe than believed because of a different objective function (cooperative members are interested in consumer surplus plus profit, while investor-owned firms are interested only in profits). The presence of open membership for group members also has an important effect, since this membership structure introduces a behavioural norm, that if followed, encourages members to invest today in return for the benefits that emerge from investments by members in previous periods. Olesen [2007] claims that the horizon problem is likely to cause over-investment rather than underinvestment, while Fahlbeck [2007] does find no empirical support for the horizon problem in Swedish agricultural co-operatives.

The impact of the horizon problem is also likely affected by land tenure relationships. This chapter will examine three cases – the decision-maker is a tenant farmer, the decision-maker is a non-farmer landowner, and the decision-maker is a farmer-landowner. The model is initially developed for the case of a tenant farmer and then extended to the other two cases.

To examine the severity (or the significance) of the horizon problem, the focus of the research in this chapter is the mandatory non-refundable levy scheme. Since this scheme removes the free-rider problem, focusing on it makes it possible to isolate the impact of the horizon problem. To do so, however, requires that the other factors discussed above are not also at work. It is assumed that because the magnitude of the levy is reasonably small (only one percent of farmers' total sales), the portfolio problem is not a major issue. Although the control problem and heterogeneity problem are likely to be at work, these problems emerge because of the manner in which decisions are made within an organization, not because of the way in which farmers view the returns. The examination of the horizon problem in this chapter focuses on the benefits to producers; once these benefits are understood it then becomes possible to examine the impact of decision-making structures.

3.4 A Framework for Analyzing the Horizon Problem

The analysis begins with the development of a formal theoretical model to determine the impact of a change in the current check-off ratio for producer-funded R&D. The focus of the analysis is on R&D expenditures in a producer organization that operates with a non-refundable mandatory check-off scheme.

Agricultural R&D generates costs and benefits to producers that participate in a check-off or levy scheme. The marginal cost of a single-period levy increase is a one-shot cost MC_0 in time period $t = 0$. The marginal benefits that occur in future time periods t are denoted as MB_t. As Figure 3.2 shows, the model assumes that the MB_t are created by a change in the check-off ratio from l_p to l'_p at period $t = 0$; the check-off ratio then returns to the original level l_p in period $t = 1$ and all remaining periods. The internal rate of return – $\overline{\text{IRR}}$ – calculated over the benefit horizon is given by the solution to $\sum_{t=1}^{L_R} \text{MB}_t/(1 + \overline{\text{IRR}})^t = \text{MC}_0$, where L_R is the total lag length for research. In contrast, the internal rate of return – IRR_h – calculated over the farmers' planning horizon is given by $\sum_{t=1}^{T} \text{MB}_t/(1 + \text{IRR}_h)^t = \text{MC}_0$ where T is the planning horizon. A comparison of IRR_h with $\overline{\text{IRR}}$ determines the impact of the horizon problem.

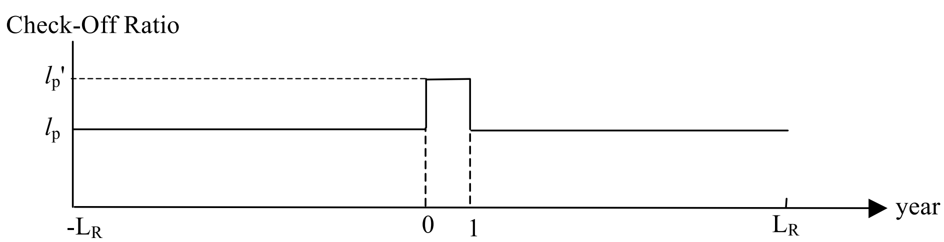


Figure 3.2: The Pattern of The Change in Check-Off Ratio

Source: Developed by the author.

The IRR is chosen over other investment criteria such as net present value (NPV) for at least two reasons. First, the IRR is a commonly-used criteria to measure R&D returns (see Alston et al. [2000]). Focusing on the IRR allows for the choice of a base value of $\overline{\text{IRR}}$ that is consistent with the values found in the previous literature. Second, the calculation of the NPV requires the specification of a discount rate. Given the heterogeneity of farmers, it is likely that farmers hold a range of discount rates. Using the IRR avoids the need to determine a discount rate for the analysis.

The use of the IRR implicitly assumes that the benefits from an investment can be reinvested at the same rate as the IRR of the investment under consideration. Such an assumption appears to be appropriate in the case of R&D funding, since opportunities do exist in principle for the reinvestment of the benefits at the IRR.

The above conceptual analysis of the horizon problem is presented graphically in figure 3.3, where DEF represents the cumulative NPV of the marginal R&D benefits for a given lag distribution, a given discount rate $\overline{\text{IRR}}$, and a given benefit horizon L_R. Thus, at $t = L_R$, this curve gives the cumulative NPV of the R&D benefits for all $t \in [1, L_R]$, i.e., $\sum_{t=1}^{L_R} \text{MB}_t/(1 + \overline{\text{IRR}})^t$; and at $t = T_1$ it represents the cumulative NPV of R&D benefits for all $t \in [1, T_1]$, i.e., $\sum_{t=1}^{T_1} \text{MB}_t/(1+\overline{\text{IRR}})^t$. Notably, after T, DEF becomes very flat; this occurs because the discount factor $1/(1+\overline{\text{IRR}})^t$ is very small and the discounted MB_t adds very little value to the cumulative R&D benefits. Note that $\overline{\text{IRR}}$ is the discount rate that makes the NPV of the R&D benefits equal to the current R&D cost MC_0.

Suppose that the producers' time horizon is given by $T < L_R$. Because of the flatness of the cumulative R&D benefit curve, IRR_h differs only slightly from $\overline{\text{IRR}}$ (recall that IRR_h is the discount rate that makes $\sum_{t=1}^{T} \text{MB}_t/(1 + \text{IRR}_h)^t = \text{MC}_0$). Thus, the horizon problem is not a significant issue as long as the farmers' planning horizon is greater than or equal to T.

If the individual time horizon is T_2 years, then at $t = T_2$, the cumulative NPV of R&D benefits is smaller than the R&D cost by m_2. To equate the marginal benefits with the marginal cost, the research benefits have to be discounted with a smaller discount rate, i.e., IRR_{h2}. The cumulative NPV of R&D benefits with IRR_{h2} can be demonstrated by curve DG in figure 3.3; the dashed line means the benefits after T_2 are truncated.

As is clear from figure 3.3, the shorter is the time horizon T, the smaller is IRR_h – i.e., the larger is the impact of the horizon problem. For instance, if the individual time horizon is $t = T_1$, then the benefit-cost-gap m_1 becomes larger; to compensate the cost research benefits have to be discounted with a even smaller discount rate IRR_{h1}.

3.5 The Theoretical Model

For producer-funded R&D, what is important are the benefits seen by those farmers that effectively make the decision in the organization – these farmers are referred to as the pivotal farmers.

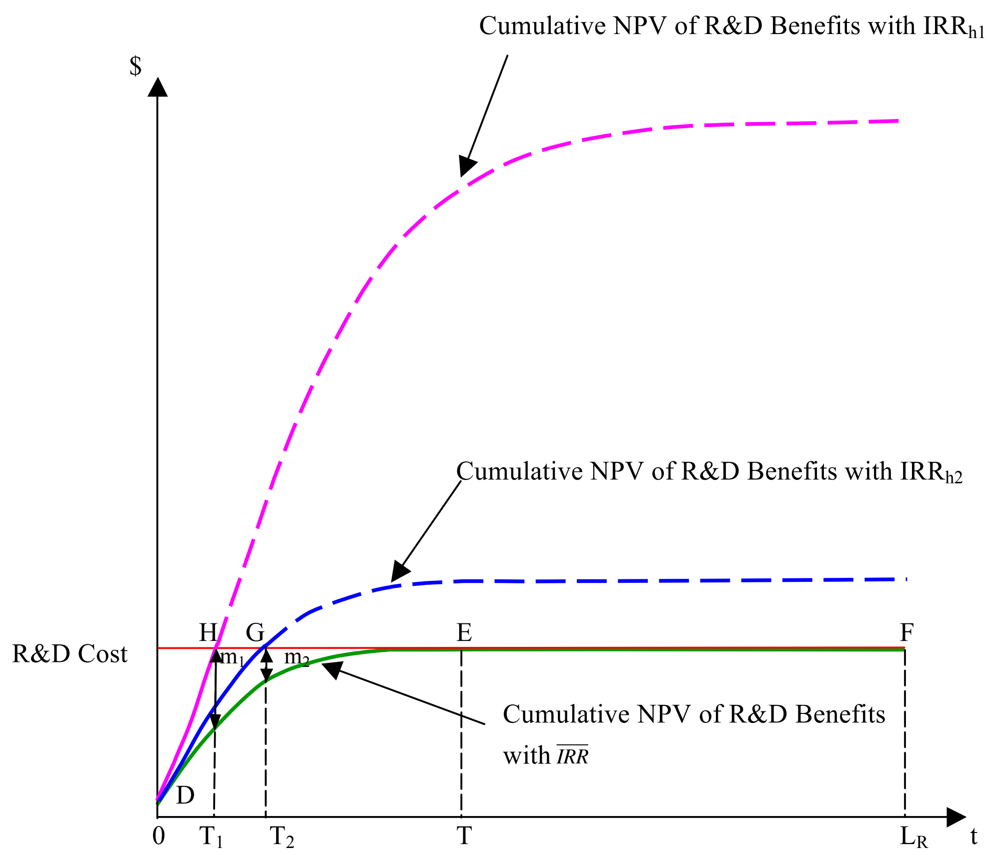


Figure 3.3: A Conceptual Model of the Horizon Problem: Marginal Cumulative Benefits versus Marginal Cost

Source: Developed by the author.

If the pivotal farmers do not see the full benefits of R&D, they can be expected to make decisions that underinvest in R&D.

The purpose of this section is to derive the marginal internal rate of return – i.e., the internal rate of return on the marginal R&D investment. To do this, a model determining the optimal R&D investment, via an optimal levy rate, is developed. The marginal internal rate of return is then determined from the first-order condition for this problem. This calculation is carried out by taking the current levy rate as given and finding the discount rate that makes the first-order condition equal to zero. Note that this procedure reverses the normal practice of taking the discount rate as given and finding the levy rate that equals marginal benefit with marginal cost. As will be seen, the first-order condition involves the equating of the discounted value of future benefits with an immediate cost; hence the need for a discount rate.

The determination of the optimal R&D investment can be modelled as a two-stage sequential game with complete information. In stage one, the pivotal farmer determines the R&D investment, which in turn augments the cumulative knowledge stock of the industry. In stage two, farmers in the group take the knowledge stock as given and determine their profit-maximizing level of output. The game is solved backwards – i.e., given the knowledge stock, the optimal profit of the individual farmer is determined; with the knowledge of this optimal profit, the optimal R&D is determined. To make the problem tractable, the analysis is carried out for the case of the Cobb-Douglas production function.

3.5.1 Stage 2 – Determination of the Optimal Output

Consider an individual tenant farmer (the pivotal farmer) in a producer association with a Cobb-Douglas production function

$$y_t(x_t, K_t) = A x_t^{\beta} K_t^{\alpha} \qquad (A > 0; 0 < \alpha, \beta < 1; \alpha + \beta = 1) \tag{3.1}$$

where y_t is the output in period t, x_t is a composite conventional input (e.g., labor, land and machinery) in period t, and K_t is the cumulated stock of industry R&D knowledge in period t, and the parameter A is a positive constant. Since the pivotal farmer determines the check-off ratio, which consequently determines the knowledge stock, K_t is effectively a choice variable for the pivotal farmer.

This study assumes constant returns to scale (CRS), i.e., $\alpha + \beta = 1$. Since farmers are price takers in both input and output markets, they cannot operate under increasing returns to scale (as Fulton [1997] notes, increasing returns to scale requires that firms possess some degree of market power). If farmers operated under decreasing returns to scale over all levels of production, then farm size would be infinitesimal, an outcome that is not realistic for Canadian producers. Thus, CRS is a reasonable assumption for the present model.

The objective of the individual farmer is to maximize her profit subject to the production function, i.e.,

$$\max_{x_t,\, y_t} \ \pi_t = P(1-l_t)y_t - P_x x_t \qquad s.t. \qquad y_t = A x_t^{\beta} K_t^{\alpha},$$

where P and P_x are the output and input prices, respectively, and l_t is the check-off ratio in period t – i.e., the percentage of the total revenue paid to the producer association as a check-off. Therefore, $P(1-l_t)$ is the net output price that farmers receive.

Substituting the production function into the profit function gives:

$$\max_{x_t} \ \pi_t = P(1-l_t)A x_t^{\beta} K_t^{\alpha} - P_x x_t \tag{3.2}$$

The first-order condition (F.O.C.) can be derived as:

$$\frac{\partial \pi_t}{\partial x_t} = P(1-l_t)A\beta x_t^{\beta-1} K_t^{\alpha} - P_x = 0,$$

The second-order condition (S.O.C.) can be written as:

$$\frac{\partial^2 \pi_t}{\partial x_t^2} = P(1-l_t)A\beta(\beta-1) x_t^{\beta-2} K_t^{\alpha} < 0. \tag{3.3}$$

For (3.3) to hold requires $0 < \beta < 1$.

Solving the F.O.C. gives the optimal input demand for the pivotal farmer as follows:

$$x_t^*(P_x, P, l_t, K_t) = \left(\frac{P_x}{P(1-l_t)A\beta K_t^{\alpha}}\right)^{\frac{1}{\beta-1}} \tag{3.4}$$

Normalizing the input price to unity – i.e., $P_x = 1$, equation (3.4) can be rewritten as:

$$x_t^*(P, l_t, K_t) = [P(1-l_t)A\beta K_t^{\alpha}]^{\frac{1}{1-\beta}}$$

Since $\alpha + \beta = 1$, the above equation can be rewritten as:

$$x_t^*(P, l_t, K_t) = [P(1-l_t)A\beta]^{\frac{1}{\alpha}} K_t \tag{3.5}$$

Substituting equation (3.5) into equation (3.1) gives the output supply function:

$$y_t^*(P, l_t, K_t) = [P(1-l_t)]^{\frac{\beta}{\alpha}} A^{\frac{1}{\alpha}} \beta^{\frac{\beta}{\alpha}} K_t. \tag{3.6}$$

Substituting equation (3.5) into equation (3.2) gives the indirect profit function:

$$\pi_t^*(P, l_t, K_t) = P(1-l_t)[P(1-l_t)]^{\frac{\beta}{\alpha}} A^{\frac{1}{\alpha}} \beta^{\frac{\beta}{\alpha}} K_t - [P(1-l_t)A\beta]^{\frac{1}{\alpha}} K_t \tag{3.7}$$

Collecting terms, equation (3.7) can be rewritten as:

$$\pi_t^*(P, l_t, K_t) = A^{\frac{1}{\alpha}} \beta^{\frac{\beta}{\alpha}} \alpha [P(1-l_t)]^{\frac{1}{\alpha}} K_t. \tag{3.8}$$

3.5.2 Stage 1 – Determination of the Optimal Levy

In stage one, the pivotal farmer decides the R&D investment. From equation (3.8), the indirect profit at $t = 0$ can be derived as:

$$\pi_0^*(P, l_0, K_0) = A^{\frac{1}{\alpha}} \beta^{\frac{\beta}{\alpha}} \alpha [P(1-l_0)]^{\frac{1}{\alpha}} K_0 \tag{3.9}$$

The impact of a change of l_0 on π_0 can be defined by taking the derivative of equation (3.9) with respect to l_0, i.e.,

$$\frac{\partial \pi_0^*}{\partial l_0} = -(PA)^{\frac{1}{\alpha}} \beta^{\frac{\beta}{\alpha}} (1-l_0)^{\frac{\beta}{\alpha}} K_0 < 0, \tag{3.10}$$

Equation (3.10) indicates that an increase in the check-off ratio in period $t = 0$ causes a reduction in profits. The expression $(PA)^{\frac{1}{\alpha}} \beta^{\frac{\beta}{\alpha}} (1-l_0)^{\frac{\beta}{\alpha}} K_0$ is thus the marginal cost of a levy increase.

Equation (3.8) indicates that farmer profits in period t are a function of the industry R&D knowledge stock in period t. Since the knowledge stock in any period is determined by the R&D investments made previously, it is important to model the manner by which investments in R&D affect future knowledge stocks. Specifically, it is necessary to determine how check-off decisions made in the current period (period zero) affect the profits of farmers in future periods.

Based on Alston et al. [2010] (p. 276), this study defines the knowledge stock in period t as the sum of the weighted previous R&D expenditures, as follows:

$$K_t = \sum_{s=1}^{L_R} \omega_s E_{t-s} \qquad \forall\, t \in [1, L_R] \tag{3.11}$$

The extensive form of equation (3.11) can be written as follows:

$$\begin{aligned} K_1 &= \omega_1 E_0 + \omega_2 E_{-1} + \cdots + \omega_{L_R} E_{1-L_R} \\ K_2 &= \omega_1 E_1 + \omega_2 E_0 + \cdots + \omega_{L_R} E_{2-L_R} \\ &\vdots \\ K_{L_R} &= \omega_1 E_{L_R-1} + \omega_2 E_{L_R-2} + \cdots + \omega_{L_R} E_0, \end{aligned} \tag{3.12}$$

where L_R is the time length over which current R&D affects the knowledge stock, s is the number of years since the initial R&D investment; E_0 is the investment in the current time period (year 0), E_{-1} is the investment in the year before the current period, and ω_s is the lag weight.

The lag weight gives the impact on the knowledge stock for R&D expenditures in each year, and can be expressed as follows:

$$\omega_t = \frac{(t-g+1)^{\frac{\eta}{1-\eta}} \lambda^{t-g}}{\sum_{t=1}^{L_R} (t-g+1)^{\frac{\eta}{1-\eta}} \lambda^{t-g}} \text{ for } g < t \leqslant L_R; \text{ otherwise } \omega_t = 0, \tag{3.13}$$

where g is the gestation lag before research begins to affect productivity, η and λ are parameters that define the shape of the distribution ($0 \leqslant \eta < 1$; $0 \leqslant \lambda < 1$), t is the number of years since the R&D investment, and $\sum_{t=1}^{L_R} \omega_t = 1$.

For simplicity, assume all check-off revenues are used for R&D investment, thus the check-off revenues equal R&D expenditures. Since $E_t = l_t P y_t$, it follows that

$$E_0 = l_0 P y_0 = l_0 (1 - l_0)^{\frac{\beta}{\alpha}} (PA)^{\frac{1}{\alpha}} \beta^{\frac{\beta}{\alpha}} K_0, \tag{3.14}$$

Given the above, the change in the knowledge stock in period t with respect to a change in the current check-off ratio l_0 is:

$$\frac{\partial K_t}{\partial l_0} = \omega_t \frac{\partial E_0}{\partial l_0} \tag{3.15}$$

Taking the derivative of equation (3.14) with respect to l_0 gives:

$$\frac{\partial E_0}{\partial l_0} = (PA)^{\frac{1}{\alpha}} \beta^{\frac{\beta}{\alpha}} K_0 (1 - l_0)^{\frac{\beta}{\alpha}} \frac{\alpha - l_0}{\alpha (1 - l_0)} \tag{3.16}$$

Substituting equation (3.16) into (3.15) gives:

$$\frac{\partial K_t}{\partial l_0} = \omega_t (PA)^{\frac{1}{\alpha}} \beta^{\frac{\beta}{\alpha}} K_0 (1 - l_0)^{\frac{\beta}{\alpha}} \frac{\alpha - l_0}{\alpha (1 - l_0)} \tag{3.17}$$

Taking the derivative of π_t^* in equation (3.8) with respect to l_0 gives the marginal impact of l_0 on profits in any given year t ($t \in [1, L_R]$):

$$\frac{\partial \pi_t^*}{\partial l_0} = A^{\frac{1}{\alpha}} \beta^{\frac{\beta}{\alpha}} \alpha [P(1 - l_t)]^{\frac{1}{\alpha}} \frac{\partial K_t}{\partial l_0} \tag{3.18}$$

Substituting equation (3.17) into equation (3.18) gives the marginal impact of l_0 on the profit in any given year:

$$\frac{\partial \pi_t^*}{\partial l_0} = (PA)^{\frac{2}{\alpha}} \beta^{\frac{2\beta}{\alpha}} K_0 \omega_t (1 - l_t)^{\frac{1}{\alpha}} (1 - l_0)^{\frac{\beta - \alpha}{\alpha}} (\alpha - l_0) > 0 \tag{3.19}$$

Equation (3.19) indicates that an increase in the current check-off ratio (i.e., the current R&D investment) will create benefits in future periods, albeit at a diminishing rate since

$$\frac{\partial^2 \pi_t^*}{\partial l_0^2} = (PA)^{\frac{2}{\alpha}} \beta^{\frac{2\beta}{\alpha}} K_0 \omega_t (1 - l_t)^{\frac{1}{\alpha}} [-\frac{\beta - \alpha}{\alpha} (1 - l_0)^{(\frac{\beta - 2\alpha}{\alpha})} (\alpha - l_0) - (1 - l_0)^{\frac{\beta - \alpha}{\alpha}}] < 0. \tag{3.20}$$

3.5.3 Calculation of the Marginal Rate of Return

Instead of calculating the optimal check-off ratio, this study calculates the marginal internal rate of return to the pivotal farmer, and then determines how the horizon problem affects this internal rate of return. The discounted profits for the pivotal farmer are given by

$$\begin{aligned}\pi(l_0) &= \sum_{t=0}^{L_R} \pi_t^*(l_0)/(1+r)^t \\ &= \pi_0^*(l_0) + \sum_{t=1}^{L_R} \pi_t^*(l_0)/(1+r)^t\end{aligned} \tag{3.21}$$

where r is the discount rate. The net present value of the impact of l_0 on profits is given by:

$$\frac{\partial \pi(l_0)}{\partial l_0} = \frac{\partial \pi_0^*}{\partial l_0} + \sum_{t=1}^{L_R} \frac{\partial \pi_t^*}{\partial l_0}/(1+r)^t \tag{3.22}$$

The optimal check-off ratio is the one that equates equation (3.22) to zero, i.e.,

$$\underbrace{\frac{\partial \pi_0^*}{\partial l_0}}_{\text{R\&D Cost}} + \underbrace{\sum_{t=1}^{L_R} \frac{\partial \pi_t^*}{\partial l_0}/(1+r)^t}_{\text{NPV of Total R\&D Benefits}} = 0, \tag{3.23}$$

where $\frac{\partial \pi_0^*}{\partial l_0}$ is the marginal cost of R&D investment and $\frac{\partial \pi_t^*}{\partial l_0}$ is the marginal R&D benefit in year $t, t \in [1, L_R]$.

Substituting equation (3.10) and (3.19) into (3.23) gives:

$$-(PA)^{\frac{1}{\alpha}}\beta^{\frac{\beta}{\alpha}}(1-l_0)^{\frac{\beta}{\alpha}}K_0 + \sum_{t=1}^{L_R}(PA)^{\frac{2}{\alpha}}\beta^{\frac{2\beta}{\alpha}}K_0\omega_t(1-l_t)^{\frac{1}{\alpha}}(1-l_0)^{\frac{\beta-\alpha}{\alpha}}(\alpha-l_0)/(1+r)^t = 0 \tag{3.24}$$

Assuming that l_t is chosen so that $l_t = l_0$, then equation (3.24) can be rewritten as follows:

$$-(PA)^{\frac{1}{\alpha}}\beta^{\frac{\beta}{\alpha}}(1-l_0)^{\frac{\beta}{\alpha}}K_0 + \sum_{t=1}^{L_R}(PA)^{\frac{2}{\alpha}}\beta^{\frac{2\beta}{\alpha}}K_0\omega_t(1-l_0)^{\frac{2\beta}{\alpha}}(\alpha-l_0)/(1+r)^t = 0 \tag{3.25}$$

Collecting terms gives:

$$(PA)^{\frac{1}{\alpha}}\beta^{\frac{\beta}{\alpha}}(\alpha - l_0)(1 - l_0)^{\frac{\beta}{\alpha}} \sum_{t=1}^{L_R} \frac{\omega_t}{(1+r)^t} = 1 \tag{3.26}$$

Note that l_0 has to be smaller than α, otherwise there is no solution for this equation. The discount rate that solves the above equation is the marginal internal rate of return $\overline{\text{IRR}}$ for the time length of L_R years. Thus, equation (3.26) can be rewritten as:

$$(PA)^{\frac{1}{\alpha}}\beta^{\frac{\beta}{\alpha}}(\alpha - l_0)(1 - l_0)^{\frac{\beta}{\alpha}} \sum_{t=1}^{L_R} \frac{\omega_t}{(1+\overline{\text{IRR}})^t} = 1. \tag{3.27}$$

If the producer association suffers from the horizon problem, then the optimal l_0 is determined by simply truncating the R&D benefits to the first T years – i.e., the time horizon that the pivotal farmer benefits from investments made by the producer association. Consequently, the internal rate of return IRR_h for a time length of T years is given by the solution to the following equation:

$$(PA)^{\frac{1}{\alpha}}\beta^{\frac{\beta}{\alpha}}(\alpha - l_0)(1 - l_0)^{\frac{\beta}{\alpha}} \sum_{t=1}^{T} \frac{\omega_t}{(1+\text{IRR}_h)^t} = 1 \tag{3.28}$$

3.6 Empirical Analysis

The focus of much of the literature on agricultural R&D has been on the internal rate of return [Alston et al., 2000], with high estimates of the internal rate of return indicating that underinvestment has occurred. In keeping with this approach, this section empirically estimates the internal rate of return IRR_h that a pivotal producer can be expected to see given her benefit horizon. To undertake this analysis, a series of assumptions have to be made regarding the gestation lag g (i.e., the time until the first benefits of R&D occur), the lag distribution of ω_t (i.e., the pattern of the benefits over time), the internal rate of return $\overline{\text{IRR}}$ over the entire payback horizon of R&D investment, and the benefit horizon T of the pivotal farmer. Given these assumptions, the internal rate of return IRR_h can be calculated. The impact of the horizon problem is then determined by examining the magnitude of the deviation of IRR_h from $\overline{\text{IRR}}$.

3.6.1 Methodology

In what follows, we use Microsoft Excel to solve for IRR_h given assumptions about the various parameters. The $\overline{\text{IRR}}$ value is taken from Alston et al. [2010], who calculated the marginal IRR for agricultural R&D in the United States to be 0.234. The baseline value assumed for this analysis is 0.25; sensitivity analysis calculations were also carried out for values of 0.15, 0.20, and 0.30.

Following Alston et al. [2010], this analysis assumes the lag weights have a gamma distribution (equation 3.13) described by the parameters η and λ. It is assumed that these parameters take on values of 0.60, 0.65, 0.70, 0.75, 0.80, 0.85, 0.90, and 0.95. The maximum lag length L_R is assumed to be 50 years, while it is assumed that the gestation lag g takes four different values – namely zero, five, ten and fifteen years.

Figure 3.4 demonstrates that, for a given g and η, the larger is λ, the later is the time at which the lag weights peak, while for a given g and λ, the larger is η, the later is the time at which the lag weights peak. Note also that an increase in η and λ results in a flatter lag distribution. Since a later peak corresponds to a flatter distribution, the peak year is used as an index to represent both the shape and location of the lag distribution.

It is assumed that the knowledge stock factor share α takes a value of 0.10, while the output price P is set at 2.0. The current check-off ratio l_0 is assumed to be one percent, and the current knowledge stock K_0 is assumed to be 1.0.

Given the above assumptions, it is possible to solve for the value of the parameter A in the Cobb-Douglas production function that ensures that a one percent check-off levy generates an internal rate of return equal to $\overline{\text{IRR}}$. If this parameter is denoted $\hat{A}$, then $\hat{A}$ can be solved for using equation (3.28):

$$\hat{A} = \left[P^{\frac{1}{\alpha}} \beta^{\frac{\beta}{\alpha}} (\alpha - l_0)(1 - l_0)^{\frac{\beta}{\alpha}} \sum_{t=1}^{L_R} \frac{\omega_t}{(1 + \overline{\text{IRR}})^t} \right]^{-\alpha} \tag{3.29}$$

The values of $\hat{A}$ for the different assumed values of g, η, λ and $\overline{\text{IRR}}$ are shown in the Appendix.

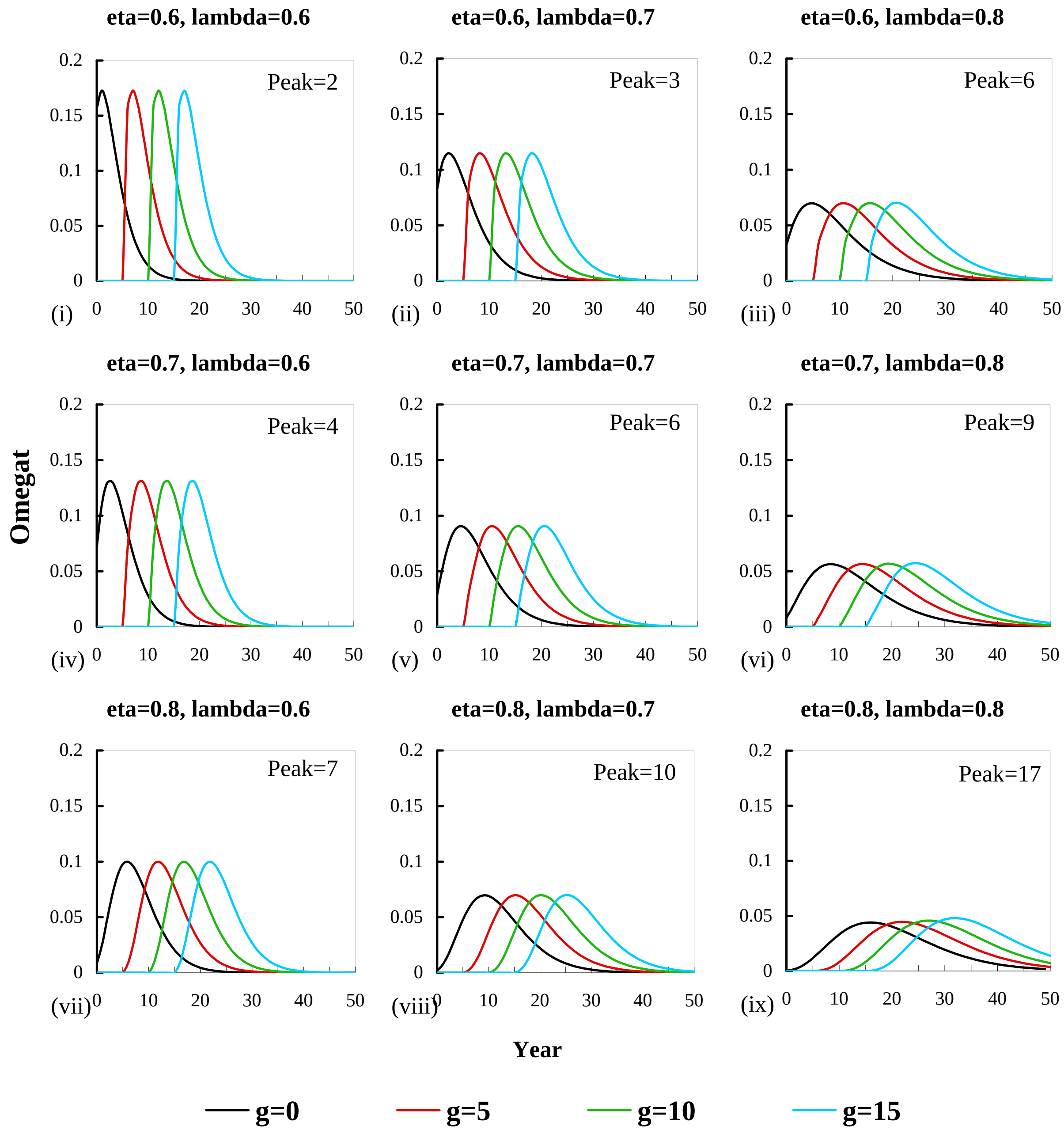


Figure 3.4: Gamma Distribution of The Lag Weights

Note: (1) Source: Calculated by the author based on Alston et al. [2010]; (2) The peak year labeled in each grid applies for the case of g=0.

3.6.2 Results and Implications

The horizon IRR_h is affected by four key variables – the shape of the lag distribution (captured by η and λ), the gestation lag g, the value of $\overline{\text{IRR}}$, and the individual time horizon T. The impact of each of these variables on IRR_h is considered in turn.

The Shape of the Lag Distribution

The impact of the lag distribution shape on the horizon IRR_h can be seen in Figures 3.5 to 3.8. A visual inspection reveals that for a given g and T, with a fixed value of η, the larger is λ, the greater is the deviation of IRR_h from $\overline{\text{IRR}}$. Similarly, with a fixed value of λ, the larger is η, the greater is the deviation of IRR_h from $\overline{\text{IRR}}$. The deviation of IRR_h from $\overline{\text{IRR}}$ is interpreted as the impact of the horizon problem.

For example, in the case of gestation lag $g = 5$ and time horizon T=10, when $\eta = 0.8$ – i.e., the bottom row in Figure 3.5 and the bottom row of Table 3.2 – as λ takes the value of 0.6, 0.7, and 0.8, IRR_h falls from 0.16 to 0.10, then to 0.03. As well, when $\lambda = 0.8$ – i.e., the last column in Figure 3.5 and Table 3.2, as the value of η increases from 0.6 to 0.7 to 0.8, IRR_h falls from 0.19 to 0.14 to 0.03.

Table 3.2: IRR_h with Different Values of η and λ: $g = 5$, T=10

	IRR_h		
λ	0.6	0.7	0.8
η		*percentage*	
0.6	23	21	19
0.7	21	18	14
0.8	16	10	3

Source: Calculated by the author.

The above empirical analysis suggests that it is appropriate to derive the following result:

Result 3.1. *The impact of the horizon problem is affected by the lag weight distribution. For a given gestation lag g, the later the lag peaks, i.e., the larger the values of η and λ, the greater is the deviation of IRR_h from $\overline{IRR}$ and thus the larger is the impact of the horizon problem, ceteris paribus.*

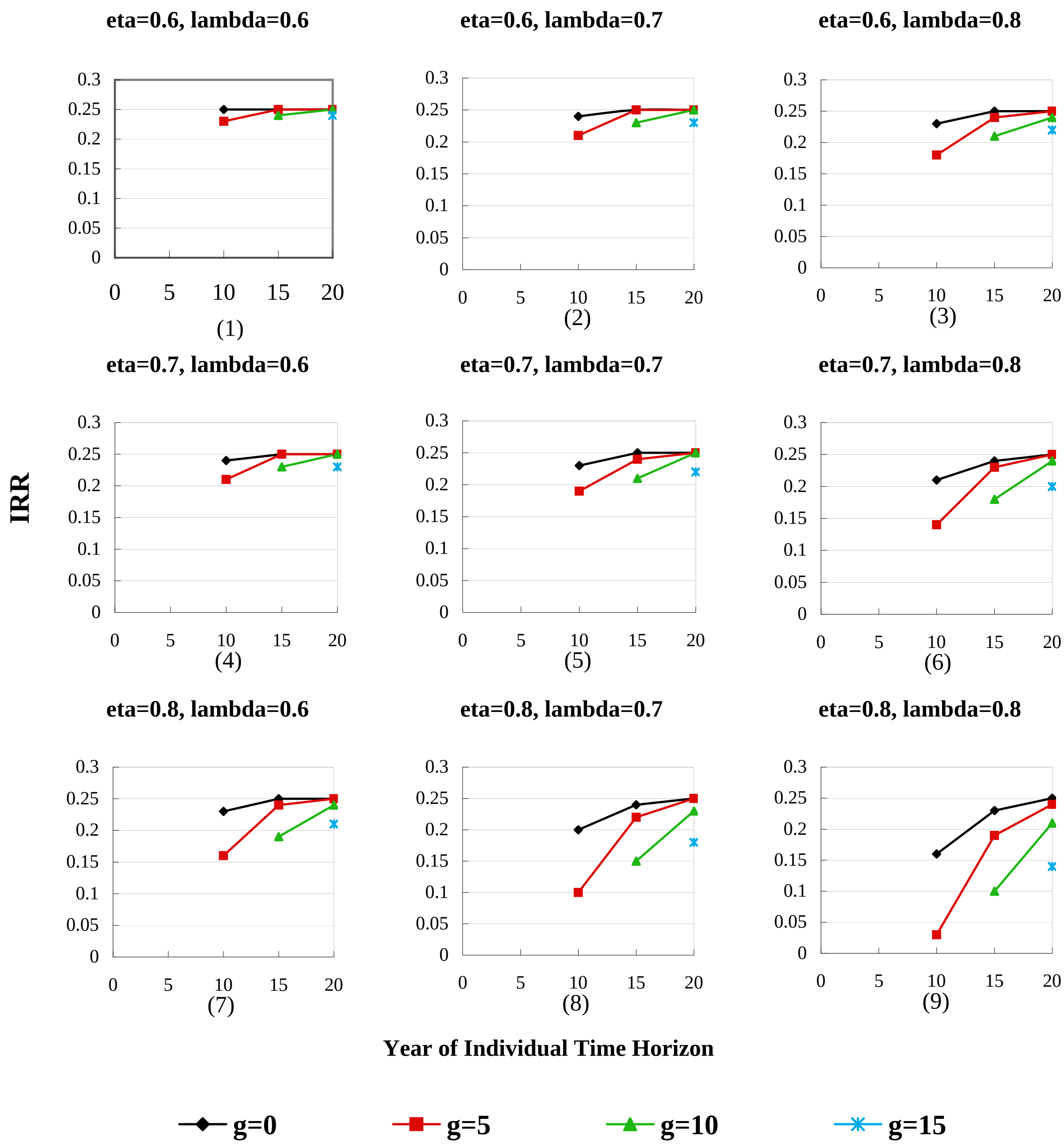


Figure 3.5: Empirical Result of The Horizon IRR for $\overline{\text{IRR}} = 0.25$

Source: Calculated by the author.

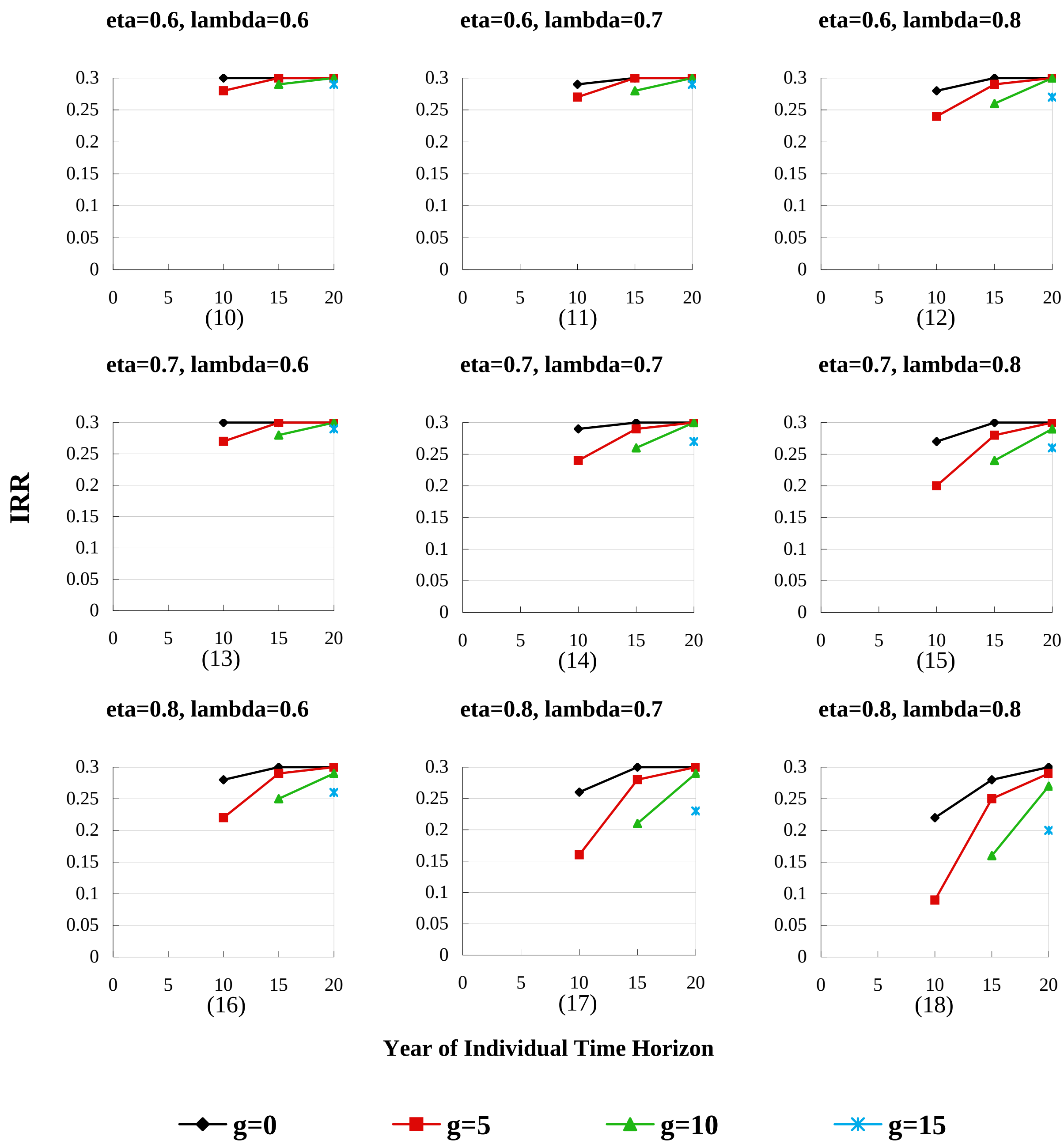


Figure 3.6: Empirical Result of The Horizon IRR for $\overline{\text{IRR}} = 0.3$

Source: Calculated by the author.

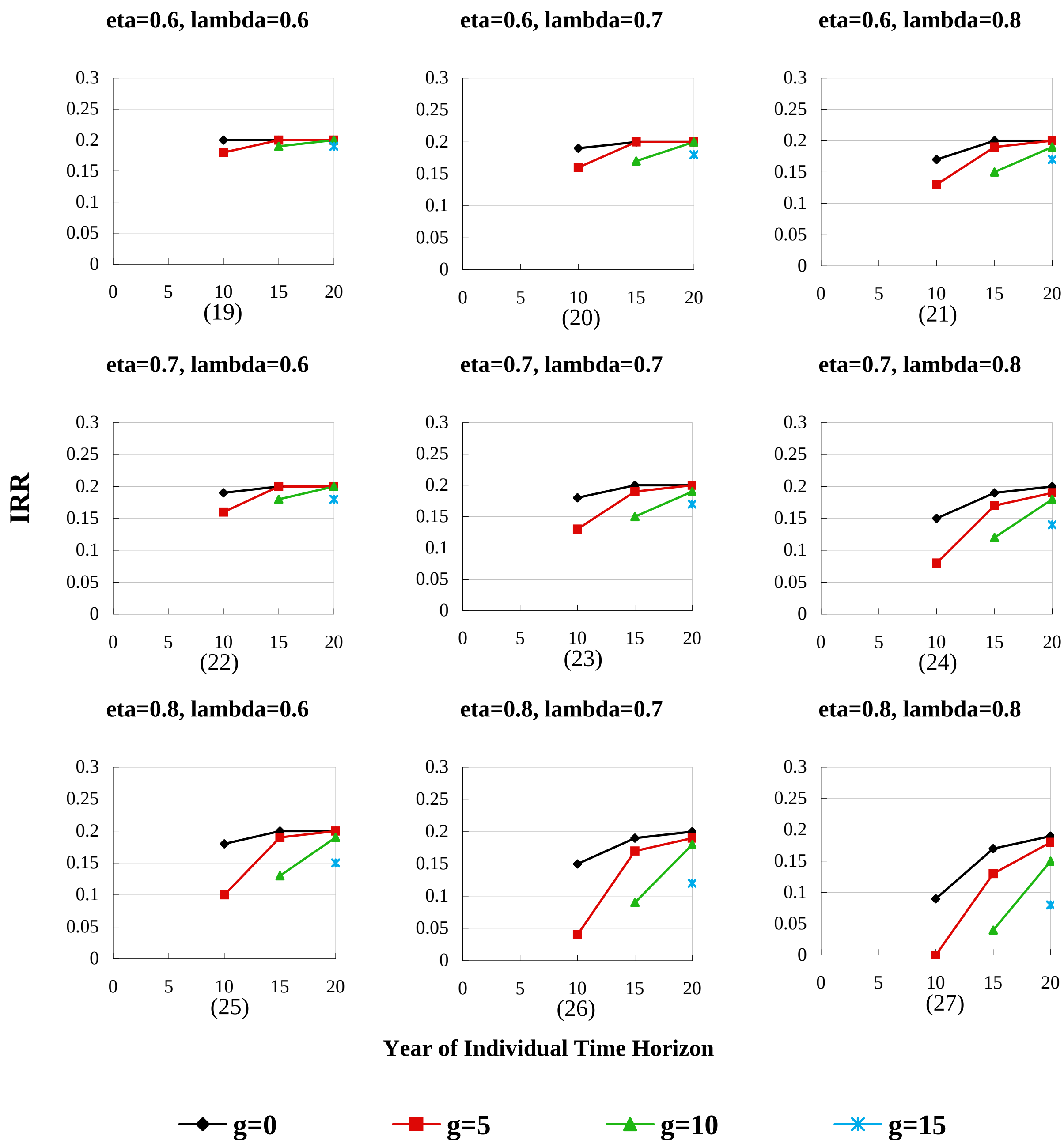


Figure 3.7: Empirical Result of The Horizon IRR for $\overline{\text{IRR}} = 0.2$

Source: Calculated by the author.

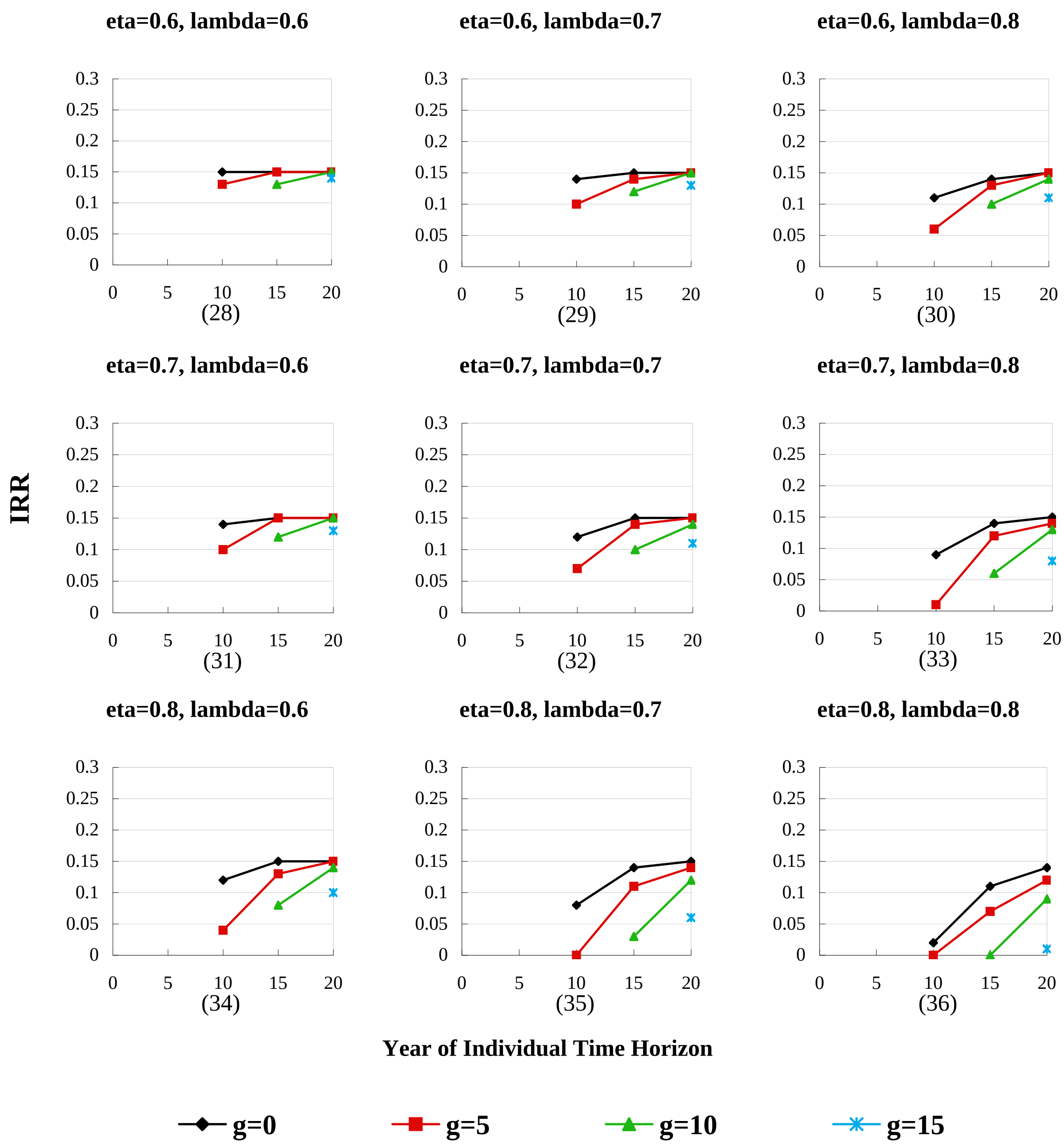


Figure 3.8: Empirical Result of The Horizon IRR for $\overline{\text{IRR}} = 0.15$

Source: Calculated by the author.

The Gestation Lag

Consider now the gestation lag. As figure 3.4 shows, an increase in the gestation lag g simply moves out the peak year of the lag distribution. For instance, when $g = 0$, the peak year is four years for $\eta = 0.7$ and $\lambda = 0.6$ (grid iv); the peak year becomes nine years when $g = 5$.

As a consequence of this relationship, the longer is the gestation lag g, the later is the time period at which current R&D investment begins to generate benefits, and therefore, the larger is the deviation of IRR_h from $\overline{\text{IRR}}$, *ceteris peribus*. This pattern can be seen in Figures 3.5 to 3.8 which show that the difference between $\overline{\text{IRR}}$ and IRR_h increases as g increases.

The above analysis suggests that it is appropriate to derive the following result:

Result 3.2. *For a given lag weight distribution (η and λ), the impact of the horizon problem is affected by the gestation lag g. The longer is the gestation lag, the bigger is the deviation of IRR_h from $\overline{IRR}$, and thus the larger is the impact of the horizon problem.*

Time Horizon and $\overline{\text{IRR}}$

A visual inspection of figures 3.5 to 3.8 reveals that IRR_h falls as T decreases within any given parameter combination, Thus, ceteris paribus, the shorter is T, the larger is the impact of the horizon problem on IRR_h. Finally, Figures 3.5 to 3.8 show that the deviation of IRR_h from $\overline{\text{IRR}}$ is not obviously affected by the magnitude of $\overline{\text{IRR}}$.

The results presented in this section provide a visual examination of the horizon problem for a specified set of parameter values. The next section provides a more quantitative analysis of the horizon problem through the use of a Monte Carlo simulation.

3.7 Monte Carlo Simulation

The purpose of this section is to estimate the probability density function of the horizon IRR_h for a set of randomly generated parameters η, λ and $\overline{\text{IRR}}$ by sampling from known distributions of these parameters. The Monte Carlo simulations are done using Wolfram *Mathematica*.

In the Monte Carlo analysis, the population means for η and λ were set at 0.80 and 0.75, respectively. Alston et al. [2010] (p. 276-277) argued that to generate a plausible lag weight distribution, the parameters η and λ should be greater than 0.5 and smaller than 1. In fact, to satisfy the gamma distribution of lag weights in equation (3.13) requires η and $\lambda \in [0, 1)$.

Assuming that the maximum value of one is within three standard deviations of the mean, the population standard deviation of η and λ can be calculated as:

$$\sigma_\eta = \frac{1-\mu_\eta}{3} = \frac{1-0.8}{3} \approx 0.07$$

$$\sigma_\lambda = \frac{1-\mu_\lambda}{3} = \frac{1-0.75}{3} \approx 0.08$$

Therefore, $\eta \sim N(0.8, 0.07^2)$, and $\lambda \sim N(0.75, 0.08^2)$. The population mean for the marginal $\overline{\text{IRR}}$ was set at 23.4 percent and the standard deviation was set at 0.17 as calculated by Alston et al. [2010] (p. 403). Thus, $\overline{\text{IRR}} \sim N(0.234, 0.17^2)$. The parameter g was set equal to zero.

The Monte Carlo analysis was undertaken by making 1,000 draws and for calculating IRR_h each draw. Each draw included a random selection of η, λ, and $\overline{\text{IRR}}$ from their individual distributions respectively. These three distributions were assumed to be statistically independent.

The result of the Monte Carlo simulation can be seen in Figure 3.9. The PDF function for T=50 represents the probability density function for $\overline{\text{IRR}}$. The PDF functions for T=20, 15, 10, and 5 years represent the probability density functions of IRR_h for different individual farmer planning time horizons T. The order of the location for the PDF from right to left is the PDF with individual time horizon of $T = 50$ to $T = 5$. Figure 3.9 shows that as the membership horizon T decreases from T=50 to 5, the PDF function moves to the left, the expected IRR_h decreases, and its variance increases.

The means and variances of the PDFs for each horizon IRR_h are numerically presented in Table 3.3. The second last column of the table is the percentage difference between the mean of IRR_h and the mean of $\overline{\text{IRR}}$, i.e., (Mean IRR_h-Mean $\overline{\text{IRR}}$)/Mean $\overline{\text{IRR}}$. The last column of the table is the percentage difference between the variance of IRR_h to the variance of $\overline{\text{IRR}}$, i.e., (Var IRR_h-Var $\overline{\text{IRR}}$)/Var $\overline{\text{IRR}}$.

As both Figure 3.9 and Table 3.3 show, the mean of the IRR_h falls and the variance increases as the membership horizon falls. Therefore, the following results can be derived:

Result 3.3. *As the membership horizon T decreases, the expected IRR_h decreases and its variance increases.*

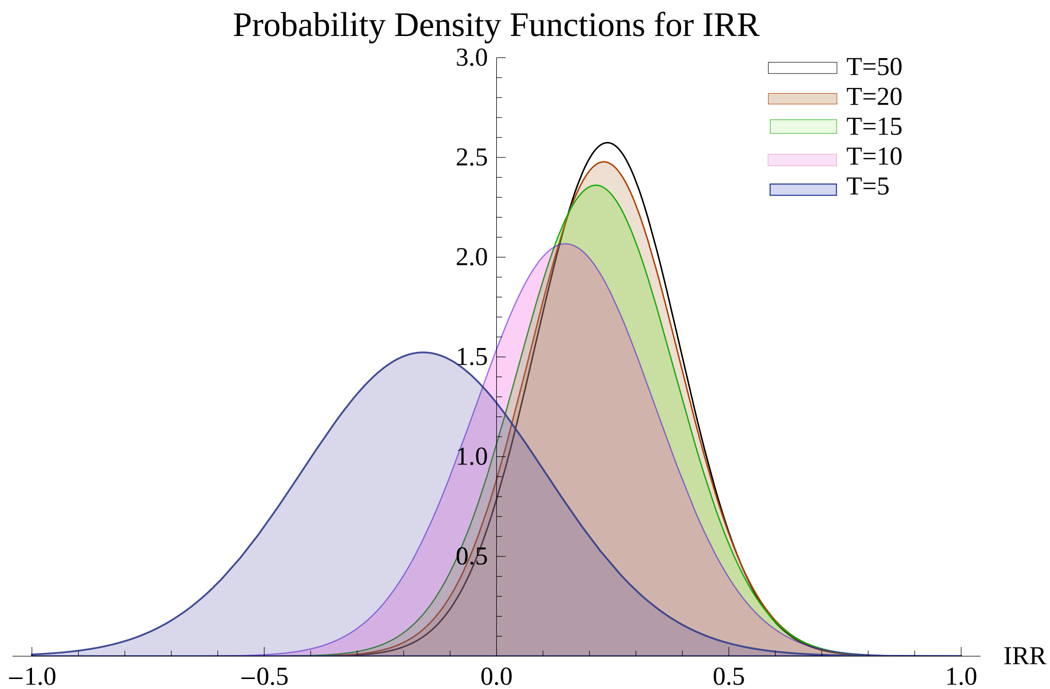


Figure 3.9: Probability Density Functions for IRRs

Source: Developed by the author.

Table 3.3: Mean and Variance of the Distributions

Time Horizon	Mean of IRR_h	Variance of IRR_h	Percentage Difference in the Mean	Percentage Difference in the Variance
			percentage	
T=50	0.239	0.155^2	-	-
T=40	0.239	0.155^2	0	0
T=30	0.238	0.156^2	-0.4	1.3
T=20	0.231	0.161^2	-3.3	7.9
T=15	0.214	0.169^2	-10.5	18.9
T=10	0.148	0.193^2	-38.1	55.0
T=9	0.119	0.202^2	-50.2	69.8
T=8	0.080	0.213^2	-66.5	88.8
T=7	0.025	0.228^2	-89.5	116.4
T=6	-0.051	0.244^2	-121.3	147.8
T=5	-0.158	0.262^2	-166.1	185.7

Source: Developed by the author.

As Table 3.3 shows, although the mean of IRR_h falls as T decreases, the mean of IRR_{20} is nearly identical with the mean of $\overline{\text{IRR}}$ (23.1% vs 23.9%). Even when T=15, the mean of IRR_{15} is very close to the mean of $\overline{\text{IRR}}$ (21.4% vs 23.9%). At T=10, the value of IRR_h is still high – 14.8% – although the difference between IRR_{10} and $\overline{\text{IRR}}$ is substantial (the difference is nearly 40%). The mean of IRR_h falls to a single digit when T is less than nine years. This observation indicates that the horizon problem is not an issue to impact the R&D investment decisions unless T is very short.

Given that the average age of Canadian producers is 54 years and their membership horizon is 15 to 20 years (assume their expected retirement age is 69 to 74), the results presented in Table 3.3 suggest that the horizon problem is not likely a significant issue for Canadian producers. Although shorter time horizons do lead to smaller IRRs, the decrease in IRR is not likely to be large enough to have a major effect on the returns that can be expected from investment in R&D.

The above analysis assumed that farmers are only concerned about profit maximization. However, farmers may consider other factors when making R&D investment decisions, such as the health of their land and the welfare of future generations. Concern with such factors can be expected to provide further incentives for farmers to invest in R&D. Thus, the results of this study support the conclusion that the horizon problem is not likely to be a major cause of the underinvestment observed in agricultural R&D. Instead, the reason is likely to lie elsewhere.

3.8 Impact of Land Tenure on The Horizon Problem

The analysis to this point has assumed that the pivotal voter is a tenant farmer – as a tenant, the farmer only sees the benefits of R&D while she is farming. However, other land tenure relationships exist. For instance, it is common nowadays that land owners rent out their land, such as in Saskatchewan 50 percent of farmers rent at least a portion of their farmland, and 39 percent of the total farmland is under lease [Saskatchewan-Government, 2007]. The purpose of this section is to examine the impact of land tenure on the horizon problem.

If the pivotal decision-maker is a landowner, then standard economic theory suggests that the horizon problem does not exist. The reason is that future R&D benefits can be expected to be fully capitalized into land values under the assumption that the land price equals the sum of discounted future rents (it is also assumed that the landowner has all the bargaining power and is able to obtain all the benefits from any improvements that are made). Thus, even if the benefits occur past the time the landowner is expected to own the land she will still benefit from future R&D through an increase in land prices.

If the pivotal voter is a tenant farmer, as the above analysis indicates, the horizon problem does not emerge until the membership horizon T is very small. As will be shown below, three different cases are examined: the pivotal voter as farmer-tenant, the pivotal voter as a non-farmer landowner, and the pivotal voter as a farmer-landowner.

The common leasing arrangements on farm land are the cash-rent lease and the crop-share lease. With cash rent arrangements, the tenant receives the income from all crop sales but pays a fixed cash payment to the landowner each year as land rent. The landowner receives a guaranteed rent, while the tenant supplies labor, machinery and pays all expenses except for property taxes, building insurance and major building repairs. In this case, the landowner is not a member of the producer organization and thus is not involved in the R&D decision making. Instead, the tenant is the registered group member, pays the levies and is eligible to vote in board elections. Thus, in this case the tenant should be considered the pivotal voter.

In the case of the crop-share lease, the non-farmer landlord receives a pre-negotiated share of all crops grown on the leased land as the land rent, pays the property taxes, and supplies grain storage. The tenant receives a pre-negotiated share of the crops and supplies the machinery, labor and crop inputs. In this case, both the non-farmer landowner and the tenant are members of the producer organization. They share the levy payment and both could be the pivotal voter.

Table 3.4 shows the impact on the horizon problem in the three cases outlined above: the tenant farmer is the pivotal voter, the non-farmer landowner is the pivotal voter, and the farmer-landowner is the pivotal farmer. As will be seen, these different pivotal voters have different benefit horizons and consequently different IRRs for R&D investment decisions.

To interpret the results in Table 3.4, define the marginal R&D cost in equation (3.23) as $\partial\pi_0^*/\partial l_0 = \mathrm{MC}$, and the NPV of marginal R&D benefits as $\sum_{t=1}^{T} \frac{\partial\pi_t^*}{\partial l_0}/(1+r)^t = \sum_{t=1}^{T} \mathrm{MB}_t/(1+r)^t$. Let a ($a \in [0,1]$) be the share of the R&D benefits and the marginal cost that are obtained/undertaken by the tenant in a crop-share lease; thus, $(1-a)$ is the share obtained/undertaken by the non-farmer landowner. The share a depends on the bargaining power between the tenant and the non-farmer landowner and on the general norms in the area (in Saskatchewan, for instance, a historically was about two thirds). Kirwan [2009] provides evidence that, contrary to the assumptions of the standard economic model of land pricing, the landowner does not capture all of the benefits – in fact, he estimates that the tenant gets about 75 percent of the benefits.

Table 3.4: Land Tenure and the Horizon Problem

Pivotal Farmer	Benefit Horizon	R&D Costs	R&D Benefits	Horizon IRR
Tenant Farmer	[1, T]	aMC	$a\sum_{t=1}^{T} \mathrm{MB}_t/(1+r)^t$	IRR_h
Non-Farmer Landowner	[1, L_R]	$(1-a)$MC	$(1-a)\sum_{t=1}^{L_R} \mathrm{MB}_t/(1+r)^t$	$\overline{\mathrm{IRR}}$
Farmer-Landowner	[1, T]	MC	$\sum_{t=1}^{T} \mathrm{MB}_t/(1+r)^t$	IRR_l
	(T, L_R]	0	$(1-a)\sum_{t=T}^{L_R} \mathrm{MB}_t/(1+r)^t$	

Source: Developed by the author.

Case 1: The tenant farmer is the pivotal voter

If the tenant farmer is the pivotal voter, then her benefit horizon is T years. In a crop-share lease, the tenant farmer incurs a proportion a of the R&D costs, i.e., aMC, in period t=0, while her marginal R&D benefits are $a\sum_{t=1}^{T} \mathrm{MB}_t/(1+r)^t$ over the T year benefit horizon. In a cash lease, the tenant incurs all the costs and all the benefits – i.e., $a = 1$. Given that both the costs and the benefits are discounted by the same fraction a, the relevant internal rate of return for a tenant farmer is thus the horizon IRR_h calculated in the previous sections. As was shown above, the horizon problem will not result in disincentives to invest in producer-funded R&D activities unless the membership horizon is very short.

Case 2: The non-farmer landowner is the pivotal voter

In this case, since the pivotal voter is the non-farmer landowner, any benefits from the R&D are capitalized into the land price. Although the landlord may only see a portion of the benefits (depending on the value of a), the landlord also only incurs a portion of the costs. Consequently, the internal rate of return is $\overline{\mathrm{IRR}}$ and the horizon problem does not exist.

Case 3: The farmer-landowner is the pivotal voter

In this case, the pivotal voter owns the land and farms it until her retirement at T years; after T, she rents the land to other farmers or sells it to other non-farmer landowners (if she sells it to other farmer-landowners then the horizon problem vanishes). During the period [1, T], the farmer-landowner incurs the entire R&D costs of MC and captures the entire R&D benefits of $\sum_{t=1}^{T} \mathrm{MB}_t/(1+r)^t$. After time period T, she either sells or rents out the land. If, as a landlord, she (or another landlord she sells to) is not able to capture all the benefits from the land (i.e., $a > 0$), then the R&D benefits are $(1-a)\sum_{t=T}^{L_R} \mathrm{MB}_t/(1+r)^t$. The resulting internal rate of return over the time period $t \in [1, L_R]$ can be calculated as IRR_l that gives $\mathrm{MC}+\sum_{t=1}^{T} \mathrm{MB}_t/(1+r)^t + (1-a)\sum_{t=T}^{L_R} \mathrm{MB}_t/(1+r)^t = 0$, and obviously $\mathrm{IRR}_h < \mathrm{IRR}_l < \overline{\mathrm{IRR}}$. Because IRR_l is greater than IRR_h the horizon problem is less severe than when the tenant farmer is the pivotal voter. Since the horizon problem is not an issue even in the case where the tenant farmer is the pivotal farmer, it can be concluded that the horizon problem is not an issue in the case the farmer-landowner is the pivotal voter.

Thus, the horizon problem is not affected by the land tenure arrangements. First, if the non-farmer landowner is the pivotal voter then the horizon problem vanishes. Second, if the tenant farmer is the pivotal farmer, then, as the analysis in the previous section shows, the horizon problem only emerges if the time horizon of the pivotal tenant farmer is very short. Finally, if the farmer-landowner is the pivotal farmer, then the horizon problem is less severe than when the tenant farmer is the pivotal voter, which in turn implies the horizon problem is unlikely to be an issue.

3.9 Concluding Remarks

The horizon problem has been widely identified as an important factor affecting individual investment behaviour in the context of a collective institution [Jensen and Meckling, 1979; Cook, 1995; Vitaliano, 1983; Porter and Scully, 1987; Rey and Tirole, 2007]. Given the aging farm population, the horizon problem emerges as a likely reason for the underinvestment that is occurring in producer-funded R&D.

As expected, the study shows the horizon problem is determined by the gestation lag and the lag weight distribution. The longer the gestation lag – i.e, the longer it takes to generate the first benefit from an R&D investment, the larger is the impact of the horizon problem. In addition, the longer it takes for the investment to generate its largest benefit – which is determined by the lag weight distribution – the larger is the impact of the horizon problem. As the Monte Carlo simulation results show, a shorter membership horizon both reduces the expected IRR and increases its variance. This increase in variance is important, since to the extent that farmers are risk averse, shorter time horizons can be expected to result in additional disincentives to invest in R&D. Moreover, the impact of the horizon problem is not affected by land tenure relationships.

However, contrary to the view that the horizon problem is an important disincentive for investment, this study shows the horizon problem is not likely to be the reason for the under-investment of producer-funded R&D, unless farmers' time horizon is very short (e.g., under 10 years). Given that the membership horizon for the average Canadian producer is 15 to 20 years, the horizon problem is not an issue for Canadian producers. Furthermore, the analysis assumes farmers only are concerned with profit maximization. However, farmer may also consider other factors when making R&D investment decisions, such as future generations of agricultural producers and environment issues. The results of this study show even under the extreme assumption of profit maximization, the horizon problem is not an issue for Canadian farmers, let alone in a more realistic model implemented by including factors other than profit.

The implicit assumption of this study is that the institutional arrangements, such as the voting mechanism, are exogenous. However, with the aging farm population in Canada, an examination of the current voting mechanism is needed. For instance, is majority voting an effective mechanism to generate sufficient collective research investment? What would be the optimal mechanism design to generate sufficient R&D investment for producer organizations? These are the research questions that need to be addressed in future studies.

The analysis in this chapter examines the decisions made by a single member of the group. Implicit in this analysis is the idea that different members of the group will have different time horizons, and hence different IRRs. The heterogeneous IRRs mean that producers have different willingness to pay for R&D activities – i.e., different preferences for check-offs. For instance, farmers with longer benefit horizons prefer a higher check-off ratio because they can capture the research benefits over a longer period of time given the costs that are born by every member today. However, farmers with shorter horizons prefer lower check-off ratio due to their inability to capture the research benefits in the future. Given these heterogeneous preferences over the check-off ratio, the choice of the check-off ratio makes some group members better off while imposing a cost on other group members. An investigation of the conflicts that exist among group members is a subject for further research.

3.10 Appendix

The estimated values of $\hat{A}$ for different lag distributions under different treatments of $\overline{\text{IRR}}$ and gestation lag g can be seen in Figure 3.10. Where $\hat{A}$ is the estimated value of the parameter A in the Cobb-Douglas production function that ensures that a one percent check-off levy generates an internal rate of return equal to $\overline{\text{IRR}}$. And $\hat{A}$ can be solved for using equation (3.28).

g	η \ λ	$\overline{IRR} = 0.3$			$\overline{IRR} = 0.25$			$\overline{IRR} = 0.2$			$\overline{IRR} = 0.15$		
		0.6	**0.7**	**0.8**	**0.6**	**0.7**	**0.8**	**0.6**	**0.7**	**0.8**	**0.6**	**0.7**	**0.8**
0	**0.6**	0.77	0.80	0.84	0.76	0.79	0.83	0.75	0.77	0.81	0.74	0.76	0.79
	0.7	0.79	0.83	0.89	0.78	0.81	0.87	0.77	0.80	0.85	0.76	0.78	0.82
	0.8	0.85	0.91	1.01	0.83	0.88	0.98	0.81	0.85	0.93	0.79	0.82	0.89
5	**0.6**	0.88	0.91	0.96	0.85	0.88	0.92	0.83	0.85	0.88	0.80	0.81	0.85
	0.7	0.90	0.94	1.02	0.87	0.91	0.97	0.84	0.87	0.93	0.81	0.83	0.88
	0.8	0.96	1.03	1.15	0.93	0.98	1.09	0.88	0.93	1.02	0.84	0.88	0.95
10	**0.6**	1.00	1.04	1.09	0.95	0.98	1.03	0.90	0.93	0.97	0.86	0.87	0.91
	0.7	0.79	1.08	1.16	0.98	1.02	1.09	0.92	0.96	1.01	0.87	0.89	0.94
	0.8	1.10	1.18	1.31	1.03	1.10	1.21	0.97	1.02	1.12	0.90	0.94	1.02
15	**0.6**	1.14	1.18	1.25	1.07	1.10	1.15	0.99	1.02	1.06	0.92	0.94	0.97
	0.7	1.18	1.23	1.32	1.09	1.14	1.21	1.01	1.05	1.11	0.93	0.96	1.01
	0.8	1.25	1.34	1.49	1.16	1.23	1.35	1.06	1.12	1.22	0.97	1.01	1.08

Figure 3.10: Calculated Values of $\hat{A}$

Source: Calculated by the author.
Note: $\hat{A}$ is the estimated value of parameter A in the Cobb-Douglas production function. It is calculated for different lag distributions under different treatments of $\overline{\text{IRR}}$ and gestation lag g.

Chapter 4

A Model of The World Pulse Market

4.1 Introduction

To examine the economic impacts of Canadian producer-funded R&D, the study develops a multi-region, multi-product partial equilibrium model of the world pulse market. Based on the evidence in Chapter 2, the model is divided into seven regions with Canada as the single pulse exporter and other regions as importers.

These seven regions are: Canada (c), India (i), China (h), Bangladesh (b), Turkey (t), the European Union (e), and the ROW (r). The model focuses on four crops: peas, lentils, wheat and canola. With this regional division, the impact of an increase in Canadian pea R&D investment can be determined on a region-by-region basis. In addition to capturing the international trade linkages, the model incorporates the relationship among peas, lentils, wheat and canola in both production and consumption within Canada.

To analyze the economic impacts of Canadian pulse innovation, it is necessary to specify the functional form of the behavioural functions and the appropriate spatial trade model. In this chapter, the demand functions are derived from indirect utility functions, while the supply functions are derived from indirect profit functions. The use of indirect utility and profit functions allows the calculation of changes in the economic surplus caused by increased Canadian pea R&D investment. Once the supply and demand curves are specified, the partial equilibrium trade model is constructed.

The outline of the chapter is as follows. Section 4.2 derives the demand functions for all seven regions (Canada, India, China, Bangladesh, Turkey, the European Union, and the ROW). Section 4.3 presents the derivation of supply functions in each region. Section 4.4 derives the function of economic surplus based on the indirect utility function and the indirect profit function. At last, the partial equilibrium model is presented in Section 4.5. Section 4.7 concludes the chapter.

4.2 Derivation of Demand Functions

Suppose there are n ($n \leq 5$) commodities (e.g., peas, lentils, wheat, and canola) and an aggregate good g in country s. Denoting the price of the aggregate good P_{gs} as the *numèraire* price, then the normalized price for good j is $p_{js} = P_{js}/P_{gs}$ ($j = 1, 2, ..., n$), and the normalized income is $m_s = M_s/P_{gs}$. Therefore, the budget constraint is $\sum_{j=1}^{n} p_{js}Q_{js}^d + Q_{gs}^d = m_s$, where Q_{js}^d is the demand for commodity j in country s. The indirect utility function can be derived from the following system of integrability equations:

$$\begin{aligned} \frac{\partial \mu(\boldsymbol{p};\boldsymbol{q},m)}{\partial p_i} &= x_i(\boldsymbol{p},\mu(\boldsymbol{p};\boldsymbol{q},m)) \qquad i = 1, \ldots, q \\ \mu(\boldsymbol{q};\boldsymbol{q},m) &= m \end{aligned} \tag{4.1}$$

where $\mu(\cdot)$ is the money metric indirect utility function, $\boldsymbol{q}$ and $\boldsymbol{p}$ are vectors for different prices (the detailed derivation is captured in Appendix A.2).

This study assumes the indirect utility function is Quasilinear. Thus, the demand function for crop j in country s, i.e., $Q_{js}^d(\boldsymbol{p}, m)$ can be specified as:

$$\begin{aligned} Q_{js}^d &= a_{js} + b_{js}p_{js} + b_{jis}p_{is} \\ Q_{is}^d &= a_{is} + b_{is}p_{is} + b_{ijs}p_{js} \end{aligned} \tag{4.2}$$

The symmetry of the substitution effects implies:

$$\frac{\partial Q_{js}^d}{\partial p_{is}} = \frac{\partial Q_{is}^d}{\partial p_{js}} \Rightarrow b_{jis} = b_{ijs} = b_s$$

Therefore, equation (4.2) can be rewritten as:

$$\begin{aligned} Q_{js}^d &= a_{js} + b_{js}p_{js} + b_s p_{is} \\ Q_{is}^d &= a_{is} + b_{is}p_{is} + b_s p_{js} \end{aligned} \tag{4.3}$$

The negative semidefiniteness of the Hessian matrix implies $b_{js} < 0, b_{is} < 0$, and $b_{js}b_{is} - b_s^2 > 0$.

Under the assumption that $P_{gs} = 1$, the demand function for crop j of importing country s is:

$$Q_{js}^d = a_{js} + b_{js}P_{js} + b_s P_{is} \tag{4.4}$$

Because both peas and lentils are used as food in importing countries such as India, China, and Bangladesh, the demand for peas (lentils) is also affected by the price of lentils (peas).

In Canada, the cross-price term between peas and lentils is zero, since peas are used for feed and lentils are used for food. Thus, the market demand function for commodity j in Canada is:

$$Q_{jc}^d = a_{jc} + b_{jc}P_{jc} \tag{4.5}$$

The detailed derivation of the demand functions expressed in elasticity form is shown in Appendix A.1.

4.3 Derivation of Supply Functions

To derive the supply functions, this study starts from a multi-product primal model. Suppose, in any one country, the production of crop j can be defined as

$$\begin{aligned} y_j &= f^j(x_j, L_j, \bar{K}_j), \quad j = \text{peas, lentils, wheat, and canola}, \\ & \textstyle\sum_j L_j = \bar{L} \end{aligned} \tag{4.6}$$

where $f(\cdot)$ is a strictly concave production function, and x_j is the quantity of aggregate conventional variable inputs such as labor, machinery, and capital. Let L_j be the quantity of land used in the production of j, and $\bar{L}$ the quantity of total productive units of land. Because land is fixed but allocatable, the total quantity of land $\bar{L}$ is fixed, while L_j is adjustable among different crops.

Let $\bar{K}_j$ represent the knowledge stock of agricultural production for crop j. It is fixed in any given year because it depends on the historical R&D investment and is not affected by current production decisions. As Alston et al. [2010] argued, the knowledge stock can be formulated as:

$$K_{jt} = \sum_{s=1}^{L_R} \omega_s E_{j(t-s)} \qquad \forall\, t \in [1, L_R] \tag{4.7}$$

where $\boldsymbol{\omega}$ is a vector of the lag weight, L_R is the overall time length that current R&D can affect the knowledge stock; parameter s is the number of years since the initial R&D investment. For simplicity, assume that all check-off revenues are used as the R&D investment, thus R&D expenditures E_t equals check-off revenues in any given year.

Canadian crop producers are price takers in the input and output markets. The objective of a farm in any given year is best described as a multi-product profit maximization problem, i.e.,

$$\max_{x_j,\, L_j} \Pi = \sum_j P_j(1 - l_j) f^j(x_j, L_j, \bar{K}_j) - P_x x_j \qquad \text{s.t.} \sum_j L_j = \bar{L} \tag{4.8}$$

where j represents one individual crop, i.e., $j =$ (peas, lentils, wheat, canola), under the assumption of only four major crops in the country. For any particular crop j, P_j is the output price, $P_j(1 - l_j)$ is the net output price after the check-off is paid, and P_x the price of the aggregate conventional input. Let $\bar{K}_j = (\bar{K}_p, \bar{K}_l, \bar{K}_w, \bar{K}_c)$ be the knowledge stock for peas, lentils, wheat and canola respectively, and $\bar{l}_j = (\bar{l}_p, \bar{l}_l, \bar{l}_w, \bar{l}_c)$ be the check-off ratio for these four crops respectively. Note that $l_p = l_l$ because pea and lentil production is subject to the same check-off ratio.

Forming the Lagrangian

$$\mathscr{L}_{x_j, L_j} = \sum_j P_j(1 - l_j) f^j(x_j, L_j, \bar{K}_j) - P_x x_j + \lambda(\bar{L} - \sum_j L_j)$$

Solutions to Max $\mathscr{L}$ in terms of x_j, L_j, and λ can be obtained by first-order conditions, i.e.,

$$\mathscr{L}_{x_j} = P_j(1 - l_j) f^j_{x_j}(x_j, L_j, \bar{K}_j) - P_x = 0 \tag{4.9a}$$

$$\mathscr{L}_{L_j} = P_j(1 - l_j) f^j_{L_j}(x_j, L_j, \bar{K}_j) - \lambda = 0 \tag{4.9b}$$

$$\mathscr{L}_{\lambda} = \bar{L} - \sum_j L_j = 0 \tag{4.9c}$$

Solving the first-order conditions simultaneously gives the input demand and output supply functions which are functionally related to all output prices, variable input prices, and total available quantity of the fixed or exogenous input – land and knowledge stock. Therefore,

$$x^*_j = x^*_j(\boldsymbol{P}(1 - \boldsymbol{l}), P_x, \bar{L}, \bar{\boldsymbol{K}}) \tag{4.10a}$$

$$L^*_j = L^*_j(\boldsymbol{P}(1 - \boldsymbol{l}), P_x, \bar{L}, \bar{\boldsymbol{K}}) \tag{4.10b}$$

$$\lambda^* = \lambda^*(\boldsymbol{P}(1 - \boldsymbol{l}), P_x, \bar{L}, \bar{\boldsymbol{K}}) \tag{4.10c}$$

where $\boldsymbol{P} = (P_p, P_l, P_w, P_c)$ is a vector of output prices, $\boldsymbol{l} = (l_p, l_l, l_w, l_c)$ is a vector of check-off ratio, and $\bar{\boldsymbol{K}} = (\bar{K}_p, \bar{K}_l, \bar{K}_w, \bar{K}_c)$ is a vector of knowledge stock. Equation (4.10a) is the demand function for the aggregate conventional input, and equation (4.10b) is the input demand for land used for each individual crop. Under the assumption of a concave production function, the second-order sufficient conditions are satisfied, and land exhibits diminishing marginal product, decreasing its marginal value as more land is employed. Input demand functions are functions of all exogenous variables such as input output prices, check-off ratio, total amount of land, and the knowledge stock. The cost of land is endogenously determined by the shadow value of the land constraint in the model.

Substituting equations (4.10a) and (4.10b) into the production function (equation 4.6) gives the output supply for each crop as:

$$y^*_j = y^*_j(\boldsymbol{P}(1 - \boldsymbol{l}), P_x, \bar{L}, \bar{\boldsymbol{K}}) \tag{4.11}$$

Substituting the input demand and output supply functions into the profit function (4.8) gives the indirect profit function as

$$\Pi^* = \Pi^*(\boldsymbol{P}(1 - \boldsymbol{l}), P_x, \bar{L}, \bar{\boldsymbol{K}}) \tag{4.12}$$

Functional Form of The Indirect Profit Function

Following Shumway et al. [1987] and Huffman and Evenson [1989], a normalized quadratic indirect profit function is used to derive a set of linear supply functions. The indirect profit function shows the profits of a farmer that produces four crops – peas, lentils, wheat, and canola.

Assuming that the price of the aggregate conventional input is P_x, the normalized net output prices can be specified as $p_j = (P_j/P_x)$, $(j = 1, ..., 4)$. Thus, the normalized indirect profit function can be written as $\pi = g(\boldsymbol{p}(1 - \boldsymbol{l}), \bar{L}, \bar{\boldsymbol{K}})$, where $\boldsymbol{p}$ is a vector of normalized output prices. Assuming a quadratic form, the normalized indirect profit function can be specified as:

$$\begin{aligned}\pi = \quad & \phi_0 + \sum_{j=1}^{4} \phi_j p_j(1 - l_j) + \sum_{n=1}^{5} \rho_n z_n + \frac{1}{2} \sum_{i=1}^{4} \sum_{j=1}^{4} \beta_{ij} p_i (1 - l_i) p_j (1 - l_j) \\ & + \tfrac{1}{2} \sum_{m=1}^{5} \sum_{n=1}^{5} \gamma_{mn} z_m z_n + \sum_{j=1}^{4} \sum_{n=1}^{5} \rho_{jn} p_j (1 - l_j) z_n \end{aligned} \tag{4.13}$$

where z_n $(n = 1..., 5)$ is a vector of fixed inputs of $\bar{L}, \bar{K}_p, \bar{K}_l, \bar{K}_w, \bar{K}_c$ respectively. The linear output supply functions of crop j can be derived from equation (4.13) using Hotelling's Lemma, i.e.,

$$Q_j^s = \phi_j + \sum_{i=1}^{4} \beta_{ij} p_i (1 - l_i) + \sum_{n=1}^{5} \rho_{jn} z_n \qquad j = 1, ..., 4 \tag{4.14}$$

Because the indirect profit function is twice continuous differentiable and its partial derivatives are invariant to the order of the differentiation, the slope of the supply functions are such that $\beta_{ij} = \beta_{ji}$ $(i \neq j; i, j = 1, ..., 4)$.

The convexity of the indirect profit function with respect to prices means that $\beta_{ij} > 0$, $(i = j; i, j = 1, ..., 4)$, which indicates that the own price elasticity ϵ_j is positive. The sign of the coefficient on the cross term of the price, i.e., β_{ij}, is determined by the cross price elasticity ϵ_{ij}. With a fixed amount of land, the four specified crops are substitutes because more land used for growing one crop reduces the land allocated to other crops. Therefore, $\epsilon_{ij} < 0$ $(i \neq j)$, and hence $\beta_{ij} < 0$ $(i \neq j)$.

In equation (4.14), because $\bar{L}$, $\bar{K}_l$, $\bar{K}_w$, and $\bar{K}_c$ are fixed, for simplicity, they can be subsumed into the constant term, i.e., $\alpha_j = \phi_j + \rho_{j1}\bar{L} + \rho_{j3}\bar{K}_l + \rho_{j4}\bar{K}_w + \rho_{j5}\bar{K}_c$. Therefore, under the assumption that $P_x = 1$, the output supply function for crop j in Canada can be derived as:

$$Q^s_{jc} = \alpha_{jc} + \sum_{i=1}^{4} \beta_{jic} P_{ic}(1 - l_i) + \rho_{jpc}\bar{K}_{pc} \tag{4.15}$$

where P_{ic} is the output price in Canada. The sign and magnitude of $\rho_{jpc}\bar{K}_{pc}$ determines how pea R&D investment affects the supply functions of the other crops in Canada; this will be discussed in section 5.4.3 of Chapter 5 .

The indirect profit function approach can also be used to determine the output supply functions in importing country s for crop j, i.e.,

$$Q^s_{js} = \alpha_{js} + \sum_{i=1}^{k} \beta_{jis} P_{is} \tag{4.16}$$

where subscript s represents the importing country, and k is the number of crops planted in the importing country. The difference between equation (4.15) and equation 4.16 is that pea production in the importing countries is not affected by the knowledge stock; this specification reflects the assumption that the development of new varieties in Canada does not affect the yield in the importing countries.

The responsiveness of the output supply to changes in prices can be interpreted in elasticities, and the detailed derivation is included in the Appendix A.1. Equation (4.15) and (4.16) will be used to form the partial equilibrium model in the later part of this chapter.

4.4 Derivation of Economic Surplus

4.4.1 Consumer Surplus

When the utility function is Quasilinear, changes in consumer surplus can be used to provide an accurate measure of the welfare change resulting from price changes – i.e., the change in consumer surplus is equal to both the compensating variation and the equivalent variation (Varian

[1992], p163). The change in consumer surplus in country s can be calculated as follows (the detailed derivation is presented in Appendix A.3):

$$\begin{aligned}\Delta\text{CS}_s &= \mu(\boldsymbol{q}_s;\boldsymbol{p}_s^1,m_s)-\mu(\boldsymbol{q}_s;\boldsymbol{p}_s^0,m_s)\\ &= a_{ps}(p_{ps}-p_{aps})-\tfrac{1}{2}b_{ps}(p_{ps}^2-p_{aps}^2)+b(p_{ps}p_{ls}-p_{aps}p_{als})+a_{ls}(p_{ls}-p_{als})\\ &\quad -\tfrac{1}{2}b_{ls}(p_{ls}^2-p_{als}^2)\end{aligned} \tag{4.17}$$

Under the assumption that $P_{gs}=1$, equation (4.17) can be rewritten as:

$$\begin{aligned}\Delta\text{CS}_s &= a_{ps}(P_{ps}-P_{aps})-\tfrac{1}{2}b_{ps}(P_{ps}^2-P_{aps}^2)+b(P_{ps}P_{ls}-P_{aps}P_{als})+a_{ls}(P_{ls}-P_{als})\\ &\quad -\tfrac{1}{2}b_{ls}(P_{ls}^2-P_{als}^2)\end{aligned} \tag{4.18}$$

where $\boldsymbol{P}_{a\cdot s}$ is the equilibrium price after the change in R&D investment and $\boldsymbol{P}_{\cdot s}$ is the initial equilibrium price before the change in R&D investment.

In the case of Canada, the change in consumer surplus in Canada is:

$$\begin{aligned}\Delta\text{CS}_c &= \mu_c(\boldsymbol{p}_c^0;\boldsymbol{p}_c^1,m_c)-\mu_c(\boldsymbol{p}_c^0;\boldsymbol{p}_c^0,m_c)\\ &= a_{pc}(p_{pc}-p_{apc})-\tfrac{1}{2}b_{pc}(p_{pc}^2-p_{apc}^2)+a_{lc}(p_{lc}-p_{alc})-\tfrac{1}{2}b_{lc}(p_{lc}^2-p_{alc}^2)\\ &\quad +a_{wc}(p_{wc}-p_{awc})-\tfrac{1}{2}b_{wc}(p_{wc}^2-p_{awc}^2)+a_{cc}(p_{cc}-p_{acc})-\tfrac{1}{2}b_{cc}(p_{cc}^2-p_{acc}^2)\end{aligned} \tag{4.19}$$

Under the assumption that $P_{gc}=1$ and that the prices for wheat and canola are fixed (Canada is assumed to be a small country in the wheat and canola markets), equation (4.19) can be rewritten as:

$$\Delta\text{CS}_c = a_{pc}(P_{pc}-P_{apc})-\frac{1}{2}b_{pc}(P_{pc}^2-P_{apc}^2)+a_{lc}(P_{lc}-P_{alc})-\frac{1}{2}b_{lc}(P_{lc}^2-P_{alc}^2) \tag{4.20}$$

4.4.2 Producer Surplus

The change in producer surplus in the case of multiple outputs is calculated as the difference in the normalized indirect profit function after and before the increase in pea R&D investment. For Canada, the change in producer surplus is:

$$\begin{aligned}
\Delta \mathrm{PS}_c &= \pi(\boldsymbol{p}_{ac}) - \pi(\boldsymbol{p}_c) \\
&= \sum_{j=1}^{4} \phi_{jc}(p_{ajc}(1-l_{ajc}) - p_{jc}(1-l_{jc}) + \sum_{n=1}^{5} \rho_{nc}(z_{anc} - z_{nc}) \\
&+ \frac{1}{2}\sum_{i=1}^{4}\sum_{j=1}^{4} \beta_{ijc}(p_{aic}(1-l_{aic})p_{ajc}(1-l_{ajc}) - p_{ic}(1-l_{ic})p_{jc}(1-l_{jc})) \\
&+ \frac{1}{2}\sum_{m=1}^{5}\sum_{n=1}^{5} \gamma_{mnc}(z_{amc}z_{anc} - z_{mc}z_{nc}) + \sum_{j=1}^{4}\sum_{n=1}^{5} \rho_{jnc}(p_{ajc}(1-l_{ajc})z_{anc} - p_{jc}(1-l_{jc})z_{nc})
\end{aligned} \tag{4.21}$$

where $\pi(\boldsymbol{p}_c)$ and $\pi(\boldsymbol{p}_{ac})$ represent, respectively, the producer surplus before and after an increase in pea R&D investment, $\boldsymbol{p}_{ajc}$ is the vector of equilibrium prices after the increase in pea R&D investment, $z_{\cdot c}$ is the fixed factor before the R&D, and $z_{a \cdot c}$ is the fixed factor after the R&D.

Because the fixed factors and the knowledge stock in the importing countries remain unchanged (and assuming $P_x = 1$), the change in producer surplus in country s is:

$$\begin{aligned}
\Delta \mathrm{PS}_s &= \pi(\boldsymbol{p}_{as}) - \pi(\boldsymbol{p}_s) \\
&= \sum_{j=1}^{k} \phi_{js}(P_{ajs} - P_{js}) + \frac{1}{2}\sum_{i=1}^{k}\sum_{j=1}^{k} \beta_{ijs}(P_{ais}P_{ajs} - P_{is}P_{js}) + \sum_{j=1}^{k}\sum_{n=1}^{3} \rho_{jns}z_{ns}(P_{ajs} - P_{js})
\end{aligned} \tag{4.22}$$

4.5 The Partial Equilibrium Model

Using equations (4.5), (4.4), (4.15), and (4.16), the multi-region, multi-product partial equilibrium model (PEM) can be specified as:

$$
\begin{aligned}
Q^d_{jc} &= a_{jc} + b_{jc}P_{jc} \\
Q^d_{js} &= a_{js} + b_{js}P_{js} + b_s P_{is} \\
Q^s_{jc} &= \alpha_{jc} + \textstyle\sum_{i=1}^{4} \beta_{jic}P_{ic}(1-l_i) + \rho_{jpc}\bar{K}_{pc} \\
Q^s_{js} &= \alpha_{js} + \textstyle\sum_{i=1}^{k} \beta_{jis}P_{is} \\
Q^d_{jc} + \textstyle\sum_{s=1}^{6} Q^d_{js} &= Q^s_{jc} + \textstyle\sum_{s=1}^{6} Q^s_{js} \\
P_{js} &= P_{jc} + \tau_{js}
\end{aligned}
\tag{4.23}
$$

where j indicates the crop (peas, lentils, wheat, and canola), s represents the importing countries (India, China, Bangladesh, Turkey, EU, and ROW), c represents Canada, and τ is a spatial price differential that captures the transportation costs and trade policy distortions. The first two equations are the demand functions for Canada and other importing countries, respectively; the third and fourth equations are the supply functions for Canada and the importing countries; the fifth equation is the world market equilibrium condition for crop j; and the last equation captures the transportation costs and trade policy distortions. The detailed mathematical derivation for the partial equilibrium model is derived in Appendix A.4.

4.6 The Dynamic Partial Equilibrium Model

The dynamic partial equilibrium model is specified when market clears in each time period with the change of the knowledge stock caused by the change of R&D investment. Thus, in any given period t, the multi-region, multi-product dynamic partial equilibrium model can be derived as:

$$\begin{aligned}
Q^d_{jct} &= a_{jc} + b_{jc}P_{jct} \\
Q^d_{jst} &= a_{js} + b_{js}P_{jst} + b_s P_{ist} \\
Q^s_{jct} &= \alpha_{jc} + \textstyle\sum_{i=1}^{4} \beta_{jic}P_{ict}(1 - l_i) + \rho_{jpc}\bar{K}_{pct} \\
Q^s_{jst} &= \alpha_{js} + \textstyle\sum_{i=1}^{k} \beta_{jis}P_{ist} \\
Q^d_{jct} + \textstyle\sum_{s=1}^{6} Q^d_{jst} &= Q^s_{jct} + \textstyle\sum_{s=1}^{6} Q^s_{jst} \\
P_{jst} &= P_{jct} + \tau_{jst}
\end{aligned} \tag{4.24}$$

where the subscript t represents time period. For simplicity, this study assumes that the elasticities for the short-run and long-run are the same.

4.7 Concluding Remarks

This chapter developed two models: a multi-region, multi-product partial equilibrium model, and a dynamic partial equilibrium model. The models capture the economic impacts of a change in the current check-off ratio for Canadian pea R&D investment on different regions and different group of agents (producers and consumers).

The linear demand functions are derived from a well-behaved indirect utility function – the normalized quasi-linear function. While the linear supply functions are derived from a normalized quadratic indirect profit function that satisfies the economic properties. Based on the derived demand and supply functions for each region, a partial equilibrium model is developed to capture the world pulse trade conditions. Thereafter, a dynamic partial equilibrium model is developed to calculate the IRR to Canadian producers. The dynamic model provides a theoretical background for the empirical calibration in the next chapter. The detailed empirical analysis of welfare and production effects caused by the increase of Canadian pea R&D investment can be seen in the following chapter.

Decisions of Producer-Funded Agricultural Research and Development

The analysis in this chapter is based on the assumption of no spillovers across levy programs. This assumption can be relaxed in further studies, where producers of other crops can free-ride the benefits generated by pulse producers' R&D investment. A new model can be developed to show how the spillover issue can affect the research benefit to pulse growers, hence their R&D investment decisions.

Chapter 5

The Returns of Canadian Producer-Funded R&D

5.1 Introduction

Producer check-offs are an important source of agricultural R&D funding that can be used to address the shortfalls of declining public funding and incomplete intellectual property rights for private funding. Producer funding provides direct benefits to producers through applied agricultural research such as disease management, genetic improvement, and weed control. Moreover, producer levies are an efficient way to fund agricultural R&D because taxing producers directly costs the society less than taxing the general population [Alston et al., 2004].

Examples of producer involvement in R&D funding can be found in Australia and Canada. In Australia, the Australian Grain Research and Development Corporation (GRDC) is funded by a mandatory non-refundable levy of 0.99 percent of the farm value matched by a maximum 0.5 percent of government funding. In wheat, for instance, basic science research is funded by the GRDC, while variety development is funded by private-public partnerships that raise funds through an End Point Royalty (EPR) collected on new varieties.

In Canada, a number of different sectors have established check-offs to fund R&D. For instance, the Saskatchewan Pulse Growers (SPG) uses a mandatory non-refundable levy of one percent of the gross sales value that is deducted at the first point of sale. Farmers who pay the check-off are automatically enrolled as registered SPG members and given the right to vote for the SPG board.

As one of the major crops of western Canada, pulses have been widely planted by prairie farmers due to the need for crop rotation. As well, the R&D investment of Canadian pulse industry has dramatically increased from $Cdn 1.02 million in 2002 to $Cdn 6.11 million in 2012 (both figures in nominal terms) [SPG, 2013]. Given that Canada is the largest pulse exporter in the world, as discussed in chapter 2, such an increase in R&D investment can be expected to have a significant impact on international trade and overseas producers and consumers. Therefore, an important question is who benefits from the research benefits, and who bears the cost. How would the allocation of research benefits and costs influence the R&D investment decisions.

5.2 Research Objectives

The purpose of this chapter is to empirically examine the distribution of R&D benefits and costs between producers and consumers in Canada and its trading partners, and then to use these results to determine the internal rate of return of R&D expenditures made by Canadian producers. Specifically, the study examines how the economic returns to buyers and sellers in the world are affected by R&D investment in Canada. Examining the global impacts is becoming increasingly important as issues of food security receive greater attention [Rosegrant et al., 2013]. For instance, while R&D is beneficial for Canadian pulse growers, it is important to determine its impact on farmers in the developing countries that are the largest purchasers of pulses grown in Canada. The results of this chapter are also used to determine the IRR obtained by Canadian farmers that invest in pulse research, and how this IRR is affected by the horizon problem.

This study explicitly specifies the linkage among the check-off ratio, R&D investment, and knowledge stock. The study also captures the lagged R&D benefits that over a number of periods as a result of an increase in investment.

To undertake this analysis, it is necessary to choose a particular crop, since the answers to the questions posed above are expected to differ depending on the characteristics of the crop in question (e.g., degree of export exposure, importance in the world market, elasticities of demand and supply). Peas are selected for the analysis because Canada is the largest exporter of peas in the world. As a result, the added production from agricultural R&D investment will necessarily affect the world price and thus the economic surplus of both domestic and foreign consumers and producers.

The research will be carried on in the following steps. First, the study examines the impact of an increase in Canadian pea R&D investment on prices and quantities in Canada and around the world. Second, the study examines the impact of agricultural R&D on the distribution of producer and consumer surplus in various regions. Third, knowledge of the economic surplus changes on Canadian producers is used to determine the rate of return to R&D funding decisions. Fourth, the sensitivity analysis is conducted to compare the impact on IRR to Canadian producers in the case of small country versus large country. Fifth, the horizon problem is re-examined under the condition of multi-product Canadian farmers in an open economy.

To examine the above impacts the study develops a multi-region, multi-product partial equilibrium model of the world pulse industry. In addition to capturing the international trade linkages, the model incorporates the relationship among peas, lentils, wheat, and canola in production within Canada. In the model, an increase in R&D investment has a lagged impact on the knowledge stock that lasts over a number of periods.

An important assumption of the analysis is that there are no spatial knowledge spillovers across territories. This assumption is made because Canadian technology is not usually applicable to importing regions, such as Asia and EU, due to the very different geographical conditions present in those regions. In addition, we also assume no spatial knowledge spillovers among provinces in Canada. According to the Saskatchewan Pulse Growers Annual Report, more than 90 percent of Canadian pulses are produced in Saskatchewan (Saskatchewan Pulse Growers Annual Report). Thus, the model effectively assumes that all Canadian production comes from Saskatchewan.

5.3 A Framework for The Analysis

The analysis starts by constructing a multi-region, multi-product partial equilibrium model that captures the market connections between different crops and different regions over time. To examine the economic impacts of Canadian pea innovation, the model is divided into seven regions (Canada, India, China, Bangladesh, Turkey, EU, and ROW), and focused on four crops (peas, lentils, wheat and canola).

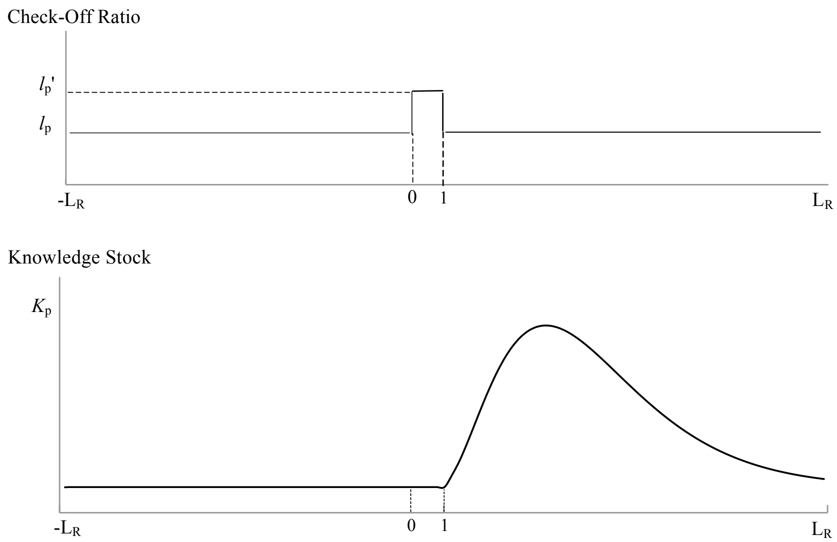


Figure 5.1: Changes in Knowledge Stock and Check-Off Ratio for The Dynamic PEM

Source: Developed by the author.

As Figure 5.1 shows, this study assumes the check-off ratio increases from l_p to l_p' at period $t = 0$ and it then returns to the original level l_p at period $t = 1$ and all remaining periods. The marginal costs MC_0 of a change of the check-off ratio occurs in period $t = 0$, while the marginal benefits MB_t occur in period $t \in [1, L_R]$ under the assumption of a zero gestation lag.

The specification of this model examines the case of a pivotal supply shift that generates the R&D cost and a parallel supply shift that generates the R&D benefit. The pivotal supply shift for R&D cost is because the check-off is collected as a percentage of total sales. The parallel supply shift as a result of R&D expenditure follows the standard modelling of R&D – see, for instance, Alston et al. [2004]. The pattern of the supply shift and the simulation results will be discussed in depth in Section 5.5.

The marginal costs MC_0 and marginal benefits MB_t in each period are determined through the partial equilibrium trade model. The net impact of the change in the check-off ratio on Canadian producers is derived as the net present value of producer surplus with increased check-off ratio

(PS'_t) minus the NPV of producer surplus with unchanged current check-off ratio (PS_t), i.e., $\mathrm{NPV}(\mathrm{PS}'_t - \mathrm{PS}_t)$. The benchmark for all calculations is the market equilibrium condition with unchanged check-off ratio.

The internal rate of return – $\overline{\mathrm{IRR}}$ – calculated over the benefit horizon is given by the solution to $\sum_{t=0}^{L_R}(\mathrm{PS}'_t - \mathrm{PS}_t)/(1+\overline{\mathrm{IRR}})^t = 0$, where L_R is the total lag length for research. However, the internal rate of return – IRR_h – calculated over the farmers' membership horizon is given by $\sum_{t=0}^{T}(\mathrm{PS}'_t - \mathrm{PS}_t)/(1+\mathrm{IRR}_h)^t = 0$, where T is the membership horizon. A comparison of IRR_h with $\overline{\mathrm{IRR}}$ determines the significance of the horizon problem.

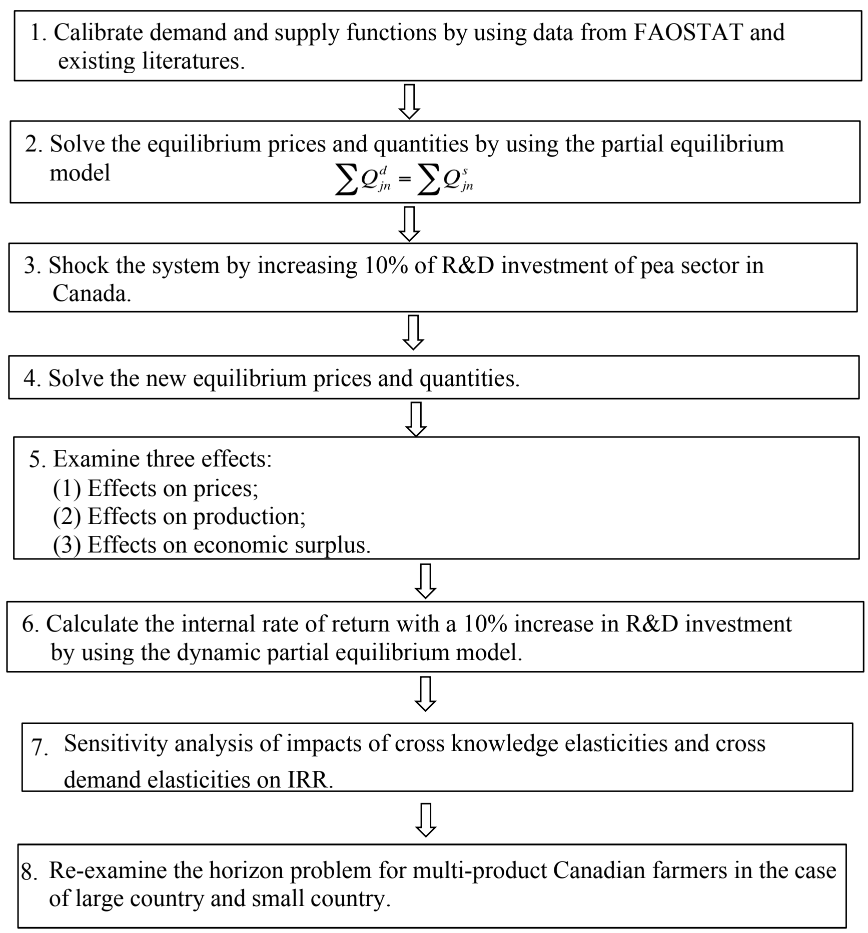


Figure 5.2: Research Framework

As Figure 5.2 shows, this study first calibrates the demand and supply functions, based on the theoretical model in Chapter 4, by using price and quantity data from FAOSTAT, and elasticities from the existing literature. Once the behavioural functions are calibrated, the model is solved for the equilibrium prices and quantities in different regions and for different crops. The worldwide impact of an increase in Canadian R&D spending on peas is then examined by shocking the system with a 10 percent increase in the R&D investment by the Canadian pea industry. Based on this shock, new market equilibrium outcomes for the following 50 years are determined. The new equilibria allow the comparative analysis of the change in prices, demand and supply quantities, and economic surplus to be carried out. Using the producer surplus changes for Canadian farmers, the internal rate of return is calculated. A sensitivity analysis is conducted to compare the impact on IRR to Canadian producers by adjusting the baseline values of the key parameters in the model, such as the cross knowledge elasticities, overseas cross demand elasticities, and demand elasticity for peas and lentils for the large country case and small country case respectively. Finally, the horizon problem is re-examined in the case of large country and small country respectively.

5.4 Simulation of The Effects of Canadian Producer-Funded R&D

5.4.1 The Simulation Procedure

The simulation procedure is captured in Figure 5.3 with the international trade market linkages for peas. Figure 5.3 only illustrates the pea market. In the simulation model, four markets – peas, lentils, wheat, and canola – are considered, as well as the feedbacks among these markets. The Canadian pea market is depicted in panel (a) and the pea markets in the importing countries are depicted in panel (c).

In panel (a), S is the supply curve for Canadian peas prior to the introduction of a checkoff and S_{pc} is the supply with the current check-off ratio of one percent of total revenue. The pivotal shift from S to S_{pc} occurs because the check-off is collected as a percentage of total sales.

With a one percent check-off ratio, the market price is P_{pc} and EQ amount of peas are exported to other countries. Given a one percent check-off ratio, the post-levy producer surplus is the area E_0GP_{pc} and the R&D investment is the purple area E_0FKP_{pc}.

Suppose the R&D investment increases by 10 percent (this is equivalent to a 10 percent increase in the knowledge stock). To get this increase in R&D investment requires an increase in the check-off ratio by more than 10 percent. With this increase in the check-off ratio, the supply curve shifts from S_{pc} to S'_{pc}. The new R&D investment is represented by the green area CBIP'_{pc}; it is ten percent larger than the purple area. With this increased R&D investment, the market price increases from P_{pc} to P'_{pc}, and ΔQ amount of peas will be exported. The increased market price means that consumers (both domestic and overseas) bear a portion of the R&D costs as well. The cost to Canadian producers of making this research investment is the loss of the producer surplus after the increase of the check-off ratio, i.e., area CDP'_{pc} minus area $\mathrm{E_0GP}_{pc}$.

As Figure 5.1 shows, the check-off ratio increases only at period $t = 0$; after $t = 0$, the supply curve shifts back from S'_{pc} to S_{pc}. The larger R&D investment results in higher productivity and causes a parallel shift of the supply curve from S_{pc} to S''_{pc}. The new market equilibrium price is P''_{pc} and EQ'' peas are exported. At the new equilibrium, the producer surplus is the area $\mathrm{E_1JP}''_{pc}$. The net R&D benefit to Canadian producers is the difference in the producer surplus before and after the increase R&D investment, i.e., area $\mathrm{E_1JP}''_{pc}$ minus area $\mathrm{E_0GP}_{pc}$.

Panel (b) represents the traded quantities, where ED_p represents the excess demand from the importing countries and ED_{pc} is the excess demand at the Canadian port faced by Canadian producers. The difference between ED_p and ED_{pc} is the transportation cost t from Canada to the import market. As a result of the increased Canadian R&D investment, the excess supply curve from Canada increases from ES'_p to ES''_p in panel (b). The increased R&D results in the market price in the importing country (panel (c)) falling from $P_{pc} + t$ to $P''_{pc} + t$; IQ'' peas are imported, with $\mathrm{EQ}'' = \mathrm{IQ}''$. In terms of welfare, consumers in the importing countries gain area $a + b$, while producers in the importing countries lose area a. The net gain of importing countries is area b in panel (c).

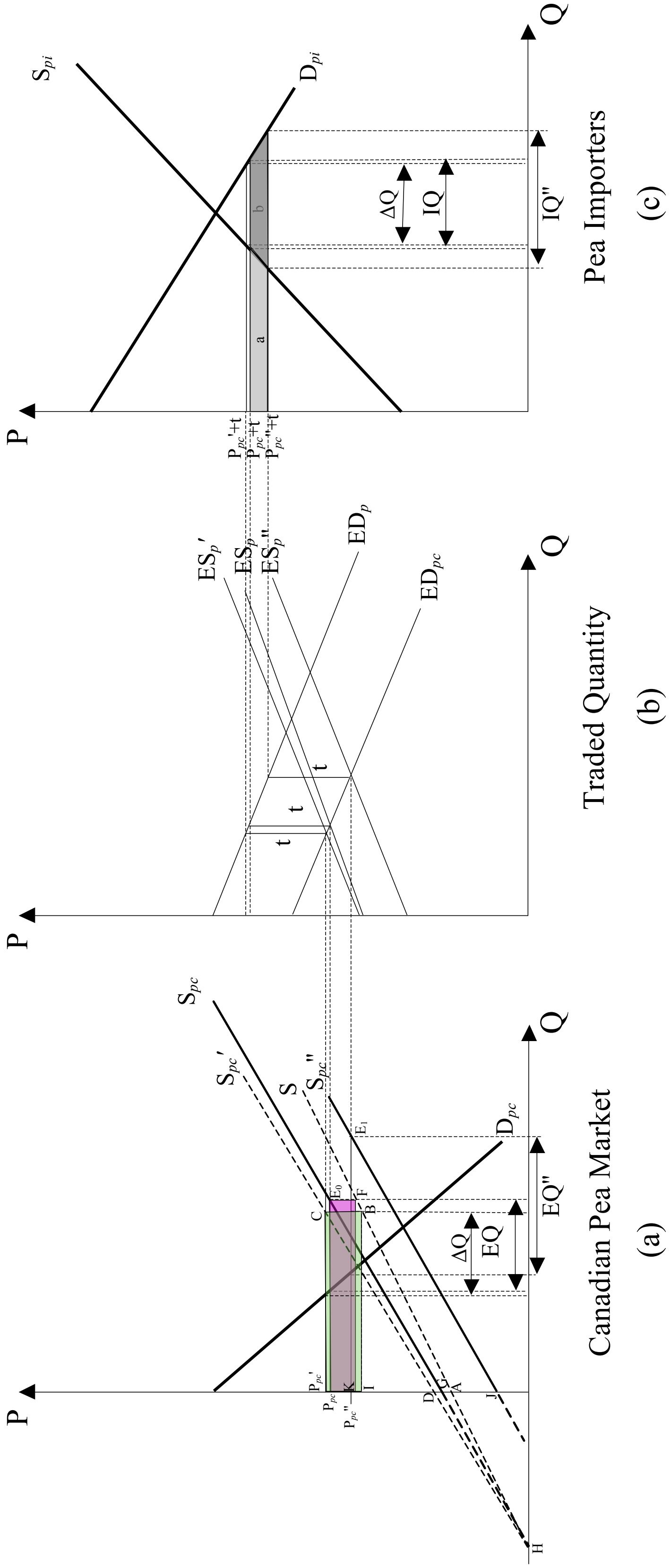


Figure 5.3: Impact of Canadian Pea Innovation on Global Pea Markets

Source: Developed by the author.

5.4.2 Data Description

Prices and Quantities of Demand and Supply

The price and quantity data used in this chapter are from FAOSTAT 2009. Table 5.1 reports the baseline value of prices and quantities in each region for dry peas, lentils, wheat, and canola respectively. The baseline prices for the model are the Canadian market prices for these four crops, which are measured in $US per ton. Consumer prices in overseas regions are assumed to be the importing price – i.e., the value of imports divided by the imported quantity.

Transportation Costs

Transportation costs and the possible effects of import policies are assumed to be captured by τ_i, the spatial price differentials between the importing country i and Canada. The values of the transportation costs are shown in Table 5.2. For instance, the transportation cost and import policy wedge between Canada and India is represented as $\tau_i = P_i - P_c$, where P_i is the market price in India, and P_c is the market price in Canada. Furthermore, for simplicity, unit transportation costs (and trade policy effects) are assumed to be on a per unit basis. The cost τ_i is assumed to be constant in the model.

5.4.3 Specification of Key Parameters and Variables

The key parameters and variables in the model are lag weight distribution, price elasticities, knowledge stock, and knowledge elasticities.

Lag Weight Distribution

As Chapter 3 indicates, the parameters of the lag weight of research benefits are crucial in determining the horizon IRR to producers within the limited membership horizon. Following Alston et al. [2010], this analysis assumes the lag weights have a gamma distribution described by parameters η and λ. Specifically, it is assumed that the lag weight for Canadian pulse crops has $\eta = 0.7$ and $\lambda = 0.85$, with a peak year of 13 years (see figure 5.4).[1] The maximum lag length L_R is assumed to be 50 years, while the gestation lag $g = 0$.

[1] The lag for pulse research is relatively short because it is applied research and its peak year is about nine to 15 years according to the conversation with the agronomist at the Crop Development Centre.

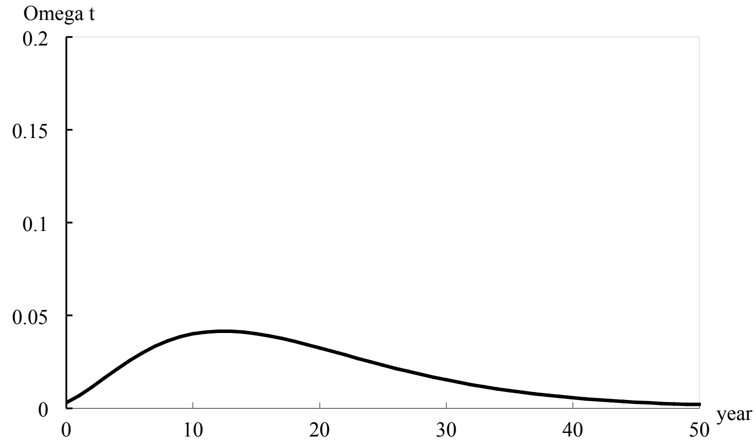


Figure 5.4: Lag Weight Distribution

Source: Developed by the author according to Alston et al. [2010].

Price Elasticities

The slope and intercept parameters of the demand and supply functions in each region are obtained from the local elasticities and the baseline price and quantity data from FAOSTAT 2009. Two relevant price elasticities used in this analysis are the own price elasticity of demand and supply, and the cross price elasticity of supply and demand. The value of these elasticities are provided in table 5.3.

Own Price Elasticity – As Table 5.3 shows, the price elasticities of demand and supply used in the model are taken from the existing literature, such as Davis et al. [1987] and Meilke et al. [2001]. Where elasticities were not available assumptions were made to provide them reasonable values. For instance, the data of demand elasticities of pulses in Turkey and the ROW are unavailable, and they were assumed to equal to the demand elasticities of Asian countries. The same criteria is used to deal with the supply elasticities as well. The detailed parametric specification can be seen in table 5.3.

Cross Price Elasticity – The cross price elasticities used in the model are taken from the existing literature or are based on assumptions consistent with this literature. For instance, values of cross price elasticities of peas and lentil for importing countries are assumed as 0.2 with India as an exception of 0.6. Such an assumption is made based on the Indian tradition of food consumption that peas and lentils have a relatively higher substitution effects than other importing countries.

The symmetry of the Hessian matrix for the normalized quasi-linear utility function indicates $b_{ij} = b_{ji}$. Therefore, the cross price demand elasticity of product j with respect to product i (η_{ji}) is linked to b_{ij} through the relationshiip $\eta_{ji} = b_{ij}\frac{P_i}{Q_j^d}$. On the supply side, the normalized quadratic profit function is twice continuous differentiable and according to Young's Theorem, $\beta_{ij} = \beta_{ji}$. Therefore, the cross price supply elasticity of product j with respect to product i (η_{ji}) is linked to β_{ij} through the relationshiip $\epsilon_{ji} = \beta_{ij}\frac{P_i}{Q_j^s}$. The values of the cross price elasticities are presented in table 5.3.

Table 5.1: Initial Values of Prices, Quantities, and Knowledge Stock in The Model

	Canada	India	China	Bangladesh	Turkey	EU	ROW
Price				*US dollars per tonne*			
Dry peas	198.39	323.74	295.01	277.62	1142.30	408.97	521.81
	(P_{pc})	(P_{pi})	(P_{ph})	(P_{pb})	(P_{pt})	(P_{pe})	(P_{pr})
Lentils	595.61	776.49	415.37	980.84	943.32	1,043.46	898.35
	(P_{lc})	(P_{li})	(P_{lh})	(P_{lb})	(P_{lt})	(P_{le})	(P_{lr})
Wheat	211.58	–	–	–	–	–	–
	(P_{wc})						
Canola	411.52	–	–	–	–	–	–
	(P_{cc})						
Demand Quantity				*thousands of tonnes*			
Dry peas	811	2,405	1,349	501	6	1,827	3,488
	(Q^d_{pc})	(Q^d_{pi})	(Q^d_{ph})	(Q^d_{pb})	(Q^d_{pt})	(Q^d_{pe})	(Q^d_{pr})
Lentils	280	1,241	105	239	314	192	1,409
	(Q^d_{lc})	(Q^d_{li})	(Q^d_{lh})	(Q^d_{lb})	(Q^d_{lt})	(Q^d_{le})	(Q^d_{lr})
Wheat	7,320	–	–	–	–	–	–
	(Q^d_{wc})						
Canola	4,938	–	–	–	–	–	–
	(Q^d_{cc})						
Supply Quantity				*thousands of tonnes*			
Dry peas	3,379	750	960	12	4	1,399	3,883
	(Q^s_{pc})	(Q^s_{pi})	(Q^s_{ph})	(Q^s_{pb})	(Q^s_{pt})	(Q^s_{pe})	(Q^s_{pr})
Lentils	1,510	953	120	61	302	32	800
	(Q^s_{lc})	(Q^s_{li})	(Q^s_{lh})	(Q^s_{lb})	(Q^s_{lt})	(Q^s_{le})	(Q^s_{lr})
Wheat	26,848	–	–	–	–	–	–
	(Q^s_{wc})						
Canola	12,889	–	–	–	–	–	–
	(Q^s_{cc})						
Knowledge Stock[1]				*US dollars*			
	6,703,510	–	–	–	–	–	–
	(K_{pc})						

Source: FAOSTAT 2009.

[1]Calculated according to equation (5.1).

Table 5.2: Transportation Costs and Exchange Rate

	Canada	India	China	Bangladesh	Turkey	EU	ROW
				US dollars			
Transportation Costs & Policy Effects[1]							
Dry Peas	–	125.36	96.62	79.23	943.91	210.58	323.42
		(t_{pi})	(t_{ph})	(t_{pb})	(t_{pt})	(t_{pe})	(t_{pr})
Lentils	-	180.88	-180.23	385.24	347.72	447.85	302.75
		(t_{li})	(t_{lh})	(t_{lb})	(t_{lt})	(t_{le})	(t_{lr})
Exchange Rate[2]	0.88	–	–	–	–	–	–

Source: [1]Calculated as the spatial price difference based on the data from FAOSTAT 2009.
[2]CAD/US$, Bank of Canada 2009.

Table 5.3: Model's Parameters and Their Baseline Values

Description	Parameter	Base Values						
		Canada	India	China	Bangladesh	Turkey	EU	ROW
Demand Elasticity								
Dry peas	η_p	-0.79[1]	-0.75[1]	-0.75[1]	-0.75[1]	-0.75[3]	-0.78[1]	-0.75[3]
Lentils	η_l	-0.79[1]	-0.75[1]	-0.75[1]	-0.75[1]	-0.75[3]	-0.75[1]	-0.75[3]
Wheat	η_w	-0.20[1]	–	–	–	–	–	–
Canola	η_c	-0.35[2]	–	–	–	–	–	–
Supply Elasticity								
Dry peas	ϵ_p	1.70[1]	0.50[1]	0.50[1]	0.50[1]	1.50[3]	1.50[1]	1.50[3]
Lentils	ϵ_l	1.70[1]	0.50[1]	0.50[1]	0.50[1]	1.50[3]	1.50[1]	1.50[3]
Wheat	ϵ_w	0.30[1]	–	–	–	–	–	–
Canola	ϵ_c	0.70[3]						
Cross Demand Elasticity								
Lentils in dry pea market	η_{pl}	-	0.60[3]	0.20[3]	0.20[3]	0.20[3]	0.20[3]	0.20[3]
Dry peas in lentil market	η_{lp}	-	0.48[4]	1.82[4]	0.12[4]	0.005[4]	0.75[4]	0.29[4]
Cross Supply Elasticity								
Lentils in dry pea market	ϵ_{pl}	-0.40[3]	-0.30[3]	-0.10[3]	-0.30[3]	-0.80[3]	-0.03[3]	-0.20[3]
Wheat in dry pea market	ϵ_{pw}	-0.50[3]	–	–	–	–	–	–
Canola in dry pea market	ϵ_{pc}	-0.40[3]	–	–	–	–	–	–
Dry peas in lentil market	ϵ_{lp}	-0.30[4]	-0.10[4]	-0.57[4]	-0.02[4]	-0.01[4]	-0.51[4]	-0.56[4]
Wheat in lentil market	ϵ_{lw}	-0.80[3]	–	–	–	–	–	–
Canola in lentil market	ϵ_{lc}	-0.80[3]	–	–	–	–	–	–
Dry peas in wheat market	ϵ_{wp}	-0.06[4]	–	–	–	–	–	–
Lentils in wheat market	ϵ_{wl}	-0.13[4]	–	–	–	–	–	–
Canola in wheat market	ϵ_{wc}	-0.20[3]	–	–	–	–	–	–
Dry peas in canola market	ϵ_{cp}	-0.05[4]	–	–	–	–	–	–
Lentils in canola market	ϵ_{cl}	-0.13[4]	–	–	–	–	–	–
Wheat in canola market	ϵ_{cw}	-0.21[4]	–	–	–	–	–	–
Own Knowledge Elasticity of Peas	θ_{pc}	0.987[3]	–	–	–	–	–	–
Cross Knowledge Elasticity								
Pea in lentil market	θ_{lpc}	-0.0005[3]	–	–	–	–	–	–
Pea in wheat market	θ_{wpc}	-0.025[3]	–	–	–	–	–	–
Pea in canola market	θ_{cpc}	-0.025[3]	–	–	–	–	–	–

Source: [1]Davis et al. [1987]; [2]Meilke et al. [2001]; [3]Assumptions; [4]Calculations.

Knowledge Stock

As discussed in Chapter 4, an important issue in determining the impact of pea R&D investment on the supply functions is to determine the sign and magnitude of $\rho_{jpc}\bar{K}_{pc}$ in equation (4.15). The knowledge stock of peas, K_{pc}, can be derived as the weighted average of historical R&D investment as equation (4.7) shows. This study assumes a base case with constant R&D investment in each and every year, i.e., $E_0 = E_1 = E_2 = ... = E_{L_R} = \overline{E}$. Therefore, equation (4.7) can be rewritten as

$$K_{pct} = \sum_{s=1}^{L_R} \omega_s \overline{E} \tag{5.1}$$

Furthermore, because $\sum_{s=1}^{L_R} \omega_s = 1$, equation (5.1) can be rewritten as

$$K_{pct} = \overline{E} = l_p PQ \tag{5.2}$$

Using the price and quantity data from FAOSTAT 2009 for P and Q, and the current check-off ratio l_p of 1%, the calculated value of the knowledge stock is presented in Table 5.1. This calculated knowledge stock is treated as the benchmark value in the analysis.

A rise in R&D investment by an amount $\Delta\overline{E}$ in period $t = 0$ (and only period $t = 0$) results in the knowledge stock in period t being determined as follows:

$$K_{pct} = \sum_{s=1}^{50} \omega_s E_{(t-s)} = \overline{E} + \omega_t \Delta E = l_p P^* Q^* + \omega_t (l'_p P_0 Q_0 - l_p P^* Q^*) \tag{5.3}$$

The numerical value of K_{pct} in equation 5.3 is calculated using the data P^* and Q^* calibrated from the model; the initial check-off ratio l_p is one percent; the increased check-off ratio l'_p is 1.1 percent that leads to 10 percent increase in R&D investment; and the equilibrium solutions from the partial equilibrium model at $t = 0$ give P_0 and Q_0. The calculated historical values of the knowledge stock can be seen in figure 5.5 panel (b).

The dynamic change of the check-off ratio, R&D investment, and the knowledge stock can be seen in table 5.4. Before period $t = 0$, the check-off ratio is constant at l_p, the market clears at (P^*, Q^*), R&D investment is $\bar{E}$, and the knowledge stock is $\bar{K}_p$. This equilibrium outcome holds until the check-off ratio increases from l_p to l'_p at $t = 0$. Under the assumption that the check-off ratio changes from l_p to l'_p at period $t = 0$ and the check-off ratio then returns to the original level l_p in period $t = 1$ and all remaining periods, K_{pt} is determined by the product of ω_t and ΔE, where $\Delta E = E_0 - \bar{E}$.

Table 5.4: Dynamic Change of the Check-off Ratio, R&D Investment, and Knowledge Stock

Time (t)	Levy Ratio l_p	P^*	Q^*	R&D Invest. (E)	Knowledge Stock (K_{pt})
t =-50	l_p	P^*	Q^*	$\bar{E} = l_p P^* Q^*$	$\bar{K}_{p(-50)} = \sum_{s=1}^{50} \omega_s \bar{E} = \bar{E}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	
t =-1	l_p	P^*	Q^*	$\bar{E} = l_p P^* Q^*$	$\bar{K}_{p(-1)} = \sum_{s=1}^{50} \omega_s \bar{E} = \bar{E}$
$t = 0$	l'_p	P_0^*	Q_0^*	$E_0 = l'_p P_0^* Q_0^*$	$\bar{K}_{p0} = \sum_{s=1}^{50} \omega_s \bar{E} = \bar{E}$
$t = 1$	l_p	P_1^*	Q_1^*	$E_1 = l_p P_1^* Q_1^*$	$K_{p1} = \sum_{s=1}^{50} \omega_s E_{(1-s)} = \bar{E} + \omega_1 \Delta E$
$t = 2$	l_p	P_2^*	Q_2^*	$E_2 = l_p P_2^* Q_2^*$	$K_{p2} = \sum_{s=1}^{50} \omega_s E_{(2-s)} = \bar{E} + \omega_2 \Delta E$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$t = 50$	l_p	P_{50}^*	Q_{50}^*	$E_{50} = l_p P_{50}^* Q_{50}^*$	$K_{p50} = \sum_{s=1}^{50} \omega_s E_{(50-s)} = \bar{E} + \omega_{50} \Delta E$

Source: Developed by the author.

Elasticities of the Knowledge Stock

According to equation (4.15), the other factor that affects the magnitude of the impact of knowledge stock on supply is the coefficient ρ_{jpc}. This coefficient can be determined by the elasticities of the knowledge stock. Two knowledge elasticities are of concern: the own knowledge elasticity represented by θ_{jpc} ($j =$ pea), and the cross knowledge elasticity represented by θ_{jpc} ($j \neq$ pea).

Own Knowledge Elasticity – The own knowledge elasticity is the percentage change of output for peas with respect to the percentage change of the pea knowledge stock, i.e.,

$$\theta_{pc} = \frac{\Delta Q^s_{pc}/Q^s_{pc}}{\Delta K_{pc}/K_{pc}} \tag{5.4}$$

where Q^s_{pc} is the output supply of Canadian peas, and K_{pc} is the knowledge stock of peas in Canada.

To isolate the effect of the pea knowledge stock on pea production, the own knowledge elasticity is derived under the assumption that Canada is a small-country exporter of pulses (by assuming a small country case, all price impacts are eliminated from the analysis). With a 10 percent increase in pea R&D investment, K_{pc} increases by approximately 10 percent. Since the denominator in equation (5.4) is known, once the percentage change in Q^s_{pc} is known, the value of θ_{pc} can be obtained.

A reasonable value for the own knowledge stock elasticity is 0.987 that is just a bit less than unitary implying that a 10 percent increase in the knowledge stock would result in an increase in output that is just a bit less than 10 percent.

Cross Knowledge Elasticity – The cross knowledge elasticity is the percentage change of output for crop j ($j \neq$ pea) with respect to the percentage change of knowledge stock of peas, i.e.,

$$\theta_{jpc} = \frac{\Delta Q^s_{j}/Q^s_{j}}{\Delta K_{pc}/K_{pc}} \tag{5.5}$$

The existence of the influence of K_{pc} on the supply of other crops is because the jointness of the production of peas, lentils, wheat, and canola on a fixed amount of land. The impact of K_{pc} on supply of other crops can be examined through the lens of acreage allocation among these four crops.

The knowledge stock of peas negatively affects the output for the other crops because with an increased knowledge stock K_{pc}, the opportunity cost of growing other crops increases. Consequently, farmers shift some of their production away from other crops and towards peas. Therefore, the cross knowledge elasticity is negative, i.e., $\theta_{ji} < 0$.

Since wheat and canola are part of the same rotation as peas, it is reasonable to assume the cross knowledge elasticity of wheat equals to the cross knowledge elasticity of canola, i.e., $\theta_{wpc} = \theta_{cpc}$. Since peas and lentils are not grown on the same type of land – peas are suitable for drier areas and lentils for more moist areas – the cross knowledge elasticity of lentils should be smaller than the one of wheat and canola, i.e., $\theta_{lpc} < \theta_{wpc} = \theta_{cpc}$.

For a given value of $\theta_{pc} = 0.987$, the base values of cross knowledge elasticities are solved as the one gives a reasonable IRR of 57.66 percent that is the closest value to the previous estimation of 58.6 percent by Alston et al. [2000]. The base values of the own knowledge elasticity and cross knowledge elasticities can be seen in table 5.3.

5.4.4 Results and Implications

The parameters and variables specified above are used to examine the dynamic impact on prices, production, and economic surplus in Canada and other regions arising from the increase of Canadian pea R&D investment.

Relationship Between Knowledge Stock and Producer Surplus in Canada

The relationship between the lag weight, the knowledge stock, and producer surplus can be seen in figure 5.5. In each panel of the graph, the horizontal axis shows the number of years from the increase in the R&D investment (recall that the increase in investment is ΔE). In panel (a), the value on the vertical axis is the weight ΔE receives t years after it has occurred. In panel (b), the value on the vertical axis is the knowledge stock that ΔE generates t years after it has occurred. The knowledge stock in the case of no increase in R&D investment, i.e., $\Delta E = 0$, is depicted as the flat dashed line. In panel (c), the value on the vertical axis is the change of the producer surplus to Canadian farmers caused by ΔE. Since ΔE occurs only at $t = 0$ and then returns to zero for all the remaining periods, its impact on the knowledge stock and the producer surplus is determined by the lag weight distribution.

It is obvious that the lag weight, knowledge stock, and producer surplus are inexorably linked. The impact of ΔE on the knowledge stock and the producer surplus is very small for the first few years, increases for several years, and then eventually declines as the effect of the investment on knowledge stock diminishes.

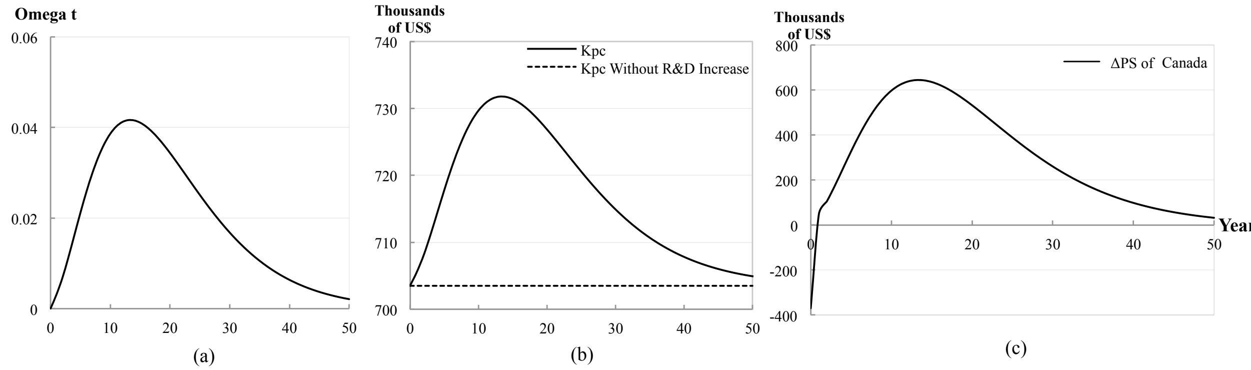


Figure 5.5: Lag Weights, Knowledge Stock and ΔPS of Canada

Source: Developed by the author.

Effects on Production

A summary of the changes in the prices and quantities that are calculated in the simulation model are presented in table 5.5. The pea price decreases in each region, which translates into an increase in the quantity demanded of peas in each region. The quantity of peas supplied increases in Canada, while it decreases in all importing countries. Since the increase in Canadian pea production is larger than the reduction in pea production in importing countries, total world pea production increases. The lentil price decreases. The quantity demanded of lentils increases in Canada and decreases in the other importing countries with the exception of Bangladesh and ROW; overall, total world lentil consumption decreases. The quantity of lentils supplied falls in Canada and in the other regions, with the exception of China and the EU; overall, however, total world lentil output decreases. The wheat and canola prices do not change given the assumption that Canada is a price taker in these two markets. Wheat and canola production decline. A more detailed analysis of the price and quantity effects is provided below.

Effects on Pea Production – The simulation results of the impact of increasing Canadian pea R&D investment on pulse production is depicted in figure 5.6. As panel (a) illustrates, Canadian pea production declines in period $t = 0$ due to the increase in R&D investment. Production then starts to increase in period $t = 1$. The increment is very small for the first few years, increases for several years, and then eventually declines as the effect of R&D diminishes.

Table 5.5: Effects on Prices and Production of Canadian Pea Innovation

	P_p	Q_p^d	Q_p^s	P_l	Q_l^d	Q_l^s	P_w	Q_w^s	P_c	Q_c^s
Canada	-	+	+	-	+	-	nv	-	nv	-
Other Regions	-	+	-	-	-	-				
India	-	+	-	-	-	-				
China	-	+	-	-	-	+				
Bangladesh	-	+	-	-	+	-				
Turkey	-	+	-	-	-	-				
EU	-	+	-	-	-	+				
ROW	-	+	-	-	+	-				
World Total	**-**	**+**	**+**	**-**	**-**	**-**				

Source: Developed by the author.

Notes: + represents positive effect caused by Canadian pea R&D investment;
- represents negative effect;
nv represents no variation;

Pea production in the importing countries increases in period $t = 0$ due to the higher price for peas that results from the larger check-off ratio. Production then starts to decrease in period $t = 1$. The decrease is very small for the first few years, gets larger for several years, and then eventually falls as the effect of the R&D diminishes. Because the increase in Canadian pea production is greater than the reduction in production in the importing countries, total world pea output increases slightly in the first few years, increases for several years until it peaks, and then falls as Canadian pea production declines.

There is an obvious inverse relationship between the pea production in Canada and the aggregate production of other regions, i.e., the aggregate pea production increases when Canadian pea production decreases, and it decreases when Canadian production increases. This inverse relationship, under the assumption of no spatial knowledge spillovers between Canada and other regions, is rooted in the price effect between the Canadian market and the other markets. The increase in Canadian pea R&D investment results in a lower price for peas. As the pea price falls, overseas pea production decreases. As Canadian pea R&D eventually loses its impact and price begins to rise, overseas production increases with the decrease in Canadian pea production. Therefore, it is appropriate to derive the following result:

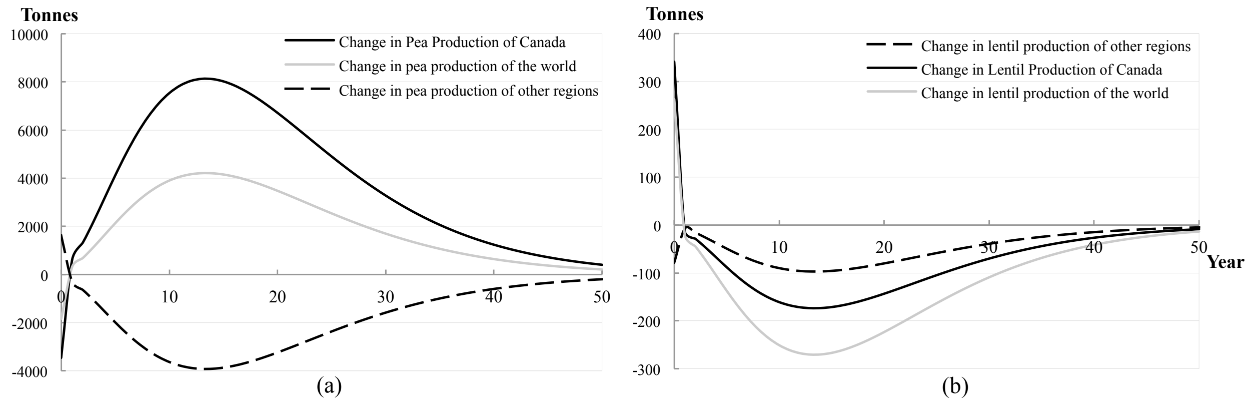


Figure 5.6: Effects on Pulse Production

Source: Developed by the author.

Result 5.1. *With increased pea R&D investment, Canadian pea production increases while overseas pea production declines. Since this increase in Canadian pea production is greater than the reduction in overseas pea production, total world pea production increases.*

Effects on Lentil Production – The simulation results of the impact of increasing Canadian pea R&D investment on lentil production are depicted in figure 5.6 panel (b). As the figure shows, lentil production in Canada and other regions decreases slightly for the first few years, decreases more substantially for several years, and then eventually increases as the effect of Canadian pea R&D diminishes. Consequently, the total world lentil production decreases as well.

The positive relationship between Canadian lentil production and aggregate lentil production in other regions is determined through the interactions between the pea and lentil markets. With the increase in pea R&D investment, the pea supply curve in Canada shifts out and the lentil supply curve shifts inward. Therefore, more peas are produced, which lowers the price of peas, while lentil output declines. The lower pea price generates more overseas demand for peas, but less demand for lentils, as consumers shift their purchases to peas. The demand shift is sufficiently large that it causes the price for lentils to fall. The result is a falling price for lentils and a decrease in production, as the following discussion illustrates.

Given theses outcomes, it is reasonable to derive the following result:

Result 5.2. *With increased pea R&D investment in Canada, lentil production declines in both Canada and the importing countries.*

Effects on Wheat and Canola Production – The effects of the increase of Canadian pea R&D investment on Canadian wheat production is illustrated in figure 5.7 panel (a). Wheat production decreases slightly for the first few years, decreases more substantially for several years, and then eventually increases as the effect of the Canadian pea R&D diminishes.

Under the assumption of an exogenous wheat price, the decreased wheat production is caused by two factors: the increase of the pea knowledge stock; and the decrease in the price of peas and lentils. To isolate the impact of the pea knowledge stock on wheat production it is first assumed that Canada is a small-country exporter for peas and lentils. After this analysis is completed, the model then considers the large-country exporter case. The small-country exporter case can be seen in Figure 5.7 panel (b), while panel (a) presents the case of large-country exporter. Comparing panel (a) and (b), it is obvious that in the large country case the decrease in the production of wheat is less than in the small country case. This is because, in the small country case, for a fixed amount of land the increase in pea R&D investment increases the opportunity cost of growing wheat resulting in a reduction in wheat production. Unlike in the small country case, Canada faces a downward sloping demand curve for pulses as a large-country exporter. Higher pea R&D investment causes lower pulse prices leading to a little more acreage allocated to wheat production. Therefore, the decrease of wheat production when Canada is the large-country exporter is less than when it is the small-country exporter.

The effects of the increase of Canadian pea R&D investment on Canadian canola production is illustrated in figure 5.7 panel (c). Canola production decreases slightly for the first few years, decreases more substantially for several years, and then eventually increases as the effect of the Canadian pea R&D diminishes.

Under the assumption of exogenous canola price the decreased canola production is caused by two factors: the increase of pea knowledge stock; and the decrease in the price of peas and lentils. To isolate the impact of pea knowledge stock on canola production an alternative situation is developed in which Canada is a small-country exporter for peas and lentils, see figure 5.7 panel (d). Comparing panel (c) and (d), it is obvious that in the large country case the decrease in the production of canola is less than in the small country case. This is because, in the small country case, for a given a fixed amount of land the increase in pea R&D investment increases the opportunity cost of growing canola resulting in the reduction in canola production. Unlike in the small country case, Canada faces a downward sloping demand curve for pulses as a large-country exporter. Higher pea R&D investment causes lower pulse prices leading to a little more acreage allocated to canola production. Therefore, the decrease of canola production when Canada is a large-country exporter is less than when it is a small-country exporter. .

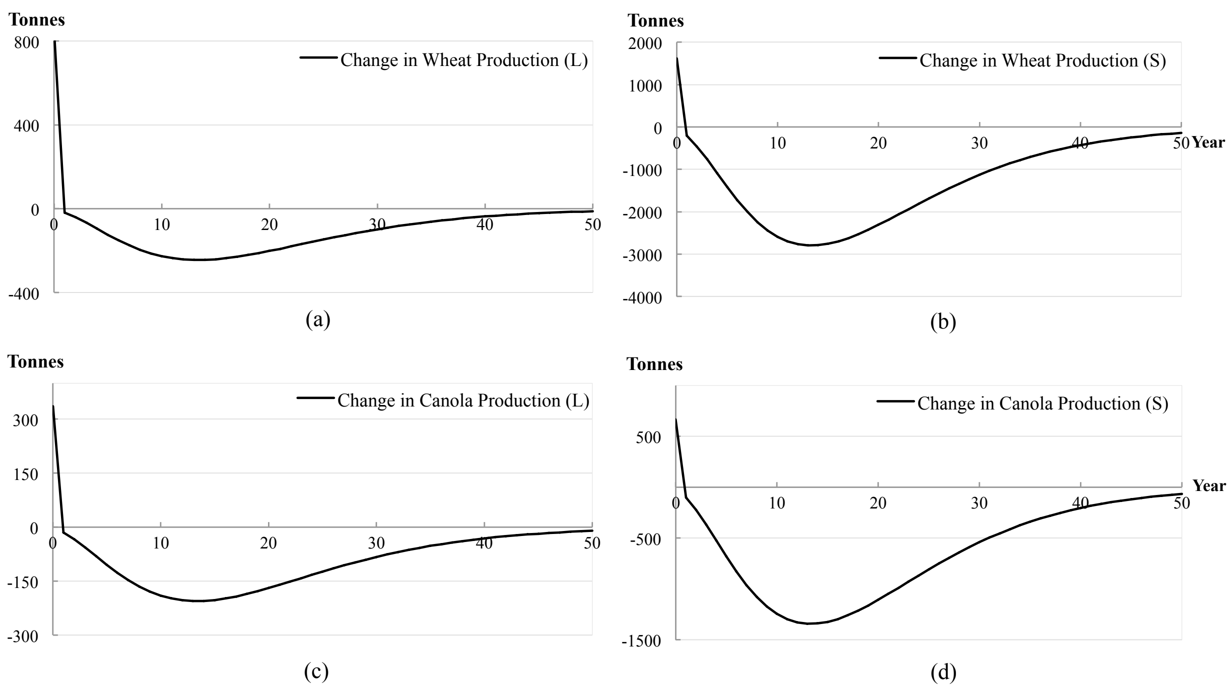


Figure 5.7: Effects on Canadian Wheat and Canola Production

Source: Developed by the author.

Effects on Prices

The simulation results of the impact of increasing Canadian pea R&D investment on pea and lentil prices are depicted in figure 5.8. The pea price and the lentil price increase in period $t = 0$ because of the increased check-off ratio, then decrease in the periods following. The decrease is very small for the first few years, then increases for several years, and then eventually falls as the R&D loses its effectiveness.

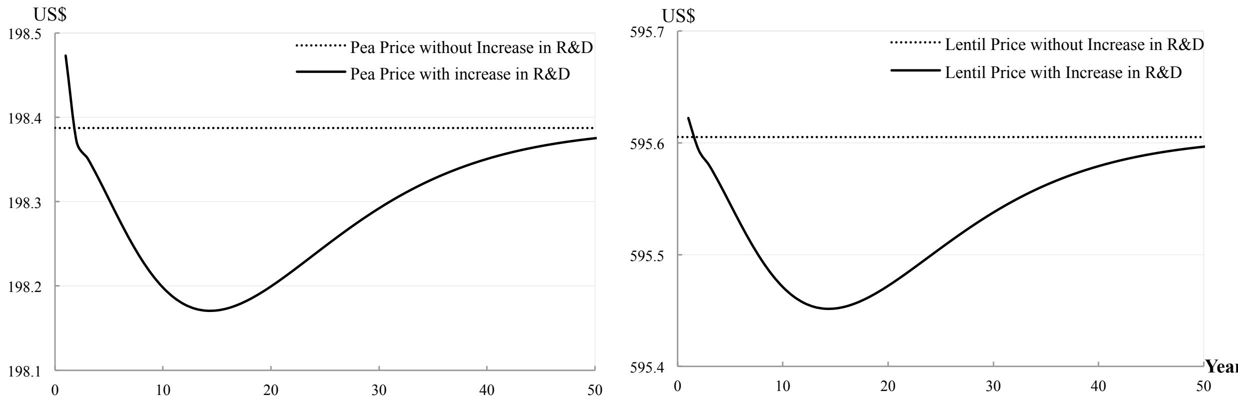


Figure 5.8: Effects on Pulse Prices

Source: Developed by the author.

The decrease in the pea price is caused by the outward shift of the Canadian pea supply curve as a result of the increase in pea R&D investment. As was discussed above, the increase in pea R&D leads to an upward shift of the Canadian lentil supply curve. In addition, because peas and lentils are substitutes on the consumption side in the importing countries, the fall in the pea price results in a fall in overseas lentil demand. This demand side impact is larger than the supply side impact, with the result that lentil prices decrease. Therefore, given these outcomes, it is reasonable to derive the following result:

Result 5.3. *With increased Canadian pea R&D investment, pea prices and lentil prices decline.*

Effects on Economic Surplus

The effects on economic surplus associated with a 10 percent increase in pea R&D investment in the Canadian pea sector can be seen in figure 5.9. Panel (a) illustrates the change in producer surplus and panel (b) the change in consumer surplus.

Effects on Producer Surplus – Although pea price falls, Canadian producers nevertheless benefit from the increased R&D investment as a result of the lower production cost that accompanies the R&D. As figure 5.9 panel (a) shows, in period $t = 0$, Canadian producer surplus decreases as a result of the increased check-off levy. Producer surplus starts to increase in period $t = 1$ and continues to do so until it achieves its maximum value at year $t = 13$. It then declines with the diminishing effects of R&D investment.

Although Canadian producers benefit from the research activities they carry out, the overseas producers are worse off, and total producer surplus at the world level decreases. Notably, there is an inverse relationship between the change of Canadian producer surplus and the aggregate producer surplus for other regions – i.e., when Canadian producer surplus decreases, overseas producer surplus increases, while when Canadian producers are better off, overseas producers are worse off.

This inverse relationship is caused by the lower pea price that results from the increased Canadian pea R&D investment. Once Canadian R&D investment starts to generate benefits, the pea price decreases, more Canadian peas are produced and exported. Under the assumption of no spatial knowledge spillovers between Canada and other regions, overseas pea production declines and producer surplus consequently decreases. Thus, the following result is reasonable:

Result 5.4. *With the increased pea R&D investment in Canada, Canadian producers are better off while overseas producers are worse off. Since this reduction in overseas producer surplus is greater than the gain by Canadian producers, total world producer surplus decreases.*

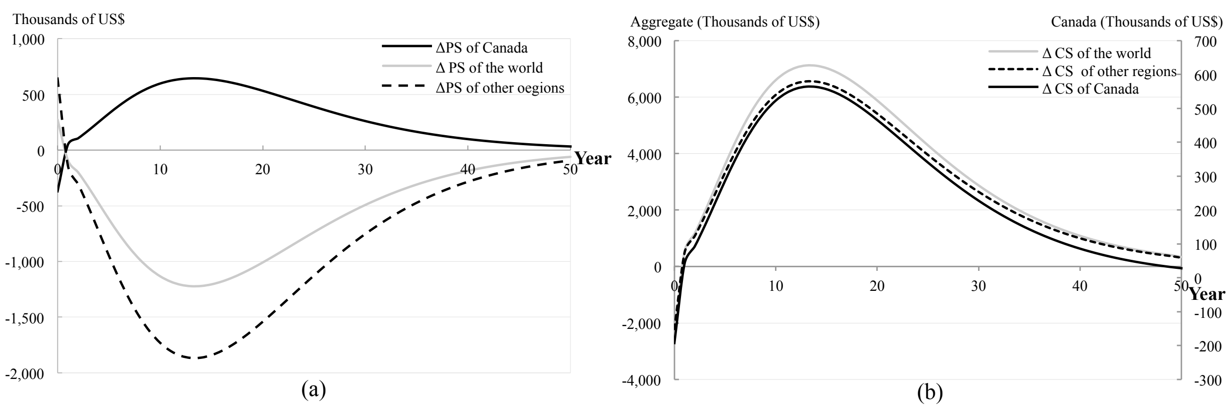


Figure 5.9: Effects on Economic Surplus

Source: Developed by the author.

Effects on Consumer Surplus – Consumers, on the other hand, are better off with the increased Canadian pea R&D investment as Figure 5.9 panel (b) shows. In period $t = 0$, consumer surplus in Canada decreases caused by the higher consumer price as a result of the increase of R&D investment. The consumer surplus starts to increase in period $t = 1$. The increase is very small for the fist few years, increases for several years, and then eventually decreases as the R&D loses its effectiveness. Therefore, it is appropriate to derive the following result:

Result 5.5. *Consumers in all regions are better off from the increase in Canadian pea R&D investment.*

Ranking of the Welfare Effects

The welfare gains and losses from the increase in Canadian producer-funded R&D investment were examined in the previous sections. The simulation results concluded that Canadian producers and consumers are better off, overseas consumers are better off while overseas producers are worse off.

A question that naturally arises is the ranking of the benefits to different agents (consumers and producers in Canada and overseas countries). Figure 5.10 shows the ranking of welfare changes for different agents. Overseas consumers are the biggest beneficiaries of Canadian pea R&D investment, followed by Canadian producers. The research benefits to Canadian consumers are slightly less than the benefits to Canadian producers and overseas producers are worse off.

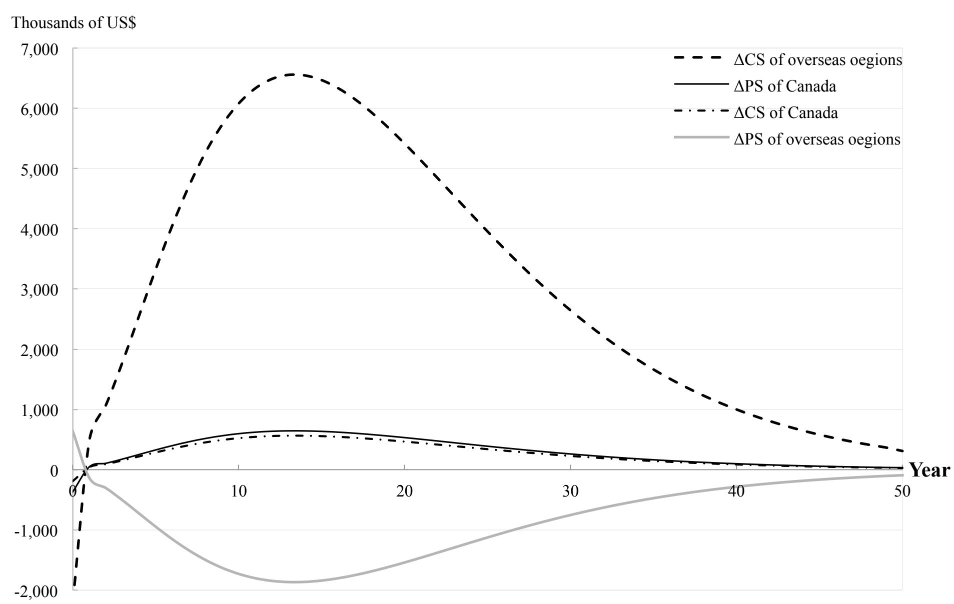


Figure 5.10: Ranking of Welfare Effects

Source: Developed by the author.

5.5 Comparison of Current Results with Traditional Analysis

Alston et al. [2004] show that in the case of a parallel supply shift, producers have the same incentive to invest in R&D if they are in a small open economy (SOE) or a large open economy (LOE)). Alston et al. [2004] also analyze the case of a pivotal supply shift.

This thesis models a pivotal supply shift that generates the R&D cost and a parallel supply shift that generates the R&D benefit; it also examines the effect of trade status (SOE versus LOE) on farmers' investment incentives in such a model. The pivotal supply shift in the case of R&D cost is empirically important because percentage levies are used in the Canadian pulse industry. Understanding how farmers' investment incentives are influenced in this case may help to shed light on the underinvestment in R&D.

In order to compare the results of the model in this thesis with that of Alston et al. [2004], this study transforms the dynamic multi-product model into a single-product model with parallel supply shifts generated both the costs and the benefits. The simulation results are presented in Table 5.6.

The IRR to Canadian producers in the case of a single-product is presented in the first row of Table 5.6. When the R&D cost is generated by a parallel supply shift, the IRR of 59 percent in the SOE case is essentially the same as the IRR in the LOE case. This result is the same as that of Alston et al. [2004] who find that farmers' investment incentives are not affected by the trade status in the case of a parallel supply shift.

However, when the R&D cost is generated by a pivotal supply shift, the IRR in the SOE is 80.09 percent, a value smaller than the IRR in the LOE case of 94.35 percent. On this basis, it is reasonable to derive the following result:

Result 5.6. *Producers have a greater incentive to invest in R&D in the LOE case than in the SOE case when the costs are generated by a pivotal supply shift.*

The detailed proof of this result is presented in Appendix A.5.

In the multi-product case, according to equation 4.15, the output supply of Canadian crops are affected by three factors – the pea price (P_{pc}), lentil price (P_{lc}), and the knowledge stock of peas (K_{pc}). To isolate the price impact and the impact of K_{pc}, the IRR calculation is conducted

Table 5.6: IRR for Single-Product and Multi-Product Models: Parallel vs Pivotal Supply Shift

	Parallel Supply Shift			Pivotal Supply Shift		
Models and Parameters	SOE	LOE(p)	LOE (p&l)	SOE	LOE(p)	LOE(p&l)
				percentage		
Single-Product Model						
	58.84	59.24	–	80.09	94.35	–
Multi-Product Model						
θ_{ij} ($\epsilon_{ij} = 0$)						
Base values × 0	58.84	59.24	59.26	80.09	94.35	101.63
Base values × 1/2	51.12	48.80	47.77	69.43	77.27	81.26
Base values	42.51	36.49	33.86	57.70	57.75	57.61
Base values × 3/2	32.38	19.59	12.65	44.14	32.15	23.46
ϵ_{ij} ($\theta_{ij} = 0$)						
Base values × 0	58.84	59.24	59.26	80.09	94.35	101.63
Base values × 1/2	58.84	59.24	57.39	80.09	94.35	96.12
Base values	58.84	59.24	55.39	80.09	94.35	90.60
Base values × 3/2	58.84	59.24	53.24	80.09	94.35	85.05

Source: Developed by the author.

Note:

1. “Parallel supply shift” and “pivotal supply shift” describe the pattern of the supply shift that generates the R&D cost;
2. LOE (p) captures the case where Canada is a LOE for peas only, while LOE (p&l) captures the case where Canada is a LOE for both peas and lentils;
3. θ_{ij} is the cross knowledge elasticity that captures the impact of the pea knowledge stock on the production of other crops;
4. ϵ_{ij} is the cross supply elasticities of peas with other crops;
5. When the impact of θ_{ij} on IRR is calculated, the value of ϵ_{ij} is set equal to zero; similarly when the impact of ϵ_{ij} on IRR is calculated, the value of θ_{ij} is set equal to zero. In all cases the demand elasticities are kept at their base values.

in two scenarios: (1) the impact of the cross knowledge elasticities (θ_{ij}) is examined by setting the cross supply elasticities to zero ($\epsilon_{ij} = 0$); (2) the impact of cross supply elasticities (ϵ_{ij}) is examined by setting the cross knowledge elasticities to zero ($\theta_{ij} = 0$). The calibrated results are presented in Table 5.6.

The second row of Table 5.6 shows that when the output supply of Canadian crops is only affected by the knowledge stock of peas, i.e., $\theta \neq 0$ and $\epsilon = 0$, the larger is the impact of K_{pc}, the smaller is the IRR to Canadian producers regardless the trade status. In the parallel shift case, when the cross knowledge elasticity is equal to zero, farmers' investment incentives are not distorted by the trade status and the IRR is approximately equal to 59 percent in the SOE, LOE (p), and LOE (p&l) cases. However, when the cross knowledge elasticities are not equal to zero, the IRRs in the large exporter case are smaller than those in the SOE case. The ranking of IRRs of different trade status is: IRRs in SOE $>$ IRRs in LOE (p) $>$ IRRs in LOE (p&l). In the case of pivotal shift, i.e., row two to five of the last three columns in Table 5.6, when θ_{ij} are smaller than the base values, the IRRs in the large country case are greater than those in the small country case. However, when θ_{ij} are greater than or equal to the base values, the IRRs in large country cases are smaller than those in the SOE.

The impact of the cross supply elasticities are presented in row six to nine in Table 5.6. Cross supply elasticities (ϵ_{ij}) do not affect the IRR in the SOE and LOE (p) cases for both the parallel and pivotal shift. In fact, the cross supply elasticities only affect the LOE (p&l), with the IRR decreasing as ϵ_{ij} increases.

From the above analysis, it can be seen that the cross knowledge elasticity θ_{ij} is a key parameter in determining investment incentives. The next section will focus on the sensitivity analysis for the multi-product pivotal shift model. In addition to the cross knowledge elasticities and cross supply elasticities, the impact of cross demand elasticities and own demand elasticities on IRRs will be conducted.

5.6 Sensitivity Analysis

To investigate the robustness of the results, a number of sensitivity analyses were conducted. Since it is difficult to examine the impact of different parameter values on the full range of outcomes examined above (e.g., prices, quantities, consumer and producer surplus), the focus is on a single outcome, namely the IRR that would accrue to Canadian producers from the R&D investment.

For comparison purposes the IRR is calculated for the base value of all the parameters and for three alternative values. Each alternative value is applied to one of four sets of parameters: (1) the cross knowledge elasticities θ_{jpc} ($j \neq$ pea); (2) the demand elasticity for peas η_{pi}; (3) the demand elasticity of lentils η_{li}, (4) the cross demand elasticities of peas and lentils in importing countries η_{pli}. Thus, if the sensitivity analysis is done for the demand elasticity of peas, then the demand elasticities of peas in all countries would be changed at the same time while holding all other parameters constant.

The base value of the parameters and their alternative values are presented in Table 5.7. The first alternative value is base value times zero, the second alternative value is the base values times one half, and the third alternative value is the base values times one and half.

The sensitivity analysis is carried out under the maintained assumption that Canada is a large exporter of peas and lentils. To isolate the impact of the knowledge stock of peas on other crops, the effects on IRR are also examined in that case in which Canada is a large-country exporter of peas but a small-country exporter of lentils, and the case in which Canada is a small-country exporter (i.e., the prices of lentils and peas are fixed).

Table 5.7: Base and Alternative Values of Parameters Used in Sensitivity Analysis

Prm.	Base Value	Alt. Value 1	Alt. Value 2	Alt. Value 3
θ_{jpc}	{-0.0005, -0.025, -0.025 }	BV×0	BV×$\frac{1}{2}$	BV×$\frac{3}{2}$
η_{pli}	{ 0.6, 0.2, 0.2, 0.2, 0.2, 0.2 }	BV× 0	BV×$\frac{1}{2}$	BV×$\frac{3}{2}$
η_{pi}	{-0.79, -0.75, -0.75, -0.75, -0.75, -0.78, -0.75 }	BV×0	BV×$\frac{1}{2}$	BV×$\frac{3}{2}$
η_{li}	{-0.79, -0.75, -0.75, -0.75, -0.75, -0.78, -0.75 }	BV×0	BV×$\frac{1}{2}$	BV×$\frac{3}{2}$

Source: Developed by the author.

5.6.1 Effects of Cross Knowledge Elasticities on Canadian Producer IRR

The first four rows in Table 5.8 show how the IRR is affected by different values of the cross knowledge elasticities. As the cross knowledge elasticities increase in absolute value, the knowledge stock of peas has a greater negative impact on the production of other crops (wheat, canola, lentils), and the IRR to Canadian producers decreases. Thus it is appropriate to derive the following result:

Result 5.7. *The larger is the impact of pea innovation on other crop production, the smaller is the R&D returns to Canadian producers.*

The impact of the cross knowledge elasticities does differ depending on whether Canada is a large or a small country. In the SOE case, the impact of different cross knowledge elasticities is muted compared to what happens in the large country case. Most notably, larger absolute values of the cross knowledge elasticities have a significant impact on the IRR in the large country case, with the IRR falling to 10.54 in the case where the cross crop impact is the largest.

5.6.2 Effects of Cross Demand Elasticities on Canadian Producer IRR

Table 5.8 also presents the effects of different cross demand elasticities on Canadian producer IRR. As the cross demand elasticities increase, the IRR to Canadian producers decreases in the case where Canada is the large country exporter for both peas and lentils. However, the cross demand elasticities have no impact on the IRR if Canada is a LOE for peas only. Thus, the larger is the substitution effect between the demand of peas and lentils, the smaller are the research benefits to Canadian producers in the case of LOE (p&l).

The reason for this result is as follows. The higher are the cross demand elasticities of peas and lentils, the greater is the inward shift of the lentil demand curve in response to a drop in the pea price, and the lower is the lentil price. With the decreased lentil price, the research benefits to Canadian producers decrease, *ceteris paribus*. In the case where Canada is a large exporter of peas only, the lentil price is fixed and the IRRs are not affected by the variation of cross knowledge elasticities. Thus it is appropriate to derive the following result:

Result 5.8. *The larger is the substitution effect between the demand of peas and lentils, the smaller are the research benefits to Canadian producers in the case where Canada is a large country exporter for both peas and lentils.*

5.6.3 Effects of Demand Elasticities on Canadian Producer IRR

Table 5.8 presents the sensitivity analysis for different values of the demand elasticities. The demand elasticity of peas does not affect the IRR if Canada is a large exporter of peas only. However, in the case of LOE (p&l), as the demand elasticity of peas or lentils increase in absolute value, the IRR to Canadian producers increases. In other words, the flatter are the demand curves for peas and lentils, the more research benefits can be captured by Canadian producers. Thus it is appropriate to derive the following result:

Result 5.9. *The demand elasticity of peas (lentils) does not impact the IRR to Canadian producers in the case of LOE (p). However, in the case of LOE (p&l), the larger are the demand elasticities of peas (lentils), the larger are the research benefits that are captured by Canadian producers.*

Table 5.8: Sensitivity Analysis for Selected Parameter Values: IRR to Canadian Producers

	IRR		
Parameters	SOE	LOE (p)	LOE (p&l)
	percentage		
Cross Knowledge Elasticities			
Base values × 0	80.09	94.35	90.60
Base values × 1/2	69.43	77.27	71.52
Base values	57.70	57.75	48.78
Base values × 3/2	44.14	32.15	10.54
Cross Demand Elasticities of Pulses			
Base values × 0	–	57.75	51.32
Base values × 1/2	–	57.75	50.25
Base values	–	57.75	48.78
Base values × 3/2	–	57.75	46.58
Demand Elasticities of Peas			
Base values × 1/2	–	57.7	45.34
Base values	–	57.7	48.78
Base values × 3/2	–	57.7	50.37
Base values × ∞	–	57.7	54.61
Demand Elasticities of Lentils			
Base values × 1/2	–	–	46.40
Base values	–	–	48.78
Base values × 3/2	–	–	50.32
Base values × ∞	–	–	57.75

Source: Developed by the author.

Note: When calculating the impact of cross knowledge elasticities on IRR, the other elasticities are kept at the base values; similarly when calculating the impact of demand elasticities (both cross and own elasticities) on IRR, cross knowledge elasticities are kept at their base values.

5.7 Re-examine the Horizon Problem

The analysis of the horizon problem in Chapter 3 was carried out under the assumption of a single-product producer operating in a small open economy. A more realistic model is developed in this chapter by relaxing the above two assumptions under the condition of a multi-product producer facing downward sloping demand curves. How would the multi-product production impact the horizon problem? How would the large-country assumption influence the horizon problem? To answer these two questions, a sensitivity analysis regarding the effects of trade status and cross knowledge elasticities on the horizon problem is conduced in this section.

5.7.1 Effects of Trade Status on the Horizon Problem

The simulation results of the horizon problem for the case of small country and large country can be seen in Figure 5.11. The change in Canadian producer surplus (ΔPS) is the marginal benefits of R&D to Canadian producers. This figure provides an intuition of the impact of trade status on the marginal research benefits, the corresponding numerical values of the marginal benefits can be seen in Table 5.9 as well.

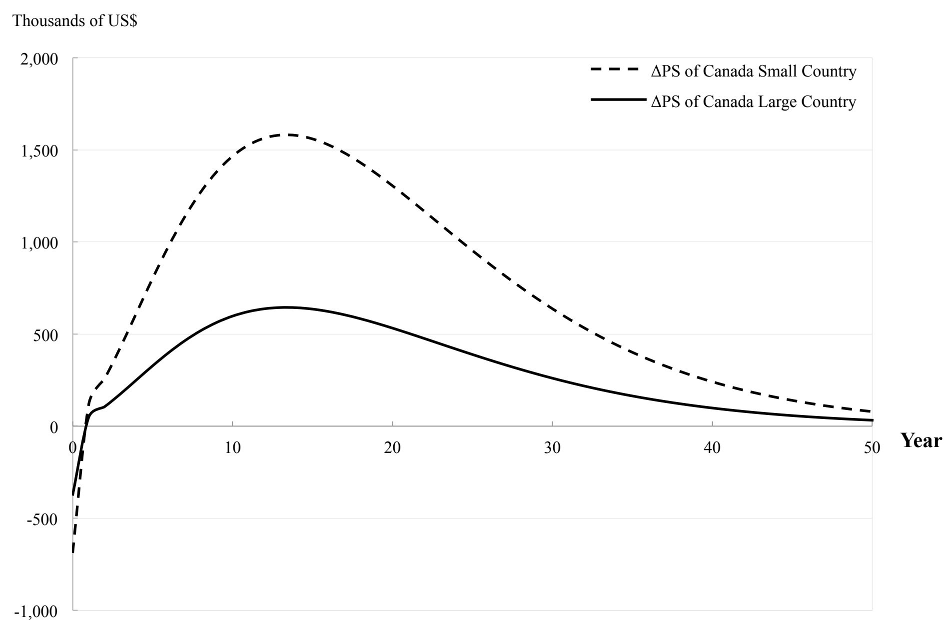


Figure 5.11: Sensitivity Analysis of Trade Status on the Horizon Problem

Source: Developed by the author.

Table 5.9 shows the IRR earned by Canadian producers for different membership horizons under the condition that Canada is a small-country exporter and a large-country exporter for both peas and lentils. In both the small-country exporter and large-country exporter cases, there is no obvious deviation of the horizon IRR to $\overline{\text{IRR}}$ (the IRR with T=50) until T<10. However, even when T is smaller than ten years, the absolute value of horizon IRR is still very high, indicating that the horizon problem is not an issue for underinvestment. Therefore, it is reasonable to derive the following result:

Result 5.10. *The horizon problem is not affected by the trade status, i.e., under all trade scenarios, the horizon problem does not have an adverse impact on the incentives for producer-funded agricultural R&D.*

Table 5.9: Effects of Trade Status on the Horizon Problem

	IRR	
	Small-country Exporter	Large-country Exporter (p&l)
Time Horizon	η_{pc}=-∞; η_{lc}=-∞	η_{pc}=-0.79; η_{lc}=-0.79
	percentage	
T=50	57.70	48.78
T=45	57.70	48.78
T=40	57.70	48.78
T=35	57.70	48.78
T=30	57.70	48.78
T=25	57.70	48.78
T=20	57.69	48.75
T=15	57.56	48.53
T=10	56.15	46.60
T=5	40.17	28.75

Source: Developed by the author.

5.7.2 Effects of Cross Knowledge Elasticities on the Horizon Problem

The simulation results of the horizon problem for different values of cross knowledge elasticities can be seen in Figure 5.12. This figure shows an intuition of the impact of cross knowledge elasticities on the marginal research benefits, the corresponding numerical values of the marginal benefits can be seen in Table 5.10 as well.

Table 5.10 shows the IRR earned by Canadian producers for different membership horizons for different values of cross knowledge elasticities under the condition that Canada is a small-country exporter and a large-country exporter for both peas and lentils. When the cross knowledge elasticities are no larger in absolute value than the base values, there is no obvious deviation of the horizon IRR to $\overline{\text{IRR}}$ until T<10 in both the small country and large country cases. Even at T=10, the horizon IRRs are high, indicating that the horizon problem does not likely affect farmers R&D investment decisions. When the cross knowledge elasticities are greater than the base values, the horizon problem is not an issue in the small exporter case; but in the large

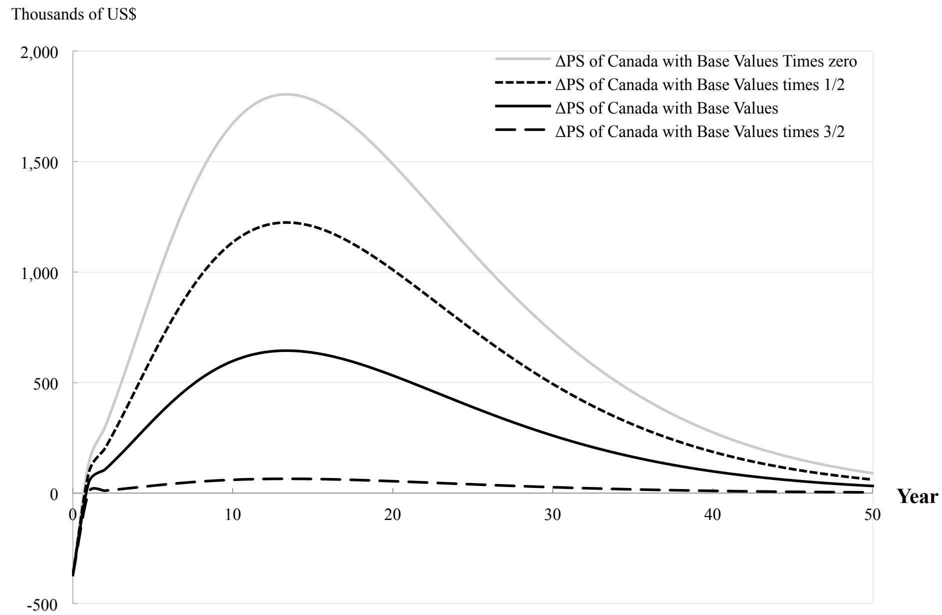


Figure 5.12: Sensitivity Analysis of Cross Knowledge Elasticities on Canadian $\triangle$PS (Large-country Exporter)

Source: Developed by the author.

exporter case, the horizon IRR has negative values when T< 20. The numerical results indicate that the impact of the horizon problem is not affected by the cross knowledge elasticities unless they are greater than the base values in the large country case. Therefore, it is reasonable to derive the following result:

Result 5.11. *The impact of the horizon problem is not affected by cross knowledge elasticities when their values are no greater than the base values.*

5.8 Concluding Remarks

In this chapter, a partial equilibrium model is developed for an open economy with seven regions and four products to examine the worldwide impact on prices, output and economic welfare of Canadian producer-funded R&D. The model captures the market connections within Canada, the connections within the overseas importing countries, and between Canada and the importing countries. The internal rate of return to Canadian producers for the pea R&D investment is calculated and a sensitivity analysis is conducted with respect to the key parameters. Furthermore, the horizon problem is re-examined under the condition of multi-product producers in a large country case.

The key results indicate that while consumers in all the regions are better off, overseas producers are worse off. Although overseas pea production declines, total world pea production increases as a consequence of the increased pea production in Canada. The concentration of pea production in Canada makes importing countries more reliant on food imports, an outcome that has the potential to raise food security issues in developing countries

An important contribution of this chapter is that the marginal returns to producer-funded R&D are modelled under the condition of a pivotal supply shift when the levy is imposed and a parallel supply shift when the R&D benefits are generate. This model fills a gap in the existing literature which to date has assumed that the R&D costs and benefits are generated by the same supply shift pattern (see, for example, Alston et al. [2004]). The results of this study indicate that trade status does affect the incentives to undertake R&D.

The results that have been discussed above are obviously subject to a number of limitations. First, the world is divided into seven regions and there is no heterogeneity within the importing countries. Second, given the available information on the parameters such as the elasticity of the knowledge stock, attention should be focused on direction of the change and the order of the magnitude of the welfare effects rather than on their specific values. Third, the model does not include the environmental benefits that accrue because the pea innovation in Canada induces a substitution of fertilizer use.

The analysis in this chapter is based on the assumption of no spillovers among the four crops. Further research needs to be carried out by relaxing this assumption. The analysis can be extended to the case where producers of other crops can free-ride on the benefits generated by R&D investment of pulse producers, and how this free-riding can affect R&D investment decisions.

Table 5.10: Effects of Cross Knowledge Elasticities on the Horizon Problem

		IRR	
Parameters	Time Horizon	Canada is Small-country Exporter	Canada is Large-country Exporter
Cross Knowledge Elasticities		*percentage*	
Base values × 0			
	T=50	80.09	90.60
	T=40	80.09	90.60
	T=30	80.09	90.60
	T=20	80.09	90.60
	T=10	79.40	90.12
	T=5	67.30	79.47
Base values × 1/2			
	T=50	69.43	71.52
	T=40	69.43	71.52
	T=30	69.43	71.52
	T=20	69.43	71.52
	T=10	68.40	70.55
	T=5	54.60	57.11
Base values × 1			
	T=50	57.70	48.78
	T=40	57.70	48.78
	T=30	57.70	48.78
	T=20	57.65	48.67
	T=10	56.10	46.51
	T=5	40.12	28.64
Base values × 3/2			
	T=50	44.14	10.54
	T=40	44.14	10.52
	T=30	44.14	9.97
	T=20	44.03	8.83
	T=10	41.46	-
	T=5	22.49	-

Source: Developed by the author.

Chapter 6

Summary and Conclusions

6.1 Summary and Conclusions

Agricultural R&D investment is becoming an increasingly important policy issue as food prices push upwards and food security problems emerge [Alston et al., 2009a]. An important source of agricultural R&D funding is from producer check-offs, which are increasingly being used to fund applied agricultural research such as disease management, genetic improvement, and weed control. Existing studies of producer-funded agricultural R&D indicate that there are high private and social rates of return to agricultural R&D investment by farmers, and thus that farmers are under investing in R&D.

There are a number of explanations as to why farmer organizations would underinvest in R&D. These problems include the free-rider problem, the portfolio problem, the control problem, the heterogeneity problem, and the horizon problem [Olson, 1971; Jensen and Meckling, 1979; Cook, 1995; Alston and Fulton, 2012; Vitaliano, 1983]. These problems emerge because of the individual incentives facing producers in a collective organization and because of the manner in which decisions are made within the organization.

The objective of the thesis is to examine one of the factors – the horizon problem – behind the apparent disincentive that exists for farmers to invest in producer-funded R&D investment. To undertake this analysis, two models were developed. The first one consisted of a framework for determining the marginal internal rate of return of investing in R&D, while the second one consisted of a trade model that could be used to examine the impact of R&D funding by Canadian pulse growers. Pulses were chosen because they are an important crop for western Canadian grain farmers and because Canada is a major exporter of pulses (Canada has over 50 percent of the export market in peas and lentils).

The first model – the one focusing on the marginal internal rate of return – was used to examine a particular issue that has been identified as a source of the underinvestment in R&D, namely the horizon problem. Given the long period of time over which the benefits of R&D investment occur, the increasing age of the farm population implies that the horizon problem could be an important factor in the underinvestment. The argument is that a farmer's planning horizon is less than the length of the R&D benefits, with the result that the incentive to invest is reduced.

The results of this thesis show that, contrary to what has been argued by some authors, the horizon problem is not a severe disincentive for R&D investment, unless the time horizon is very short. Since the membership horizon for the average Canadian producer is 15 to 20 years, the horizon problem is likely not an issue for Canadian producers. Furthermore, the analysis assumes farmers only are concerned with profit maximization. However, farmer may also consider other factors when making R&D investment decisions, such as future generations of agricultural producers and environment issues. The results of this study show even under the extreme assumption of profit maximization, the horizon problem is not expected to be an issue for Canadian farmers, let alone in a more realistic model implemented by including factors other than profit. The results of the horizon problem model also show that the impact of the horizon problem is not affected by land tenure relationships.

The second model – the one focusing on production and trade relationships in the pulse industry – was used to examine the economic impact of Canadian pea R&D investment on producers and consumers in Canada and in the various countries around the world that produce and consume pulses. To address the underinvestment issue, it is important to understand the question of who benefits from the research that is undertaken, and who bears the cost. Given that Canada is the largest pulse exporter in the world an increase in R&D investment can be expected to have a significant impact on international trade and overseas producers and consumers.

The simulation results from the second model illustrate that with increased pea R&D investment, the price of peas and lentils decreases. Canadian pea production increases while overseas pea production declines; overall, total world pea production increases. Lentil production in Canada and importing countries declines. While Canadian producers and consumers in all regions are better off as a result of the R&D investment, overseas producers are worse off.

The results of the sensitivity analysis, which extend the results of Alston et al. [2004], show that a pivotal supply shift resulting from an increased levy, combined with a parallel supply curve shift as a result of a greater knowledge stock, changes the incentives for producers to invest in the LOE versus the SOE case. Thus, trade status does affect the incentives for R&D, although not to the extent that the horizon problem has any impact.

The IRR to Canadian producers does depend critically on the magnitude of impact that pea R&D has on the production of other crops (e.g., wheat and canola). The larger is this impact – i.e., the more that wheat and canola production falls as a result of higher yields/lower costs of pea production – the smaller is the IRR. The results also indicate that the elasticities of demand for peas and lentils in the importing countries do not have an impact on the IRR in the case where Canada is the large country exporter for peas only; however, they do have an impact on the IRR in the case where Canada is a large exporter for both peas and lentils. As expected, the more elastic is the demand, the higher is the IRR.

6.2 Implications for Further Study

This study contributes to the producer-funded R&D literature and the producer cooperatives literature. However, there a number of areas that can be developed further.

One area for future study is to model the horizon problem for a risk averse farmer that maximizes expected utility rather than for a risk neutral producer with a profit maximization objective as was assumed in this thesis. As Just [1974] argued, risk is a critical factor influencing farmers' decisions on new technology adoption, which in turn affects their R&D investment decisions. Recall that the Monte Carlo simulation in chapter 3 indicates that as the membership horizon decreases the variance of the expected IRR increases. This increase in the variance is likely to cause an additional disincentive for R&D investment for risk-averse producers.

A second area for future research is to examine the impact of different institutional arrangements such as the voting mechanism on producer-funded R&D investment decisions. The horizon problem model in this thesis implicitly assumes that the voting mechanism is exogenous. However, a study to empirically examine the efficiency of different voting systems could provide important insights into questions such as: Is majority voting an effective mechanism to generate sufficient collective research investment? What would be the optimal mechanism design to generate sufficient R&D investment for producer organizations?

A third area for future study is to examine the determination of the check-off level under the condition of heterogeneous IRRs to producers. Heterogeneous IRRs mean different producers have different willingnesses to pay for R&D activities – i.e., different preferences for check-offs. For instance, farmers with a larger IRR prefer a higher check-off ratio because they can capture higher research benefits. Farmers with smaller IRR prefer a lower check-off ratio. Given these heterogeneous preferences over the check-off ratio, the choice of the check-off ratio makes some group members better off while imposing a cost on other group members. An investigation of the conflicts that exist among group members is a worthwhile subject for further research.

A fourth area of future research is to quantify the spillovers among crops. One reason why farmers might underinvest in R&D is that R&D funding decisions are made on a crop-by-crop basis, but the benefits flow to other crops via spillovers. For instance, wheat growers can benefit from the R&D activities conducted by pulse growers (pulses can fix nitrogen in the soil, improve land quality, and increase wheat productivity). The spillovers across levy programs are particularly important in Canada, where agricultural R&D activity has been organized on a commodity-by-commodity basis. A study could be carried out to quantify the spillovers across the various crops using the partial equilibrium trade model developed in chapter 4. Furthermore, the economic returns for Canadian pulse producers can be re-calculated with the spillover issue being addressed.

A fifth area of research is to incorporate the impact of foreign trade policy of importing countries into the trade model to examine its impact on IRR to Canadian producers. The trade model in this thesis assumes that trade policy is captured by the transportation cost τ. However, the trade policies in importing countries are often more complicated – a good case in point is the policy of zero tolerance of GM products in the EU. Determining the impact of these trade restrictions on Canadian pulse R&D investment decisions would provide a fuller understanding of the policies' impact.

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Appendix A

Technical Notes of Chapter 5

A.1 Demand and Supply Functions for Each Region

The responsiveness of the supply and demand to changes in prices is summarized in elasticities. The own price elasticity of demand (supply) can be represented by η_j (ϵ_j) and the cross price elasticity of demand (supply) is η_{ij} (ϵ_{ij}), i.e.,

$$\eta_j = \frac{\partial \ln Q_j^d}{\partial \ln p_j} = b_j \frac{P_j}{Q_j^d} \tag{A.1a}$$

$$\eta_{ij} = \frac{\partial \ln Q_i^d}{\partial \ln p_j} = b \frac{P_j}{Q_i^d} \tag{A.1b}$$

$$\epsilon_j = \frac{\partial \ln Q_j^s}{\partial \ln p_j} = \beta_j \frac{P_j}{Q_j^s} \tag{A.1c}$$

$$\epsilon_{ij} = \frac{\partial \ln Q_i^s}{\partial \ln p_j} = \beta_{ij} \frac{P_j}{Q_i^s} \tag{A.1d}$$

A.1.1 Demand Functions

The structural model that we developed requires the specification of demand and supply functions for the four crops, in each of the seven regions as well as the equilibrium conditions such as the spatial equilibrium across regions for each crop. The demand function for one individual crop in each country can be derived as the following with given values of elasticities[1].

■ Demand Functions of **Canada**

[1]For notation ease, elasticities used by the mathematical derivation represent the absolute value

♦ Demand for Peas

$$\begin{aligned} Q_{pc}^d &= a_{pc} + b_{pc}P_{pc} \\ \Rightarrow b_{pc} &= \tfrac{dQ_{pc}^d}{dP_{pc}} = \tfrac{dQ_{pc}^d}{dP_{pc}}\tfrac{P_{pc}}{Q_{pc}^d}\tfrac{Q_{pc}^d}{P_{pc}} = \eta_{pc}\tfrac{Q_{pc}^d}{P_{pc}} \\ a_{pc} &= Q_{pc}^d - b_{pc}P_{pc} = Q_{pc}^d - \eta_{pc}\tfrac{Q_{pc}^d}{P_{pc}}P_{pc} = Q_{pc}^d(1-\eta_{pc}) \end{aligned}$$

— Inverse Demand Function for Peas

$$P_{pc} = -\frac{a_{pc}}{b_{pc}} + \frac{1}{b_{pc}}Q_{pc}^d$$

where P_{pc}, as mentioned before, is the net output price after check-off is paid, and the same notation for prices in lentils, wheat, and canola supply functions of Canada.

♦ Demand for Lentils

$$\begin{aligned} Q_{lc}^d &= a_{lc} + b_{lc}P_{lc} \\ \Rightarrow b_{lc} &= \tfrac{dQ_{lc}^d}{dP_{lc}} = \tfrac{dQ_{lc}^d}{dP_{lc}}\tfrac{P_{lc}}{Q_{lc}^d}\tfrac{Q_{lc}^d}{P_{lc}} = \eta_{lc}\tfrac{Q_{lc}^d}{P_{lc}} \\ a_{lc} &= Q_{lc}^d - b_{lc}P_{lc} = Q_{lc}^d - \eta_{lc}\tfrac{Q_{lc}^d}{P_{lc}}P_{lc} = Q_{lc}^d(1-\eta_{lc}) \end{aligned}$$

— Inverse Demand Function for Lentils

$$P_{lc} = -\frac{a_{lc}}{b_{lc}} + \frac{1}{b_{lc}}Q_{lc}^d$$

♦ Demand for Wheat

$$\begin{aligned} Q_{wc}^d &= a_{wc} + b_{wc}P_{wc} \\ \Rightarrow b_{wc} &= \tfrac{dQ_{wc}^d}{dP_{wc}} = \tfrac{dQ_{wc}^d}{dP_{wc}}\tfrac{P_{wc}}{Q_{wc}^d}\tfrac{Q_{wc}^d}{P_{wc}} = \eta_{wc}\tfrac{Q_{wc}^d}{P_{wc}} \\ a_{wc} &= Q_{wc}^d - b_{wc}P_{wc} = Q_{wc}^d - \eta_{wc}\tfrac{Q_{wc}^d}{P_{wc}}P_{wc} = Q_{wc}^d(1-\eta_{wc}) \end{aligned}$$

— Inverse Demand Function for Wheat

$$P_{wc} = -\frac{a_{wc}}{b_{wc}}$$

Under the assumption that Canadian producers face flat demand curve for wheat i.e., η_{wc} goes to infinity.

⧫ Demand for Canola

$$\begin{aligned} Q^d_{cc} &= a_{cc} + b_{cc}P_{cc} \\ \Rightarrow b_{cc} &= \tfrac{dQ^d_{cc}}{dP_{cc}} = \tfrac{dQ^d_{cc}}{dP_{cc}}\tfrac{P_{cc}}{Q^d_{cc}}\tfrac{Q^d_{cc}}{P_{cc}} = \eta_{cc}\tfrac{Q^d_{cc}}{P_{cc}} \\ a_{cc} &= Q^d_{cc} - b_{cc}P_{cc} = Q^d_{cc} - \eta_{cc}\tfrac{Q^d_{cc}}{P_{cc}}P_{cc} = Q^d_{cc}(1-\eta_{cc}) \end{aligned}$$

— Inverse Demand Function for Canola

$$P_{cc} = -\frac{a_{cc}}{b_{cc}}$$

Under the assumption that Canadian producers face flat demand curve for canola, i.e., η_{cc} goes to infinity.

■ Demand Functions for **India**

⧫ Peas

$$\begin{aligned} Q^d_{pi} &= a_{pi} + b_{pi}P_{pi} + b_{pli}P_{li} \\ \Rightarrow b_{pi} &= \tfrac{dQ^d_{pi}}{dP_{pi}} = \tfrac{dQ^d_{pi}}{dP_{pi}}\tfrac{P_{pi}}{Q^d_{pi}}\tfrac{Q^d_{pi}}{P_{pi}} = \eta_{pi}\tfrac{Q^d_{pi}}{P_{pi}} \\ b_{pli} &= \tfrac{dQ^d_{pi}}{dP_{li}} = \tfrac{dQ^d_{pi}}{dP_{li}}\tfrac{P_{li}}{Q^d_{pi}}\tfrac{Q^d_{pi}}{P_{li}} = \eta_{pli}\tfrac{Q^d_{pi}}{P_{li}} \\ a_{pi} &= Q^d_{pi} - b_{pi}P_{pi} - b_{pli}P_{li} = Q^d_{pi} - \eta_{pi}\tfrac{Q^d_{pi}}{P_{pi}}P_{pi} - \eta_{pli}\tfrac{Q^d_{pi}}{P_{li}}P_{li} = Q^d_{pi}(1-\eta_{pi}-\eta_{pli}) \end{aligned}$$

— Inverse Demand Function for Peas

$$P_{pi} = -(\frac{a_{pi}}{b_{pi}} + \frac{b_{pli}}{b_{pi}}P_{li}) + \frac{1}{b_{pi}}Q^d_{pi}$$

♦ Lentils

$$
\begin{aligned}
Q_{li}^d &= a_{li} + b_{lpi}P_{pi} + b_{li}P_{li} \\
\Rightarrow b_{li} &= \tfrac{dQ_{li}^d}{dP_{li}} = \tfrac{dQ_{li}^d}{dP_{li}}\tfrac{P_{li}}{Q_{li}^d}\tfrac{Q_{li}^d}{P_{li}} = \eta_{li}\tfrac{Q_{li}^d}{P_{li}} \\
b_{lpi} &= \tfrac{dQ_{li}^d}{dP_{pi}} = \tfrac{dQ_{li}^d}{dP_{pi}}\tfrac{P_{pi}}{Q_{li}^d}\tfrac{Q_{li}^d}{P_{pi}} = \eta_{lpi}\tfrac{Q_{li}^d}{P_{pi}} \\
\eta_{lpi} &= b_{pli}\tfrac{P_{pi}}{Q_{li}^d} \qquad (\because b_{pli} = b_{lpi}) \\
a_{li} &= Q_{li}^d - b_{li}P_{li} - b_{lpi}P_{pi} = Q_{li}^d - \eta_{li}\tfrac{Q_{li}^d}{P_{li}}P_{li} - \eta_{lpi}\tfrac{Q_{li}^d}{P_{pi}}P_{pi} = Q_{li}^d(1 - \eta_{li} - \eta_{lpi})
\end{aligned}
$$

— Inverse Demand Function for Lentils

$$
P_{li} = -(\frac{a_{li}}{b_{li}} + \frac{b_{lpi}}{b_{li}}P_{pi}) + \frac{1}{b_{li}}Q_{li}^d
$$

■ Demand Functions for **China**

♦ Peas

$$
\begin{aligned}
Q_{ph}^d &= a_{ph} + b_{ph}P_{ph} + b_{plh}P_{lh} \\
\Rightarrow b_{ph} &= \tfrac{dQ_{ph}^d}{dP_{ph}} = \tfrac{dQ_{ph}^d}{dP_{ph}}\tfrac{P_{ph}}{Q_{ph}^d}\tfrac{Q_{ph}^d}{P_{ph}} = \eta_{ph}\tfrac{Q_{ph}^d}{P_{ph}} \\
b_{plh} &= \tfrac{dQ_{ph}^d}{dP_{lh}} = \tfrac{dQ_{ph}^d}{dP_{lh}}\tfrac{P_{lh}}{Q_{ph}^d}\tfrac{Q_{ph}^d}{P_{lh}} = \eta_{plh}\tfrac{Q_{ph}^d}{P_{lh}} \\
a_{ph} &= Q_{ph}^d - b_{ph}P_{ph} - b_{plh}P_{lh} = Q_{ph}^d - \eta_{ph}\tfrac{Q_{ph}^d}{P_{ph}}P_{ph} - \eta_{plh}\tfrac{Q_{ph}^d}{P_{lh}}P_{lh} = Q_{ph}^d(1 - \eta_{ph} - \eta_{plh})
\end{aligned}
$$

— Inverse Demand Function for Peas

$$
P_{ph} = -(\frac{a_{ph}}{b_{ph}} + \frac{b_{plh}}{b_{ph}}P_{lh}) + \frac{1}{b_{ph}}Q_{ph}^d
$$

♦ Lentils

$$
\begin{aligned}
Q_{lh}^d &= a_{lh} + b_{lph}P_{ph} + b_{lh}P_{lh} \\
\Rightarrow b_{lh} &= \tfrac{dQ_{lh}^d}{dP_{lh}} = \tfrac{dQ_{lh}^d}{dP_{lh}}\tfrac{P_{lh}}{Q_{lh}^d}\tfrac{Q_{lh}^d}{P_{lh}} = \eta_{lh}\tfrac{Q_{lh}^d}{P_{lh}} \\
b_{lph} &= \tfrac{dQ_{lh}^d}{dP_{ph}} = \tfrac{dQ_{lh}^d}{dP_{ph}}\tfrac{P_{ph}}{Q_{lh}^d}\tfrac{Q_{lh}^d}{P_{ph}} = \eta_{lph}\tfrac{Q_{lh}^d}{P_{ph}} \\
\eta_{lph} &= b_{plh}\tfrac{P_{ph}}{Q_{lh}^d} \qquad (\because b_{plh} = b_{lph}) \\
a_{lh} &= Q_{lh}^d - b_{lph}P_{ph} - b_{lh}P_{lh} = Q_{lh}^d - \eta_{lph}\tfrac{Q_{lh}^d}{P_{ph}}P_{ph} - \eta_{lh}\tfrac{Q_{lh}^d}{P_{lh}}P_{lh} = Q_{lh}^d(1 - \eta_{lph} - \eta_{lh})
\end{aligned}
$$

— Inverse Demand Function for Lentils

$$P_{lh} = -(\frac{a_{lh}}{b_{lh}} + \frac{b_{lph}}{b_{lh}} P_{ph}) + \frac{1}{b_{lh}} Q^d_{lh}$$

■ Demand Functions for **Bangladesh**

⧫ Peas

$$\begin{aligned}
Q^d_{pb} &= a_{pb} + b_{pb}P_{pb} + b_{plb}P_{lb} \\
\Rightarrow b_{pb} &= \tfrac{dQ^d_{pb}}{dP_{pb}} = \tfrac{dQ^d_{pb}}{dP_{pb}}\tfrac{P_{pb}}{Q^d_{pb}}\tfrac{Q^d_{pb}}{P_{pb}} = \eta_{pb}\tfrac{Q^d_{pb}}{P_{pb}} \\
b_{plb} &= \tfrac{dQ^d_{pb}}{dP_{lb}} = \tfrac{dQ^d_{pb}}{dP_{lb}}\tfrac{P_{lb}}{Q^d_{pb}}\tfrac{Q^d_{pb}}{P_{lb}} = \eta_{plb}\tfrac{Q^d_{pb}}{P_{lb}} \\
a_{pb} &= Q^d_{pb} - b_{pb}P_{pb} - b_{plb}P_{lb} = Q^d_{pb} - \eta_{pb}\tfrac{Q^d_{pb}}{P_{pb}}P_{pb} - \eta_{plb}\tfrac{Q^d_{pb}}{P_{lb}}P_{lb} = Q^d_{pb}(1 - \eta_{pb} - \eta_{plb})
\end{aligned}$$

— Inverse Demand Function for Peas

$$P_{pb} = -(\frac{a_{pb}}{b_{pb}} + \frac{b_{plb}}{b_{pb}} P_{lb}) + \frac{1}{b_{pb}} Q^d_{pb}$$

⧫ Lentils

$$\begin{aligned}
Q^d_{lb} &= a_{lb} + b_{lpb}P_{pb} + b_{lb}P_{lb} \\
\Rightarrow b_{lb} &= \tfrac{dQ^d_{lb}}{dP_{lb}} = \tfrac{dQ^d_{lb}}{dP_{lb}}\tfrac{P_{lb}}{Q^d_{lb}}\tfrac{Q^d_{lb}}{P_{lb}} = \eta_{lb}\tfrac{Q^d_{lb}}{P_{lb}} \\
b_{lpb} &= \tfrac{dQ^d_{lb}}{dP_{pb}} = \tfrac{dQ^d_{lb}}{dP_{pb}}\tfrac{P_{pb}}{Q^d_{lb}}\tfrac{Q^d_{lb}}{P_{pb}} = \eta_{lpb}\tfrac{Q^d_{lb}}{P_{pb}} \\
\eta_{lpb} &= b_{plb}\tfrac{P_{pb}}{Q^d_{lb}} \qquad (\because b_{plb} = b_{lpb}) \\
a_{lb} &= Q^d_{lb} - b_{lb}P_{lb} - b_{lpb}P_{pb} = Q^d_{lb} - \eta_{lb}\tfrac{Q^d_{lb}}{P_{lb}}P_{lb} - \eta_{lpb}\tfrac{Q^d_{lb}}{P_{pb}}P_{pb} = Q^d_{lb}(1 - \eta_{lb} - \eta_{lpb})
\end{aligned}$$

— Inverse Demand Function for Lentils

$$P_{lb} = -(\frac{a_{lb}}{b_{lb}} + \frac{b_{lpb}}{b_{lb}} P_{pb}) + \frac{1}{b_{lb}} Q^d_{lb}$$

■ Demand Functions for **Turkey**

♦ Peas

$$\begin{aligned}
Q^d_{pt} &= a_{pt} + b_{pt}P_{pt} + b_{plt}P_{lt} \\
\Rightarrow b_{pt} &= \tfrac{dQ^d_{pt}}{dP_{pt}} = \tfrac{dQ^d_{pt}}{dP_{pt}}\tfrac{P_{pt}}{Q^d_{pt}}\tfrac{Q^d_{pt}}{P_{pt}} = \eta_{pt}\tfrac{Q^d_{pt}}{P_{pt}} \\
b_{plt} &= \tfrac{dQ^d_{pt}}{dP_{lt}} = \tfrac{dQ^d_{pt}}{dP_{lt}}\tfrac{P_{lt}}{Q^d_{pt}}\tfrac{Q^d_{pt}}{P_{lt}} = \eta_{plt}\tfrac{Q^d_{pt}}{P_{lt}} \\
a_{pt} &= Q^d_{pt} - b_{pt}P_{pt} - b_{plt}P_{lt} = Q^d_{pt} - \eta_{pt}\tfrac{Q^d_{pt}}{P_{pt}}P_{pt} - \eta_{plt}\tfrac{Q^d_{pt}}{P_{lt}}P_{lt} = Q^d_{pt}(1 - \eta_{pt} - \eta_{plt})
\end{aligned}$$

— Inverse Demand Function for Peas

$$P_{pt} = -(\frac{a_{pt}}{b_{pt}} + \frac{b_{plt}}{b_{pt}}P_{lt}) + \frac{1}{b_{pt}}Q^d_{pt}$$

♦ Lentils

$$\begin{aligned}
Q^d_{lt} &= a_{lt} + b_{lpt}P_{pt} + b_{lt}P_{lt} \\
\Rightarrow b_{lt} &= \tfrac{dQ^d_{lt}}{dP_{lt}} = \tfrac{dQ^d_{lt}}{dP_{lt}}\tfrac{P_{lt}}{Q^d_{lt}}\tfrac{Q^d_{lt}}{P_{lt}} = \eta_{lt}\tfrac{Q^d_{lt}}{P_{lt}} \\
b_{lpt} &= \tfrac{dQ^d_{lt}}{dP_{pt}} = \tfrac{dQ^d_{lt}}{dP_{pt}}\tfrac{P_{pt}}{Q^d_{lt}}\tfrac{Q^d_{lt}}{P_{pt}} = \eta_{lpt}\tfrac{Q^d_{lt}}{P_{pt}} \\
\eta_{lpt} &= b_{plt}\tfrac{P_{pt}}{Q^d_{lt}} \qquad (\because b_{plt} = b_{lpt}) \\
a_{lt} &= Q^d_{lt} - b_{lt}P_{lt} - b_{lpt}P_{pt} = Q^d_{lt} - \eta_{lt}\tfrac{Q^d_{lt}}{P_{lt}}P_{lt} - \eta_{lpt}\tfrac{Q^d_{lt}}{P_{pt}}P_{pt} = Q^d_{lt}(1 - \eta_{lt} - \eta_{lpt})
\end{aligned}$$

— Inverse Demand Function for Lentils

$$P_{lt} = -(\frac{a_{lt}}{b_{lt}} + \frac{b_{lpt}}{b_{lt}}P_{pt}) + \frac{1}{b_{lt}}Q^d_{lt}$$

■ Demand Functions for the **European Union**

♦ Peas

$$\begin{aligned}
Q^d_{pe} &= a_{pe} + b_{pe}P_{pe} + b_{ple}P_{le} \\
\Rightarrow b_{pe} &= \tfrac{dQ^d_{pe}}{dP_{pe}} = \tfrac{dQ^d_{pe}}{dP_{pe}}\tfrac{P_{pe}}{Q^d_{pe}}\tfrac{Q^d_{pe}}{P_{pe}} = \eta_{pe}\tfrac{Q^d_{pe}}{P_{pe}} \\
b_{ple} &= \tfrac{dQ^d_{pe}}{dP_{le}} = \tfrac{dQ^d_{pe}}{dP_{le}}\tfrac{P_{le}}{Q^d_{pe}}\tfrac{Q^d_{pe}}{P_{le}} = \eta_{ple}\tfrac{Q^d_{pe}}{P_{le}} \\
a_{pe} &= Q^d_{pe} - b_{pe}P_{pe} - b_{ple}P_{le} = Q^d_{pe} - \eta_{pe}\tfrac{Q^d_{pe}}{P_{pe}}P_{pe} - \eta_{ple}\tfrac{Q^d_{pe}}{P_{le}}P_{le} = Q^d_{pe}(1 - \eta_{pe} - \eta_{ple})
\end{aligned}$$

— Inverse Demand Function for Peas

$$P_{pe} = -(\frac{a_{pe}}{b_{pe}} + \frac{b_{ple}}{b_{pe}} P_{le}) + \frac{1}{b_{pe}} Q^d_{pe}$$

♦ Lentils

$$\begin{aligned}
Q^d_{le} &= a_{le} + b_{lpe} P_{pe} + b_{le} P_{le} \\
\Rightarrow b_{le} &= \tfrac{dQ^d_{le}}{dP_{le}} = \tfrac{dQ^d_{le}}{dP_{le}} \tfrac{P_{le}}{Q^d_{le}} \tfrac{Q^d_{le}}{P_{le}} = \eta_{le} \tfrac{Q^d_{le}}{P_{le}} \\
b_{lpe} &= \tfrac{dQ^d_{le}}{dP_{pe}} = \tfrac{dQ^d_{le}}{dP_{pe}} \tfrac{P_{pe}}{Q^d_{le}} \tfrac{Q^d_{le}}{P_{pe}} = \eta_{lpe} \tfrac{Q^d_{le}}{P_{pe}} \\
\eta_{lpe} &= b_{ple} \tfrac{P_{pe}}{Q^d_{le}} \qquad (\because b_{ple} = b_{lpe}) \\
a_{le} &= Q^d_{le} - b_{le} P_{le} - b_{lpe} P_{pe} = Q^d_{le} - \eta_{le} \tfrac{Q^d_{le}}{P_{le}} P_{le} - \eta_{lpe} \tfrac{Q^d_{le}}{P_{pe}} P_{pe} = Q^d_{le}(1 - \eta_{le} - \eta_{lpe})
\end{aligned}$$

— Inverse Demand Function for Lentils

$$P_{le} = -(\frac{a_{le}}{b_{le}} + \frac{b_{lpe}}{b_{le}} P_{pe}) + \frac{1}{b_{le}} Q^d_{le}$$

■ Demand Functions for the **ROW**

♦ Peas

$$\begin{aligned}
Q^d_{pr} &= a_{pr} + b_{pr} P_{pr} + b_{plr} P_{lr} \\
\Rightarrow b_{pr} &= \tfrac{dQ^d_{pr}}{dP_{pr}} = \tfrac{dQ^d_{pr}}{dP_{pr}} \tfrac{P_{pr}}{Q^d_{pr}} \tfrac{Q^d_{pr}}{P_{pr}} = \eta_{pr} \tfrac{Q^d_{pr}}{P_{pr}} \\
b_{plr} &= \tfrac{dQ^d_{pr}}{dP_{lr}} = \tfrac{dQ^d_{pr}}{dP_{lr}} \tfrac{P_{lr}}{Q^d_{pr}} \tfrac{Q^d_{pr}}{P_{lr}} = \eta_{plr} \tfrac{Q^d_{pr}}{P_{lr}} \\
a_{pr} &= Q^d_{pr} - b_{pr} P_{pr} - b_{plr} P_{lr} = Q^d_{pr} - \eta_{pr} \tfrac{Q^d_{pr}}{P_{pr}} P_{pr} - \eta_{plr} \tfrac{Q^d_{pr}}{P_{lr}} P_{lr} = Q^d_{pr}(1 - \eta_{pr} - \eta_{plr})
\end{aligned}$$

— Inverse Demand Function for Peas

$$P_{pr} = -(\frac{a_{pr}}{b_{pr}} + \frac{b_{plr}}{b_{pr}} P_{lr}) + \frac{1}{b_{pr}} Q^d_{pr}$$

♦ Lentils

$$
\begin{aligned}
Q^d_{lr} &= a_{lr} + b_{lpr}P_{pr} + b_{lr}P_{lr} \\
\Rightarrow b_{lr} &= \tfrac{dQ^d_{lr}}{dP_{lr}} = \tfrac{dQ^d_{lr}}{dP_{lr}}\tfrac{P_{lr}}{Q^d_{lr}}\tfrac{Q^d_{lr}}{P_{lr}} = \eta_{lr}\tfrac{Q^d_{lr}}{P_{lr}} \\
b_{lpr} &= \tfrac{dQ^d_{lr}}{dP_{pr}} = \tfrac{dQ^d_{lr}}{dP_{pr}}\tfrac{P_{pr}}{Q^d_{lr}}\tfrac{Q^d_{lr}}{P_{pr}} = \eta_{lpr}\tfrac{Q^d_{lr}}{P_{pr}} \\
\eta_{lpr} &= b_{plr}\tfrac{P_{pr}}{Q^d_{lr}} \qquad (\because b_{plr} = b_{lpr}) \\
a_{lr} &= Q^d_{lr} - b_{lr}P_{lr} - b_{lpr}P_{pr} = Q^d_{lr} - \eta_{lr}\tfrac{Q^d_{lr}}{P_{lr}}P_{lr} - \eta_{lpr}\tfrac{Q^d_{lr}}{P_{pr}}P_{pr} = Q^d_{lr}(1 - \eta_{lr} - \eta_{lpr})
\end{aligned}
$$

— Inverse Demand Function for Lentils

$$
P_{lr} = -(\frac{a_{lr}}{b_{lr}} + \frac{b_{lpr}}{b_{lr}}P_{pr}) + \frac{1}{b_{lr}}Q^d_{lr}
$$

A.1.2 Supply Functions

■ Supply Functions of **Canada**

Based on equation (4.15), output supply functions in Canada can be derived as the following[2]:

♦ Peas

$$
\begin{aligned}
Q^s_{pc} &= (\alpha_{pc} + \rho_{pc}\bar{K}_{pc}) + \beta_{pc}P_{pc}(1-l_p) + \beta_{plc}P_{lc}(1-l_l) + \beta_{pwc}P_{wc}(1-l_w) + \beta_{pcc}P_{cc}(1-l_c) \\
\Rightarrow \beta_{pc} &= \tfrac{dQ^s_{pc}}{dP_{pc}(1-l_p)} = \tfrac{dQ^s_{pc}}{dP_{pc}(1-l_p)}\tfrac{P_{pc}}{Q^s_{pc}}\tfrac{Q^s_{pc}}{P_{pc}} = \epsilon_{pc}\tfrac{Q^s_{pc}}{P_{pc}(1-l_p)} \\
\beta_{plc} &= \tfrac{dQ^s_{pc}}{dP_{lc}(1-l_l)} = \tfrac{dQ^s_{pc}}{dP_{lc}(1-l_l)}\tfrac{P_{lc}}{Q^s_{pc}}\tfrac{Q^s_{pc}}{P_{lc}} = \epsilon_{plc}\tfrac{Q^s_{pc}}{P_{lc}(1-l_l)} \\
\beta_{pwc} &= \tfrac{dQ^s_{pc}}{dP_{wc}(1-l_w)} = \tfrac{dQ^s_{pc}}{dP_{wc}(1-l_w)}\tfrac{P_{wc}}{Q^s_{pc}}\tfrac{Q^s_{pc}}{P_{wc}} = \epsilon_{pwc}\tfrac{Q^s_{pc}}{P_{wc}(1-l_w)} \\
\beta_{pcc} &= \tfrac{dQ^s_{pc}}{dP_{cc}(1-l_c)} = \tfrac{dQ^s_{pc}}{dP_{cc}(1-l_c)}\tfrac{P_{cc}}{Q^s_{pc}}\tfrac{Q^s_{pc}}{P_{cc}} = \epsilon_{pcc}\tfrac{Q^s_{pc}}{P_{cc}(1-l_c)} \\
\rho_{pc} &= \tfrac{dQ^s_{pc}}{dK_{pc}} = \tfrac{dQ^s_{pc}}{dK_{pc}}\tfrac{K_{pc}}{Q^s_{pc}}\tfrac{Q^s_{pc}}{K_{pc}} = \theta_{pc}\tfrac{Q^s_{pc}}{K_{pc}} \\
\alpha_{pc} &= Q^s_{pc} - \beta_{pc}P_{pc}(1-l_p) - \beta_{plc}P_{lc}(1-l_l) - \beta_{pwc}P_{wc}(1-l_w) - \beta_{pcc}P_{cc}(1-l_c) - \rho_{pc}K_{pc} \\
&= Q^s_{pc} - \epsilon_{pc}\tfrac{Q^s_{pc}}{P_{pc}(1-l_p)}P_{pc}(1-l_p) - \epsilon_{plc}\tfrac{Q^s_{pc}}{P_{lc}(1-l_l)}P_{lc}(1-l_l) - \epsilon_{pwc}\tfrac{Q^s_{pc}}{P_{wc}(1-l_w)}P_{wc}(1-l_w) \\
&\quad -\epsilon_{pcc}\tfrac{Q^s_{pc}}{P_{cc}(1-l_c)}P_{cc}(1-l_c) - \theta_{pc}\tfrac{Q^s_{pc}}{K_{pc}}K_{pc} \\
&= Q^s_{pc}(1 - \epsilon_{pc} - \epsilon_{plc} - \epsilon_{pwc} - \epsilon_{pcc} - \theta_{pc})
\end{aligned}
$$

[2]For notation ease, the subscript uses one letter to represent the crop when $i = j$. For example, β_{pc} is used, rather than β_{ppc}, to represent the own price elasticity of pea supply.

where Q^s_{pc} is the domestic production of peas in Canada, P_{pc}, P_{lc}, P_{wc} and P_{cc} are the domestic prices for peas, lentils, wheat and canola respectively, ϵ_{pc} is the supply elasticity of peas, ϵ_{plc} is the cross supply elasticity of peas and lentils, ϵ_{pwc} is the cross supply elasticity of peas and wheat, ϵ_{pcc} is the cross supply elasticity of peas and canola, α and β are parameters for intercept and slope respectively.

— Inverse Supply Function for Peas

$$P_{pc} = -\frac{1}{\beta_{pc}(1-l_p)}(\alpha_{pc}+\rho_{pc}\bar{K}_{pc}+\beta_{plc}P_{lc}(1-l_l)+\beta_{pwc}P_{wc}(1-l_w)+\beta_{pcc}P_{cc}(1-l_c))+\frac{1}{\beta_{pc}(1-l_p)}Q^s_{pc}$$

♦ Lentils

$$\begin{aligned}
Q^s_{lc} &= (\alpha_{lc}+\rho_{lpc}\bar{K}_{pc})+\beta_{lpc}P_{pc}(1-l_p)+\beta_{lc}P_{lc}(1-l_l)+\beta_{lwc}P_{wc}(1-l_w)+\beta_{lcc}P_{cc}(1-l_c)\\
\Rightarrow \beta_{lpc} &= \tfrac{dQ^s_{lc}}{dP_{pc}(1-l_p)} = \tfrac{dQ^s_{lc}}{dP_{pc}(1-l_p)}\tfrac{P_{pc}}{Q^s_{lc}}\tfrac{Q^s_{lc}}{P_{pc}} = \epsilon_{lpc}\tfrac{Q^s_{lc}}{P_{pc}(1-l_p)}\\
\beta_{lc} &= \tfrac{dQ^s_{lc}}{dP_{lc}(1-l_l)} = \tfrac{dQ^s_{lc}}{dP_{lc}(1-l_l)}\tfrac{P_{lc}}{Q^s_{lc}}\tfrac{Q^s_{lc}}{P_{lc}} = \epsilon_{lc}\tfrac{Q^s_{lc}}{P_{lc}(1-l_l)}\\
\beta_{lwc} &= \tfrac{dQ^s_{lc}}{dP_{wc}(1-l_w)} = \tfrac{dQ^s_{lc}}{dP_{wc}(1-l_w)}\tfrac{P_{wc}}{Q^s_{lc}}\tfrac{Q^s_{lc}}{P_{wc}} = \epsilon_{lwc}\tfrac{Q^s_{lc}}{P_{wc}(1-l_w)}\\
\beta_{lcc} &= \tfrac{dQ^s_{lc}}{dP_{cc}(1-l_c)} = \tfrac{dQ^s_{lc}}{dP_{cc}(1-l_c)}\tfrac{P_{cc}}{Q^s_{lc}}\tfrac{Q^s_{lc}}{P_{cc}} = \epsilon_{lcc}\tfrac{Q^s_{lc}}{P_{cc}(1-l_c)}\\
\rho_{lpc} &= \tfrac{dQ^s_{lc}}{d\bar{K}_{pc}} = \tfrac{dQ^s_{lc}}{d\bar{K}_{pc}}\tfrac{\bar{K}_{pc}}{Q^s_{lc}}\tfrac{Q^s_{lc}}{\bar{K}_{pc}} = \theta_{lpc}\tfrac{Q^s_{lc}}{\bar{K}_{pc}}\\
\epsilon_{lpc} &= \beta_{plc}\tfrac{P_{pc}(1-l_p)}{Q^s_{lc}} \qquad (\because \beta_{plc}=\beta_{lpc})\\
\alpha_{lc} &= Q^s_{lc}-\beta_{lpc}P_{pc}(1-l_p)-\beta_{lc}P_{lc}(1-l_l)-\beta_{lwc}P_{wc}(1-l_w)-\beta_{lcc}P_{cc}(1-l_c)-\rho_{lpc}\bar{K}_{pc}\\
&= Q^s_{lc}-\epsilon_{lpc}\tfrac{Q^s_{lc}}{P_{pc}(1-l_p)}P_{pc}(1-l_p)-\epsilon_{lc}\tfrac{Q^s_{lc}}{P_{lc}(1-l_l)}P_{lc}(1-l_l)-\epsilon_{lwc}\tfrac{Q^s_{lc}}{P_{wc}(1-l_w)}P_{wc}(1-l_w)\\
&-\epsilon_{lcc}\tfrac{Q^s_{lc}}{P_{cc}(1-l_c)}P_{cc}(1-l_c)-\theta_{lpc}\tfrac{Q^s_{lc}}{\bar{K}_{pc}}\bar{K}_{pc}\\
&= Q^s_{lc}(1-\epsilon_{lpc}-\epsilon_{lc}-\epsilon_{lwc}-\epsilon_{lcc}-\theta_{lpc})
\end{aligned}$$

— Inverse Supply Function for Lentils

$$P_{lc} = -\frac{1}{\beta_{lc}(1-l_l)}(\alpha_{lc}+\rho_{lpc}\bar{K}_{pc}+\beta_{lpc}P_{pc}(1-l_p)+\beta_{lwc}P_{wc}(1-l_w)+\beta_{lcc}P_{cc}(1-l_c))+\frac{1}{\beta_{lc}(1-l_l)}Q^s_{lc}$$

♦ Wheat

$$
\begin{aligned}
Q_{wc}^s &= (\alpha_{wc} + \rho_{wpc}\bar{K}_{pc}) + \beta_{pwc}P_{pc}(1-l_p) + \beta_{lwc}P_{lc}(1-l_l) + \beta_{wc}P_{wc}(1-l_w) + \beta_{wcc}P_{cc}(1-l_c) \\
\Rightarrow \beta_{wpc} &= \tfrac{dQ_{wc}^s}{dP_{pc}(1-l_p)} = \tfrac{dQ_{wc}^s}{dP_{pc}(1-l_p)}\tfrac{P_{pc}}{Q_{wc}^s}\tfrac{Q_{wc}^s}{P_{pc}} = \epsilon_{wpc}\tfrac{Q_{wc}^s}{P_{pc}(1-l_p)} \\
\beta_{wlc} &= \tfrac{dQ_{wc}^s}{dP_{lc}(1-l_l)} = \tfrac{dQ_{wc}^s}{dP_{lc}(1-l_l)}\tfrac{P_{lc}}{Q_{wc}^s}\tfrac{Q_{wc}^s}{P_{lc}} = \epsilon_{wlc}\tfrac{Q_{wc}^s}{P_{lc}(1-l_l)} \\
\beta_{wc} &= \tfrac{dQ_{wc}^s}{dP_{wc}(1-l_w)} = \tfrac{dQ_{wc}^s}{dP_{wc}(1-l_w)}\tfrac{P_{wc}}{Q_{wc}^s}\tfrac{Q_{wc}^s}{P_{wc}} = \epsilon_{wc}\tfrac{Q_{wc}^s}{P_{wc}(1-l_w)} \\
\beta_{wcc} &= \tfrac{dQ_{wc}^s}{dP_{cc}(1-l_c)} = \tfrac{dQ_{wc}^s}{dP_{cc}(1-l_c)}\tfrac{P_{cc}}{Q_{wc}^s}\tfrac{Q_{wc}^s}{P_{cc}} = \epsilon_{wcc}\tfrac{Q_{wc}^s}{P_{cc}(1-l_c)} \\
\rho_{wpc} &= \tfrac{dQ_{wc}^s}{d\bar{K}_{pc}} = \tfrac{dQ_{wc}^s}{d\bar{K}_{pc}}\tfrac{\bar{K}_{pc}}{Q_{wc}^s}\tfrac{Q_{wc}^s}{\bar{K}_{pc}} = \theta_{wpc}\tfrac{Q_{wc}^s}{\bar{K}_{pc}} \\
\epsilon_{wpc} &= \beta_{pwc}\tfrac{P_{pc}(1-l_p)}{Q_{wc}^s} \qquad (\because \beta_{pwc} = \beta_{wpc}) \\
\epsilon_{wlc} &= \beta_{lwc}\tfrac{P_{lc}(1-l_l)}{Q_{wc}^s} \qquad (\because \beta_{lwc} = \beta_{wlc}) \\
\alpha_{wc} &= Q_{wc}^s - \beta_{wpc}P_{pc}(1-l_p) - \beta_{wlc}P_{lc}(1-l_l) - \beta_{wc}P_{wc}(1-l_w) - \beta_{wcc}P_{cc}(1-l_c) - \rho_{wpc}\bar{K}_{pc} \\
&= Q_{wc}^s - \epsilon_{wpc}\tfrac{Q_{wc}^s}{P_{pc}(1-l_p)}P_{pc}(1-l_p) - \epsilon_{wlc}\tfrac{Q_{wc}^s}{P_{lc}(1-l_l)}P_{lc}(1-l_l) - \epsilon_{wc}\tfrac{Q_{wc}^s}{P_{wc}(1-l_w)}P_{wc}(1-l_w) \\
&-\epsilon_{wcc}\tfrac{Q_{wc}^s}{P_{cc}(1-l_c)}P_{cc}(1-l_c) - \theta_{wpc}\tfrac{Q_{wc}^s}{K_{pc}}K_{pc} \\
&= Q_{wc}^s(1 - \epsilon_{wpc} - \epsilon_{wlc} - \epsilon_{wc} - \epsilon_{wcc} - \theta_{wpc})
\end{aligned}
$$

— Inverse Supply Function for Wheat

$$
P_{wc} = -\frac{1}{\beta_{wc}(1-l_w)}(\alpha_{wc}+\rho_{wpc}\bar{K}_{pc}+\beta_{wpc}P_{pc}(1-l_p)+\beta_{wlc}P_{lc}(1-l_l)+\beta_{wcc}P_{cc}(1-l_c))+\frac{1}{\beta_{wc}(1-l_w)}Q_{wc}^s \tag{A.2}
$$

♦ Canola

$$
\begin{aligned}
Q^s_{cc} &= (\alpha_{cc} + \rho_{cpc}\bar{K}_{pc}) + \beta_{pcc}P_{pc}(1-l_p) + \beta_{lcc}P_{lc}(1-l_l) + \beta_{wcc}P_{wc}(1-l_w) + \beta_{cc}P_{cc}(1-l_c) \\
\Rightarrow \beta_{cpc} &= \tfrac{dQ^s_{cc}}{dP_{pc}(1-l_p)} = \tfrac{dQ^s_{cc}}{dP_{pc}(1-l_p)}\tfrac{P_{pc}}{Q^s_{cc}}\tfrac{Q^s_{cc}}{P_{pc}} = \epsilon_{cpc}\tfrac{Q^s_{cc}}{P_{pc}(1-l_p)} \\
\beta_{clc} &= \tfrac{dQ^s_{cc}}{dP_{lc}(1-l_l)} = \tfrac{dQ^s_{cc}}{dP_{lc}(1-l_l)}\tfrac{P_{lc}}{Q^s_{cc}}\tfrac{Q^s_{cc}}{P_{lc}} = \epsilon_{clc}\tfrac{Q^s_{cc}}{P_{lc}(1-l_l)} \\
\beta_{cwc} &= \tfrac{dQ^s_{cc}}{dP_{wc}(1-l_w)} = \tfrac{dQ^s_{cc}}{dP_{wc}(1-l_w)}\tfrac{P_{wc}}{Q^s_{cc}}\tfrac{Q^s_{cc}}{P_{wc}} = \epsilon_{cwc}\tfrac{Q^s_{cc}}{P_{wc}(1-l_w)} \\
\beta_{cc} &= \tfrac{dQ^s_{cc}}{dP_{cc}(1-l_c)} = \tfrac{dQ^s_{cc}}{dP_{cc}(1-l_c)}\tfrac{P_{cc}}{Q^s_{cc}}\tfrac{Q^s_{cc}}{P_{cc}} = \epsilon_{cc}\tfrac{Q^s_{cc}}{P_{cc}(1-l_c)} \\
\rho_{cpc} &= \tfrac{dQ^s_{cc}}{d\bar{K}_{pc}} = \tfrac{dQ^s_{cc}}{d\bar{K}_{pc}}\tfrac{\bar{K}_{pc}}{Q^s_{cc}}\tfrac{Q^s_{cc}}{\bar{K}_{pc}} = \theta_{cpc}\tfrac{Q^s_{cc}}{\bar{K}_{pc}} \\
\epsilon_{cpc} &= \beta_{pcc}\tfrac{P_{pc}(1-l_p)}{Q^s_{cc}} \qquad (\because \beta_{pcc} = \beta_{cpc}) \\
\epsilon_{clc} &= \beta_{lcc}\tfrac{P_{lc}(1-l_l)}{Q^s_{cc}} \qquad (\because \beta_{lcc} = \beta_{clc}) \\
\epsilon_{cwc} &= \beta_{wcc}\tfrac{P_{wc}(1-l_w)}{Q^s_{cc}} \qquad (\because \beta_{wcc} = \beta_{cwc}) \\
\alpha_{cc} &= Q^s_{cc} - \beta_{cpc}P_{pc}(1-l_p) - \beta_{clc}P_{lc}(1-l_l) - \beta_{cwc}P_{wc}(1-l_w) - \beta_{cc}P_{cc} - \rho_{cpc}K_{pc} \\
&= Q^s_{cc} - \epsilon_{cpc}\tfrac{Q^s_{cc}}{P_{pc}(1-l_p)}P_{pc}(1-l_p) - \epsilon_{clc}\tfrac{Q^s_{cc}}{P_{lc}(1-l_l)}P_{lc}(1-l_l) - \epsilon_{cwc}\tfrac{Q^s_{cc}}{P_{wc}(1-l_w)}P_{wc}(1-l_w) \\
&\quad -\epsilon_{cpc}\tfrac{Q^s_{cc}}{P_{cc}(1-l_c)}P_{cc}(1-l_c) - \theta_{cpc}\tfrac{Q^s_{cc}}{\bar{K}_{pc}}K_{pc} \\
&= Q^s_{cc}(1 - \epsilon_{cpc} - \epsilon_{clc} - \epsilon_{cwc} - \epsilon_{cc} - \theta_{cpc})
\end{aligned}
$$

— Inverse Supply Function for Canola

$$
P_{cc} = -\frac{1}{\beta_{cc}(1-l_c)}(\alpha_{cc}+\rho_{cpc}\bar{K}_{pc}+\beta_{pcc}P_{pc}(1-l_p)+\beta_{lcc}P_{lc}(1-l_l)+\beta_{wcc}P_{wc}(1-l_w))+\frac{1}{\beta_{cc}(1-l_c)}Q^s_{cc} \tag{A.3}
$$

■ Supply Functions of **India**

♦ Peas

$$
\begin{aligned}
Q^s_{pi} &= \alpha_{pi} + \beta_{pi}P_{pi} + \beta_{pli}P_{li} \\
\Rightarrow \beta_{pi} &= \tfrac{dQ^s_{pi}}{dP_{pi}} = \tfrac{dQ^s_{pi}}{dP_{pi}}\tfrac{P_{pi}}{Q^s_{pi}}\tfrac{Q^s_{pi}}{P_{pi}} = \epsilon_{pi}\tfrac{Q^s_{pi}}{P_{pi}} \\
\beta_{pli} &= \tfrac{dQ^s_{pi}}{dP_{li}} = \tfrac{dQ^s_{pi}}{dP_{li}}\tfrac{P_{li}}{Q^s_{pi}}\tfrac{Q^s_{pi}}{P_{li}} = \epsilon_{pli}\tfrac{Q^s_{pi}}{P_{li}} \\
\alpha_{pi} &= Q^s_{pi} - \beta_{pi}P_{pi} - \beta_{pli}P_{li} \\
&= Q^s_{pi} - \epsilon_{pi}\tfrac{Q^s_{pi}}{P_{pi}}P_{pi} - \epsilon_{pli}\tfrac{Q^s_{pi}}{P_{li}}P_{li} \\
&= Q^s_{pi}(1 - \epsilon_{pi} - \epsilon_{pli})
\end{aligned}
$$

— Inverse Supply Function for Peas

$$P_{pi} = -(\frac{\alpha_{pi}}{\beta_{pi}} + \frac{\beta_{pli}}{\beta_{pi}} P_{li}) + \frac{1}{\beta_{pi}} Q^s_{pi}$$

♦ Lentils

$$\begin{aligned}
Q^s_{li} &= \alpha_{li} + \beta_{lpi} P_{pi} + \beta_{li} P_{li} \\
\Rightarrow \beta_{lpi} &= \tfrac{dQ^s_{li}}{dP_{pi}} = \tfrac{dQ^s_{li}}{dP_{pi}} \tfrac{P_{pi}}{Q^s_{li}} \tfrac{Q^s_{li}}{P_{pi}} = \epsilon_{lpi} \tfrac{Q^s_{li}}{P_{pi}} \\
\beta_{li} &= \tfrac{dQ^s_{li}}{dP_{li}} = \tfrac{dQ^s_{li}}{dP_{li}} \tfrac{P_{li}}{Q^s_{li}} \tfrac{Q^s_{li}}{P_{li}} = \epsilon_{li} \tfrac{Q^s_{li}}{P_{li}} \\
\epsilon_{lpi} &= \beta_{pli} \tfrac{P_{pi}}{Q^s_{li}} \qquad (\because \beta_{pli} = \beta_{lpi}) \\
\alpha_{li} &= Q^s_{li} - \beta_{lpi} P_{pi} - \beta_{li} P_{li} \\
&= Q^s_{li} - \epsilon_{lpi} \tfrac{Q^s_{li}}{P_{pi}} P_{pi} - \epsilon_{li} \tfrac{Q^s_{li}}{P_{li}} P_{li} \\
&= Q^s_{li}(1 - \epsilon_{lpi} - \epsilon_{li})
\end{aligned}$$

— Inverse Supply Function for Lentils

$$P_{li} = -(\frac{\alpha_{li}}{\beta_{li}} + \frac{\beta_{lpi}}{\beta_{li}} P_{pi}) + \frac{1}{\beta_{li}} Q^s_{li}$$

■ Supply Functions of **China**

♦ Peas

$$\begin{aligned}
Q^s_{ph} &= \alpha_{ph} + \beta_{ph} P_{ph} + \beta_{plh} P_{lh} \\
\Rightarrow \beta_{ph} &= \tfrac{dQ^s_{ph}}{dP_{ph}} = \tfrac{dQ^s_{ph}}{dP_{ph}} \tfrac{P_{ph}}{Q^s_{ph}} \tfrac{Q^s_{ph}}{P_{ph}} = \epsilon_{ph} \tfrac{Q^s_{ph}}{P_{ph}} \\
\beta_{plh} &= \tfrac{dQ^s_{ph}}{dP_{lh}} = \tfrac{dQ^s_{ph}}{dP_{lh}} \tfrac{P_{lh}}{Q^s_{ph}} \tfrac{Q^s_{ph}}{P_{lh}} = \epsilon_{plh} \tfrac{Q^s_{ph}}{P_{lh}} \\
\alpha_{ph} &= Q^s_{ph} - \beta_{ph} P_{ph} - \beta_{plh} P_{lh} \\
&= Q^s_{ph} - \epsilon_{ph} \tfrac{Q^s_{ph}}{P_{ph}} P_{ph} - \epsilon_{plh} \tfrac{Q^s_{ph}}{P_{lh}} P_{lh} \\
&= Q^s_{ph}(1 - \epsilon_{ph} - \epsilon_{plh})
\end{aligned}$$

— Inverse Supply Function for Peas

$$P_{ph} = -(\frac{\alpha_{ph}}{\beta_{ph}} + \frac{\beta_{plh}}{\beta_{ph}} P_{lh}) + \frac{1}{\beta_{ph}} Q^s_{ph}$$

♦ Lentils

$$\begin{aligned}
Q^s_{lh} &= \alpha_{lh} + \beta_{lph}P_{ph} + \beta_{lh}P_{lh} \\
\Rightarrow \beta_{lph} &= \tfrac{dQ^s_{lh}}{dP_{ph}} = \tfrac{dQ^s_{lh}}{dP_{ph}}\tfrac{P_{ph}}{Q^s_{lh}}\tfrac{Q^s_{lh}}{P_{ph}} = \epsilon_{lph}\tfrac{Q^s_{lh}}{P_{ph}} \\
\beta_{lh} &= \tfrac{dQ^s_{lh}}{dP_{lh}} = \tfrac{dQ^s_{lh}}{dP_{lh}}\tfrac{P_{lh}}{Q^s_{lh}}\tfrac{Q^s_{lh}}{P_{lh}} = \epsilon_{lh}\tfrac{Q^s_{lh}}{P_{lh}} \\
\epsilon_{lph} &= \beta_{plh}\tfrac{P_{ph}}{Q^s_{lh}} \qquad (\because \beta_{plh} = \beta_{lph}) \\
\alpha_{lh} &= Q^s_{lh} - \beta_{lph}P_{ph} - \beta_{lh}P_{lh} \\
&= Q^s_{lh} - \epsilon_{lph}\tfrac{Q^s_{lh}}{P_{ph}}P_{ph} - \epsilon_{lh}\tfrac{Q^s_{lh}}{P_{lh}}P_{lh} \\
&= Q^s_{lh}(1 - \epsilon_{lph} - \epsilon_{lh})
\end{aligned}$$

— Inverse Supply Function for Lentils

$$P_{lh} = -(\frac{\alpha_{lh}}{\beta_{lh}} + \frac{\beta_{lph}}{\beta_{lh}}P_{ph}) + \frac{1}{\beta_{lh}}Q^s_{lh}$$

■ Supply Functions of **Bangladesh**

♦ Peas

$$\begin{aligned}
Q^s_{pb} &= \alpha_{pb} + \beta_{pb}P_{pb} + \beta_{plb}P_{lb} \\
\Rightarrow \beta_{pb} &= \tfrac{dQ^s_{pb}}{dP_{pb}} = \tfrac{dQ^s_{pb}}{dP_{pb}}\tfrac{P_{pb}}{Q^s_{pb}}\tfrac{Q^s_{pb}}{P_{pb}} = \epsilon_{pb}\tfrac{Q^s_{pb}}{P_{pb}} \\
\beta_{plb} &= \tfrac{dQ^s_{pb}}{dP_{lb}} = \tfrac{dQ^s_{pb}}{dP_{lb}}\tfrac{P_{lb}}{Q^s_{pb}}\tfrac{Q^s_{pb}}{P_{lb}} = \epsilon_{plb}\tfrac{Q^s_{pb}}{P_{lb}} \\
\alpha_{pb} &= Q^s_{pb} - \beta_{pb}P_{pb} - \beta_{plb}P_{lb} \\
&= Q^s_{pb} - \epsilon_{pb}\tfrac{Q^s_{pb}}{P_{pb}}P_{pb} - \epsilon_{plb}\tfrac{Q^s_{pb}}{P_{lb}}P_{lb} \\
&= Q^s_{pb}(1 - \epsilon_{pb} - \epsilon_{plb})
\end{aligned}$$

— Inverse Supply Function for Peas

$$P_{pb} = -(\frac{\alpha_{pb}}{\beta_{pb}} + \frac{\beta_{plb}}{\beta_{pb}}P_{lb}) + \frac{1}{\beta_{pb}}Q^s_{pb}$$

♦ Lentils

$$\begin{aligned}
Q^s_{lb} &= \alpha_{lb} + \beta_{lpb}P_{pb} + \beta_{lb}P_{lb} \\
\Rightarrow \beta_{lpb} &= \tfrac{dQ^s_{lb}}{dP_{pb}} = \tfrac{dQ^s_{lb}}{dP_{pb}}\tfrac{P_{pb}}{Q^s_{lb}}\tfrac{Q^s_{lb}}{P_{pb}} = \epsilon_{lpb}\tfrac{Q^s_{lb}}{P_{pb}} \\
\beta_{lb} &= \tfrac{dQ^s_{lb}}{dP_{lb}} = \tfrac{dQ^s_{lb}}{dP_{lb}}\tfrac{P_{lb}}{Q^s_{lb}}\tfrac{Q^s_{lb}}{P_{lb}} = \epsilon_{lb}\tfrac{Q^s_{lb}}{P_{lb}} \\
\epsilon_{lpb} &= \beta_{plb}\tfrac{P_{pb}}{Q^s_{lb}} \qquad (\because \beta_{plb} = \beta_{lpb}) \\
\alpha_{lb} &= Q^s_{lb} - \beta_{lpb}P_{pb} - \beta_{lb}P_{lb} \\
&= Q^s_{lb} - \epsilon_{lpb}\tfrac{Q^s_{lb}}{P_{pb}}P_{pb} - \epsilon_{lb}\tfrac{Q^s_{lb}}{P_{lb}}P_{lb} \\
&= Q^s_{lb}(1 - \epsilon_{lpb} - \epsilon_{lb})
\end{aligned}$$

— Inverse Supply Function for Lentils

$$P_{lb} = -(\frac{\alpha_{lb}}{\beta_{lb}} + \frac{\beta_{lpb}}{\beta_{lb}}P_{pb}) + \frac{1}{\beta_{lb}}Q^s_{lb}$$

■ Supply Functions of **Turkey**

♦ Peas

$$\begin{aligned}
Q^s_{pt} &= \alpha_{pt} + \beta_{pt}P_{pt} + \beta_{plt}P_{lt} \\
\Rightarrow \beta_{pt} &= \tfrac{dQ^s_{pt}}{dP_{pt}} = \tfrac{dQ^s_{pt}}{dP_{pt}}\tfrac{P_{pt}}{Q^s_{pt}}\tfrac{Q^s_{pt}}{P_{pt}} = \epsilon_{pt}\tfrac{Q^s_{pt}}{P_{pt}} \\
\beta_{plt} &= \tfrac{dQ^s_{pt}}{dP_{lt}} = \tfrac{dQ^s_{pt}}{dP_{lt}}\tfrac{P_{lt}}{Q^s_{pt}}\tfrac{Q^s_{pt}}{P_{lt}} = \epsilon_{plt}\tfrac{Q^s_{pt}}{P_{lt}} \\
\alpha_{pt} &= Q^s_{pt} - \beta_{pt}P_{pt} - \beta_{plt}P_{lt} \\
&= Q^s_{pt} - \epsilon_{pt}\tfrac{Q^s_{pt}}{P_{pt}}P_{pt} - \epsilon_{plt}\tfrac{Q^s_{pt}}{P_{lt}}P_{lt} \\
&= Q^s_{pt}(1 - \epsilon_{pt} - \epsilon_{plt})
\end{aligned}$$

— Inverse Supply Function for Peas

$$P_{pt} = -(\frac{\alpha_{pt}}{\beta_{pt}} + \frac{\beta_{plt}}{\beta_{pt}}P_{lt}) + \frac{1}{\beta_{pt}}Q^s_{pt}$$

♦ Lentils

$$\begin{aligned}
Q_{lt}^s &= \alpha_{lt} + \beta_{lpt}P_{pt} + \beta_{lt}P_{lt} \\
\Rightarrow \beta_{lpt} &= \tfrac{dQ_{lt}^s}{dP_{pt}} = \tfrac{dQ_{lt}^s}{dP_{pt}}\tfrac{P_{pt}}{Q_{lt}^s}\tfrac{Q_{lt}^s}{P_{pt}} = \epsilon_{lpt}\tfrac{Q_{lt}^s}{P_{pt}} \\
\beta_{lt} &= \tfrac{dQ_{lt}^s}{dP_{lt}} = \tfrac{dQ_{lt}^s}{dP_{lt}}\tfrac{P_{lt}}{Q_{lt}^s}\tfrac{Q_{lt}^s}{P_{lt}} = \epsilon_{lt}\tfrac{Q_{lt}^s}{P_{lt}} \\
\epsilon_{lpt} &= \beta_{plt}\tfrac{P_{pt}}{Q_{lt}^s} \qquad (\because \beta_{plt} = \beta_{lpt}) \\
\alpha_{lt} &= Q_{lt}^s - \beta_{lpt}P_{pt} - \beta_{lt}P_{lt} \\
&= Q_{lt}^s - \epsilon_{lpt}\tfrac{Q_{lt}^s}{P_{pt}}P_{pt} - \epsilon_{lt}\tfrac{Q_{lt}^s}{P_{lt}}P_{lt} \\
&= Q_{lt}^s(1 - \epsilon_{lpt} - \epsilon_{lt})
\end{aligned}$$

— Inverse Supply Function for Lentils

$$P_{lt} = -(\frac{\alpha_{lt}}{\beta_{lt}} + \frac{\beta_{lpt}}{\beta_{lt}}P_{pt}) + \frac{1}{\beta_{lt}}Q_{lt}^s$$

■ Supply Functions of the **European Union**

♦ Peas

$$\begin{aligned}
Q_{pe}^s &= \alpha_{pe} + \beta_{pe}P_{pe} + \beta_{ple}P_{le} \\
\Rightarrow \beta_{pe} &= \tfrac{dQ_{pe}^s}{dP_{pe}} = \tfrac{dQ_{pe}^s}{dP_{pe}}\tfrac{P_{pe}}{Q_{pe}^s}\tfrac{Q_{pe}^s}{P_{pe}} = \epsilon_{pe}\tfrac{Q_{pe}^s}{P_{pe}} \\
\beta_{ple} &= \tfrac{dQ_{pe}^s}{dP_{le}} = \tfrac{dQ_{pe}^s}{dP_{le}}\tfrac{P_{le}}{Q_{pe}^s}\tfrac{Q_{pe}^s}{P_{le}} = \epsilon_{ple}\tfrac{Q_{pe}^s}{P_{le}} \\
\alpha_{pe} &= Q_{pe}^s - \beta_{pe}P_{pe} - \beta_{ple}P_{le} \\
&= Q_{pe}^s - \epsilon_{pe}\tfrac{Q_{pe}^s}{P_{pe}}P_{pe} - \epsilon_{ple}\tfrac{Q_{pe}^s}{P_{le}}P_{le} \\
&= Q_{pe}^s(1 - \epsilon_{pe} - \epsilon_{ple})
\end{aligned}$$

— Inverse Supply Function for Peas

$$P_{pe} = -(\frac{\alpha_{pe}}{\beta_{pe}} + \frac{\beta_{ple}}{\beta_{pe}}P_{le}) + \frac{1}{\beta_{pe}}Q_{pe}^s$$

♦ Lentils

$$\begin{aligned}
Q^s_{le} &= \alpha_{le} + \beta_{lpe} P_{pe} + \beta_{le} P_{le} \\
\Rightarrow \beta_{lpe} &= \tfrac{dQ^s_{le}}{dP_{pe}} = \tfrac{dQ^s_{le}}{dP_{pe}} \tfrac{P_{pe}}{Q^s_{le}} \tfrac{Q^s_{le}}{P_{pe}} = \epsilon_{lpe} \tfrac{Q^s_{le}}{P_{pe}} \\
\beta_{le} &= \tfrac{dQ^s_{le}}{dP_{le}} = \tfrac{dQ^s_{le}}{dP_{le}} \tfrac{P_{le}}{Q^s_{le}} \tfrac{Q^s_{le}}{P_{le}} = \epsilon_{le} \tfrac{Q^s_{le}}{P_{le}} \\
\epsilon_{lpe} &= \beta_{ple} \tfrac{P_{pe}}{Q^s_{le}} \qquad (\because \beta_{ple} = \beta_{lpe}) \\
\alpha_{le} &= Q^s_{le} - \beta_{lpe} P_{pe} - \beta_{le} P_{le} \\
&= Q^s_{le} - \epsilon_{lpe} \tfrac{Q^s_{le}}{P_{pe}} P_{pe} - \epsilon_{le} \tfrac{Q^s_{le}}{P_{le}} P_{le} \\
&= Q^s_{le}(1 - \epsilon_{lpe} - \epsilon_{le})
\end{aligned}$$

— Inverse Supply Function for Lentils

$$P_{le} = -(\frac{\alpha_{le}}{\beta_{le}} + \frac{\beta_{lpe}}{\beta_{le}} P_{pe}) + \frac{1}{\beta_{le}} Q^s_{le}$$

■ Supply Functions of the **ROW**

♦ Peas

$$\begin{aligned}
Q^s_{pr} &= \alpha_{pr} + \beta_{pr} P_{pr} + \beta_{plr} P_{lr} \\
\Rightarrow \beta_{pr} &= \tfrac{dQ^s_{pr}}{dP_{pr}} = \tfrac{dQ^s_{pr}}{dP_{pr}} \tfrac{P_{pr}}{Q^s_{pr}} \tfrac{Q^s_{pr}}{P_{pr}} = \epsilon_{pr} \tfrac{Q^s_{pr}}{P_{pr}} \\
\beta_{plr} &= \tfrac{dQ^s_{pr}}{dP_{lr}} = \tfrac{dQ^s_{pr}}{dP_{lr}} \tfrac{P_{lr}}{Q^s_{pr}} \tfrac{Q^s_{pr}}{P_{lr}} = \epsilon_{plr} \tfrac{Q^s_{pr}}{P_{lr}} \\
\alpha_{pr} &= Q^s_{pr} - \beta_{pr} P_{pr} - \beta_{plr} P_{lr} \\
&= Q^s_{pr} - \epsilon_{pr} \tfrac{Q^s_{pr}}{P_{pr}} P_{pr} - \epsilon_{plr} \tfrac{Q^s_{pr}}{P_{lr}} P_{lr} \\
&= Q^s_{pr}(1 - \epsilon_{pr} - \epsilon_{plr})
\end{aligned}$$

— Inverse Supply Function for Peas

$$P_{pr} = -(\frac{\alpha_{pr}}{\beta_{pr}} + \frac{\beta_{plr}}{\beta_{pr}} P_{lr}) + \frac{1}{\beta_{pr}} Q^s_{pr}$$

♦ Lentils

$$
\begin{aligned}
Q^s_{lr} &= \alpha_{lr} + \beta_{lpr}P_{pr} + \beta_{lr}P_{lr} \\
\Rightarrow \beta_{lpr} &= \tfrac{dQ^s_{lr}}{dP_{pr}} = \tfrac{dQ^s_{lr}}{dP_{pr}}\tfrac{P_{pr}}{Q^s_{lr}}\tfrac{Q^s_{lr}}{P_{pr}} = \epsilon_{lpr}\tfrac{Q^s_{lr}}{P_{pr}} \\
\beta_{lr} &= \tfrac{dQ^s_{lr}}{dP_{lr}} = \tfrac{dQ^s_{lr}}{dP_{lr}}\tfrac{P_{lr}}{Q^s_{lr}}\tfrac{Q^s_{lr}}{P_{lr}} = \epsilon_{lr}\tfrac{Q^s_{lr}}{P_{lr}} \\
\epsilon_{lpr} &= \beta_{plr}\tfrac{P_{pr}}{Q^s_{lr}} \qquad (\because \beta_{plr} = \beta_{lpr}) \\
\alpha_{lr} &= Q^s_{lr} - \beta_{lpr}P_{pr} - \beta_{lr}P_{lr} \\
&= Q^s_{lr} - \epsilon_{lpr}\tfrac{Q^s_{lr}}{P_{pr}}P_{pr} - \epsilon_{lr}\tfrac{Q^s_{lr}}{P_{lr}}P_{lr} \\
&= Q^s_{lr}(1 - \epsilon_{lpr} - \epsilon_{lr})
\end{aligned}
$$

— Inverse Supply Function for Lentils

$$
P_{lr} = -(\frac{\alpha_{lr}}{\beta_{lr}} + \frac{\beta_{lpr}}{\beta_{lr}}P_{pr}) + \frac{1}{\beta_{lr}}Q^s_{lr}
$$

A.2 Derivation of Indirect Utility Functions

If we observe a demand function that is homogeneous of degree zero in prices and income, satisfies Walras' law, and have a symmetric and negative semidefinite substitution matrix, then to find (indirect) utility functions that rationalize the above demand function is called the integrability problem.

A.2.1 Importing Countries

Suppose there are three commodities: peas, lentils, and an aggregate of all other goods, in the importing country s. Denote the price of the aggregate commodity P_{gs} as the *numèraire* price, then the normalized price for good j is $p_{js} = P_{js}/P_{gs}$ ($j = 1$, 2 represent peas and lentils respectively), and the normalized income is $m_s = M_s/P_{gs}$. Therefore, the budget constraint is $\sum_{j=1}^{2} p_{js}Q_{js}^d + Q_{gs}^d = m_s$, where Q_{js}^d is the demand for commodity j in country s.

In the importing country, the market demand function for commodity j, i.e., $Q_{js}^d(\boldsymbol{p}, m)$ can be specified as follows:

$$\begin{aligned} Q_{ps}^d &= a_{ps} + b_{ps}p_{ps} + b_{pls}p_{ls} \\ Q_{ls}^d &= a_{ls} + b_{ls}p_{ls} + b_{lps}p_{ps} \end{aligned} \tag{A.4}$$

The symmetry of the substitution effects implies

$$\frac{\partial Q_{ps}^d}{\partial p_{ls}} = \frac{\partial Q_{ls}^d}{\partial p_{ps}} \Rightarrow b_{pls} = b_{lps}$$

Let $b_{pls} = b_{lps} = b_s$, then equation (A.4) can be rewritten as

$$\begin{aligned} Q_{ps}^d &= a_{ps} + b_{ps}p_{ps} + b_s p_{ls} \\ Q_{ls}^d &= a_{ls} + b_{ls}p_{ls} + b_s p_{ps} \end{aligned} \tag{A.5}$$

The negative semidefiniteness of the substitution matrix implies $b_{ps} < 0$, and $b_{ps}b_{ls} - b_s^2 < 0$ and $b_{ls} < 0$ as well. For notation ease, we will use the absolute value of the parameters and put the negative sign in front, then equation (A.5) can be rewritten as

$$\begin{aligned} Q_{ps}^d &= a_{ps} - b_{ps}p_{ps} + b_s p_{ls} \\ Q_{ls}^d &= a_{ls} - b_{ls}p_{ls} + b_s p_{ps} \end{aligned} \tag{A.6}$$

Define the money metric indirect utility function as

$$\mu_s(\boldsymbol{q}_s; \boldsymbol{p}_s, m_s) = e_s(\boldsymbol{q}_s, v_s(\boldsymbol{p}_s, m_s)) \tag{A.7}$$

That is, $\mu_s(\boldsymbol{q}_s; \boldsymbol{p}_s, m_s)$ measures how much money one would need at prices $\boldsymbol{q}_s$ to be as well off as one would be facing prices $\boldsymbol{p}_s$ and having income m. Therefore, $\mu_s(\boldsymbol{q}_s; \boldsymbol{p}_s, m_s)$ behaves like an expenditure function with respect to $\boldsymbol{q}_s$, and an indirect utility function with respect to $\boldsymbol{p}_s$ and m_s, because it is a monotonic transformation of an indirect utility function (Varian [1992], p110, p 158, 9.4).

To get the demand functions in equation (A.6), we have to solve the following system of partial differential equations,

$$\begin{aligned} \frac{\partial \mu_s(\boldsymbol{q}_s; \boldsymbol{p}_s, m_s)}{\partial p_{ps}} &= a_{ps} - b_{ps}p_{ps} + b_s p_{ls} \\ \frac{\partial \mu_s(\boldsymbol{q}_s; \boldsymbol{p}_s, m_s)}{\partial p_{ls}} &= a_{ls} - b_{ls}p_{ls} + b_s p_{ps} \end{aligned} \tag{A.8}$$

The first equation implies

$$\mu_s(\boldsymbol{q}_s; \boldsymbol{p}_s, m_s) = a_{ps}p_{ps} - \frac{1}{2}b_{ps}p_{ps}^2 + b_s p_{ps} p_{ls} + C_{ps} \tag{A.9}$$

where C_{ps} is a constant of integration. The second equation implies

$$\mu_s(\boldsymbol{q}_s; \boldsymbol{p}_s, m_s) = a_{ls}p_{ls} - \frac{1}{2}b_{ls}p_{ls}^2 + b_s p_{ps} p_{ls} + C_{ls} \tag{A.10}$$

Therefore, we must have the following form of the money metric indirect utility function

$$\mu_s(\boldsymbol{q}_s; \boldsymbol{p}_s, m_s) = a_{ps}p_{ps} - \frac{1}{2}b_{ps}p_{ps}^2 + b_s p_{ps} p_{ls} + a_{ls}p_{ls} - \frac{1}{2}b_{ls}p_{ls}^2 + C_s \tag{A.11}$$

Because $\mu_s(\boldsymbol{q}_s; \boldsymbol{q}_s, m_s) = m_s$, then C_{ps} and C_{ls} can be solved as an expression with respect to q_s, then plug C_{ps} and C_{ls} into equation (A.11) to get C_s. Using $\mu_s(\boldsymbol{q}_s; \boldsymbol{q}_s, m_s) = m_s$, we have

$$\mu_s(\boldsymbol{q}_s; \boldsymbol{p}_s, m_s) = m_s + a_{ps}(q_{ps} - p_{ps}) - \frac{1}{2}b_{ps}(q_{ps}^2 - p_{ps}^2) + b_s(q_{ps}q_{ls} - p_{ps}p_{ls}) + a_{ls}(q_{ls} - p_{ls}) - \frac{1}{2}b_{ls}(q_{ls}^2 - p_{ls}^2) \tag{A.12}$$

Therefore, the indirect utility function can be derived as

$$v_s(\boldsymbol{p}_s, m_s) = m_s - (a_{ps}p_{ps} - \frac{1}{2}b_{ps}p_{ps}^2 + bp_{ps}p_{ls} + a_{ls}p_{ls} - \frac{1}{2}b_{ls}p_{ls}^2) \tag{A.13}$$

By using Roy's Identity, the demand function for peas and lentils can be derived as what equation (A.6) defined.

The direct utility function can be derived as

$$u_s(Q_{ps}, Q_{ls}, g_s) = g_s - \frac{b_{ls}(Q_{ps} - a_{ps})^2 + b_{ps}(Q_{ls} - a_{ls})^2}{2(b_{ps}b_{ls} - b_s^2)} + \frac{b_s(a_{ps}Q_{ls} + a_{ls}Q_{ps} - Q_{ps}Q_{ls} - a_{ps}a_{ls})}{b_{ps}b_{ls} - b_s^2} \tag{A.14}$$

This is the quasilinear utility function. Quasilinear utility function is defined as

$$U_s(x_{0s}, x_{1s}, ..., x_{ks}) = x_{0s} + u_s(x_{1s}, ..., x_{ks}) \tag{A.15}$$

Note that the utility function is linear in one of the goods, but (possibly) nonlinear in the other goods (Varian [1992], p 164.). For the quasilinear utility function, the demand function is independent of income (Varian [1992], p 166).

A.2.2 Canada

Suppose there are five commodities – peas, lentils, wheat, canola, and the aggregate of all other commodities, in Canada. Denote the price of the aggregate commodities P_{gc} as the *numèraire* price, then the normalized price for good j is $p_{jc} = P_{jc}/P_{gc}$ (j = 1,..., 4 represent peas, lentils, wheat, and canola respectively), and the normalized income is $m_c = M_c/P_{gc}$. Therefore, the budget constraint is $\sum_{j=1}^{4} p_{jc}Q_{jc}^d + Q_{gc}^d = m_c$, where Q_{jc}^d is the demand for commodity j.

In Canada, under the assumption of $P_{gc} = 1$, the market demand function for commodity j, i.e., $Q^d_{jc}(\boldsymbol{P}_c, m_c)$ can be specified as:

$$\begin{aligned} Q^d_{pc} &= a_{pc} - b_{pc}P_{pc} \\ Q^d_{lc} &= a_{lc} - b_{lc}P_{lc} \\ Q^d_{wc} &= a_{wc} - b_{wc}P_{wc} \\ Q^d_{cc} &= a_{cc} - b_{cc}P_{cc} \end{aligned} \tag{A.16}$$

Define the money metric indirect utility function as

$$\mu_c(\boldsymbol{q}_c; \boldsymbol{p}_c, m_c) = e_c(\boldsymbol{q}_c, v_c(\boldsymbol{P}_c, m_c)) \tag{A.17}$$

That is, $\mu_c(\boldsymbol{P}_c; \boldsymbol{q}_c, m_c)$ measures how much money one would need at prices $\boldsymbol{P}_c$ to be as well off as one would be facing prices $\boldsymbol{q}_c$ and having income m. Therefore, $\mu_c(\boldsymbol{P}_c; \boldsymbol{q}_c, m_c)$ behaves like an expenditure function with respect to $\boldsymbol{P}_c$, and an indirect utility function with respect to $\boldsymbol{q}_c$ and m_c, because it is a monotonic transformation of an indirect utility function (Varian [1992], p110).

To get the demand functions in equation (A.16), it needs to solve the following system of partial differential equations,

$$\begin{aligned} \frac{\partial \mu_c(\boldsymbol{q}_c; \boldsymbol{p}_c, m_c)}{\partial p_{pc}} &= a_{pc} - b_{pc}p_{pc} \\ \frac{\partial \mu_c(\boldsymbol{q}_c; \boldsymbol{p}_c, m_c)}{\partial p_{lc}} &= a_{lc} - b_{lc}p_{lc} \\ \frac{\partial \mu_c(\boldsymbol{q}_c; \boldsymbol{p}_c, m_c)}{\partial p_{wc}} &= a_{wc} - b_{wc}p_{wc} \\ \frac{\partial \mu_c(\boldsymbol{q}_c; \boldsymbol{p}_c, m_c)}{\partial p_{cc}} &= a_{cc} - b_{cc}p_{cc} \end{aligned} \tag{A.18}$$

The first equation implies

$$\mu_c(\boldsymbol{q}_c; \boldsymbol{p}_c, m_c) = a_{pc}p_{pc} - \frac{1}{2}b_{pc}p^2_{pc} + C_{pc} \tag{A.19}$$

where C_{pc} is a constant of integration.

The second equation implies

$$\mu_c(\boldsymbol{q}_c; \boldsymbol{p}_c, m_c) = a_{lc}p_{lc} - \frac{1}{2}b_{lc}p_{lc}^2 + C_{lc} \tag{A.20}$$

The third equation implies

$$\mu_c(\boldsymbol{q}_c; \boldsymbol{p}_c, m_c) = a_{wc}p_{wc} - \frac{1}{2}b_{wc}p_{wc}^2 + C_{wc} \tag{A.21}$$

The forth equation implies

$$\mu_c(\boldsymbol{q}_c; \boldsymbol{p}_c, m_c) = a_{cc}p_{cc} - \frac{1}{2}b_{cc}p_{cc}^2 + C_{cc} \tag{A.22}$$

Therefore, we must have the following form of the money metric indirect utility function

$$\mu_c(\boldsymbol{q}_c; \boldsymbol{p}_c, m_c) = a_{pc}p_{pc} - \frac{1}{2}b_{pc}p_{pc}^2 + a_{lc}p_{lc} - \frac{1}{2}b_{lc}p_{lc}^2 + a_{wc}p_{wc} - \frac{1}{2}b_{wc}p_{wc}^2 + a_{cc}p_{cc} - \frac{1}{2}b_{cc}p_{cc}^2 + C_c \tag{A.23}$$

Because $\mu_c(\boldsymbol{q}_c; \boldsymbol{q}_c, m_c) = m_c$, then C_{pc}, C_{lc}, C_{wc}, and C_{cc} can be solved as an expression with respect to q_c, then plug C_{pc}, C_{lc}, C_{wc}, and C_{cc} into equation (A.23) to get C_c. Using $\mu_c(\boldsymbol{q}_c; \boldsymbol{q}_c, m_c) = m_c$, we have

$$\begin{aligned} \mu_c(\boldsymbol{q}_c; \boldsymbol{p}_c, m_c) \quad = \quad & m_c + a_{pc}(q_{pc} - p_{pc}) - \tfrac{1}{2}b_{pc}(q_{pc}^2 - p_{pc}^2) + a_{lc}(q_{lc} - p_{lc}) - \tfrac{1}{2}b_{lc}(q_{lc}^2 - p_{lc}^2) \\ & + a_{wc}(q_{wc} - p_{wc}) - \tfrac{1}{2}b_{wc}(q_{wc}^2 - p_{wc}^2) + a_{cc}(q_{cc} - p_{cc}) - \tfrac{1}{2}b_{cc}(q_{cc}^2 - p_{cc}^2) \end{aligned} \tag{A.24}$$

Therefore, the indirect utility function can be derived as

$$v_c(\boldsymbol{p}_c, m_c) = m_c - (a_{pc}p_{pc} - \frac{1}{2}b_{pc}p_{pc}^2 + a_{lc}p_{lc} - \frac{1}{2}b_{lc}p_{lc}^2 + a_{wc}p_{wc} - \frac{1}{2}b_{wc}p_{wc}^2 + a_{cc}p_{cc} - \frac{1}{2}b_{cc}p_{cc}^2) \tag{A.25}$$

By using Roy's Identity, the demand function for peas, lentils, wheat, and canola can be derived as what equation (A.16) defined.

A.3 Derivation of Consumer Surplus

A.3.1 Importing Countries

Suppose the consumer has a fixed wealth level $m_s > 0$, then the welfare change can be measured as of the difference of indirect utility function $v_s(\boldsymbol{p}_s^1, m_s) - v_s(\boldsymbol{p}_s^0, m_s)$. However, utility theory is purely ordinal in nature and there is no unambiguously right way to quantity utility change.

A notable measure of the welfare change that can be expressed in dollar unit is money metric indirect utility function. Because $\mu_s(\boldsymbol{p}_s^0; \boldsymbol{p}_s^1, m_s)$ measures how much income the consumer would need at prices $\boldsymbol{p}_s^0$ to be as well off as he or she would be facing prices $\boldsymbol{p}_s^1$ and having income m. That is, $\mu_s(\boldsymbol{p}_s^0; \boldsymbol{p}_s^1, m_s)$ is defined to be $e(\boldsymbol{p}_s^0, v_s(\boldsymbol{p}_s^1, m_s))$ (Varian [1992], p 161).

When the utility function is quasilinear, consumer surplus is an accurate measure for the welfare change, furthermore, it is equal to both the compensating variation and the equivalent variation (Varian [1992], p163). Moreover, for the quasilinear utility function, the integral of demand is essentially the money metric utility function. Therefore, the consumer surplus that is represented by the above utility difference can be calculated as follows by using the money metric indirect utility function

$$\Delta \mathrm{CS}_s = \mu_s(\boldsymbol{q}_s; \boldsymbol{p}_s^1, m_s) - \mu_s(\boldsymbol{q}_s; \boldsymbol{p}_s^0, m_s) \tag{A.26}$$

Set $\boldsymbol{q}_s$ equal to $\boldsymbol{p}_s^0$, then

$$\Delta \mathrm{CS}_s = \mu_s(\boldsymbol{p}_s^0; \boldsymbol{p}_s^1, m_s) - \mu_s(\boldsymbol{p}_s^0; \boldsymbol{p}_s^0, m_s) = \mu_s(\boldsymbol{p}_s^0; \boldsymbol{p}_s^1, m_s) - m_s \tag{A.27}$$

Plug equation (A.12) into (A.27) with replacing $\boldsymbol{q}_s$ by $\boldsymbol{p}_s^0$, we get

$$\Rightarrow \Delta \mathrm{CS}_s = a_{ps}(p_{ps} - p_{aps}) - \frac{1}{2} b_{ps}(p_{ps}^2 - p_{aps}^2) + b_{pls}(p_{ps}p_{ls} - p_{aps}p_{als}) + a_{ls}(p_{ls} - p_{als}) - \frac{1}{2} b_{ls}(p_{ls}^2 - p_{als}^2) \tag{A.28}$$

where $\boldsymbol{p}_{a\cdot s}$ is the equilibrium price after the R&D investment, $\boldsymbol{p}_{\cdot s}$ is the initial equilibrium price before R&D.

A.3.2 Canada

$$\Delta \text{CS}_c = \mu_c(\boldsymbol{p}_c^0; \boldsymbol{p}_c^1, m_c) - \mu_c(\boldsymbol{p}_c^0; \boldsymbol{p}_c^0, m_c) = \mu_c(\boldsymbol{p}_c^0; \boldsymbol{p}_c^1, m_c) - m_c \tag{A.29}$$

Plug equation (A.24) into (A.29) with replacing $\boldsymbol{q}$ by $\boldsymbol{p}^0$, we get

$$\begin{aligned} \Rightarrow \Delta \text{CS}_c \;=\; & a_{pc}(p_{pc} - p_{apc}) - \tfrac{1}{2}b_{pc}(p_{pc}^2 - p_{apc}^2) + a_{lc}(p_{lc} - p_{alc}) - \tfrac{1}{2}b_{lc}(p_{lc}^2 - p_{alc}^2) \\ & + a_{wc}(p_{wc} - p_{awc}) - \tfrac{1}{2}b_{wc}(p_{wc}^2 - p_{awc}^2) + a_{cc}(p_{cc} - p_{acc}) - \tfrac{1}{2}b_{cc}(p_{cc}^2 - p_{acc}^2) \end{aligned} \tag{A.30}$$

Under the assumption that $P_{gc} = 1$ and that the prices for wheat and canola are fixed (Canada is assumed to be a small country in the wheat and canola markets), equation (4.19) can be rewritten as:

$$\Delta \text{CS}_c = a_{pc}(P_{pc} - P_{apc}) - \frac{1}{2}b_{pc}(P_{pc}^2 - P_{apc}^2) + a_{lc}(P_{lc} - P_{alc}) - \frac{1}{2}b_{lc}(P_{lc}^2 - P_{alc}^2) \tag{A.31}$$

A.4 The Partial Equilibrium Trade Model

A.4.1 Partial Equilibrium Model before the Increase of Pea R&D Investment

$$Q^d_{pc} = a_{pc} + b_{pc}P_{pc} \tag{A.32}$$

$$Q^d_{pi} = a_{pi} + b_{pi}P_{pi} + b_{pli}P_{li} \tag{A.33}$$

$$Q^d_{ph} = a_{ph} + b_{ph}P_{ph} + b_{plh}P_{lh} \tag{A.34}$$

$$Q^d_{pb} = a_{pb} + b_{pb}P_{pb} + b_{plb}P_{lb} \tag{A.35}$$

$$Q^d_{pt} = a_{pt} + b_{pt}P_{pt} + b_{plt}P_{lt} \tag{A.36}$$

$$Q^d_{pe} = a_{pe} + b_{pe}P_{pe} + b_{ple}P_{le} \tag{A.37}$$

$$Q^d_{pr} = a_{pr} + b_{pr}P_{pr} + b_{plr}P_{lr} \tag{A.38}$$

$$Q^d_{lc} = a_{lc} + b_{lc}P_{lc} \tag{A.39}$$

$$Q^d_{li} = a_{li} + b_{lpi}P_{pi} + b_{li}P_{li} \tag{A.40}$$

$$Q^d_{lh} = a_{lh} + b_{lph}P_{ph} + b_{lh}P_{lh} \tag{A.41}$$

$$Q^d_{lb} = a_{lb} + b_{lpb}P_{pb} + b_{lb}P_{lb} \tag{A.42}$$

$$Q^d_{lt} = a_{lt} + b_{lpt}P_{pt} + b_{lt}P_{lt} \tag{A.43}$$

$$Q^d_{le} = a_{le} + b_{lpe}P_{pe} + b_{le}P_{le} \tag{A.44}$$

$$Q^d_{lr} = a_{lr} + b_{lpr}P_{pr} + b_{lr}P_{lr} \tag{A.45}$$

$$P_{wc} = -a_{wc}/b_{wc} \tag{A.46}$$

$$P_{cc} = -a_{cc}/b_{cc} \tag{A.47}$$

$$Q^s_{pc} = (\alpha_{pc} + \rho_{pc}\bar{K}_{pc}) + \beta_{pc}P_{pc}(1 - l_p) + \beta_{plc}P_{lc}(1 - l_l) + \beta_{pwc}P_{wc}(1 - l_w) + \beta_{pcc}P_{cc}(1 - l_c) \tag{A.48}$$

$$Q^s_{pi} = \alpha_{pi} + \beta_{pi}P_{pi} + \beta_{pli}P_{li} \tag{A.49}$$

$$Q^s_{ph} = \alpha_{ph} + \beta_{ph}P_{ph} + \beta_{plh}P_{lh} \tag{A.50}$$

$$Q^s_{pb} = \alpha_{pb} + \beta_{pb}P_{pb} + \beta_{plb}P_{lb} \tag{A.51}$$

$$Q^s_{pt} = \alpha_{pt} + \beta_{pt}P_{pt} + \beta_{plt}P_{lt} \tag{A.52}$$

$$Q^s_{pe} = \alpha_{pe} + \beta_{pe}P_{pe} + \beta_{ple}P_{le} \tag{A.53}$$

$$Q^s_{pr} = \alpha_{pr} + \beta_{pr}P_{pr} + \beta_{plr}P_{lr} \tag{A.54}$$

$$Q^s_{lc} = (\alpha_{lc} + \rho_{lpc}\bar{K}_{pc}) + \beta_{plc}P_{pc}(1 - l_p) + \beta_{lc}P_{lc}(1 - l_l) + \beta_{lwc}P_{wc}(1 - l_w) + \beta_{lcc}P_{cc}(1 - l_c) \tag{A.55}$$

$$Q^s_{li} = \alpha_{li} + \beta_{lpi}P_{pi} + \beta_{li}P_{li} \tag{A.56}$$

$$Q^s_{lh} = \alpha_{lh} + \beta_{lph}P_{ph} + \beta_{lh}P_{lh} \tag{A.57}$$

$$Q^s_{lb} = \alpha_{lb} + \beta_{lpb}P_{pb} + \beta_{lb}P_{lb} \tag{A.58}$$

$$Q^s_{lt} = \alpha_{lt} + \beta_{lpt}P_{pt} + \beta_{lt}P_{lt} \tag{A.59}$$

$$Q^s_{le} = \alpha_{le} + \beta_{lpe}P_{pe} + \beta_{le}P_{le} \tag{A.60}$$

$$Q^s_{lr} = \alpha_{lr} + \beta_{lpr}P_{pr} + \beta_{lr}P_{lr} \tag{A.61}$$

$$Q^s_{wc} = (\alpha_{wc} + \rho_{wpc}\bar{K}_{pc}) + \beta_{pwc}P_{pc}(1 - l_p) + \beta_{lwc}P_{lc}(1 - l_l) + \beta_{wc}P_{wc}(1 - l_w) + \beta_{wcc}P_{cc}(1 - l_c) \tag{A.62}$$

$$Q^s_{cc} = (\alpha_{cc} + \rho_{cpc}\bar{K}_{pc}) + \beta_{pcc}P_{pc}(1 - l_p) + \beta_{lcc}P_{lc}(1 - l_l) + \beta_{wcc}P_{wc}(1 - l_w) + \beta_{cc}P_{cc}(1 - l_c) \tag{A.63}$$

$$P_{pi} = P_{pc} + G_{pi} \tag{A.64}$$

$$P_{ph} = P_{pc} + G_{ph} \tag{A.65}$$

$$P_{pb} = P_{pc} + G_{pb} \tag{A.66}$$

$$P_{pt} = P_{pc} + G_{pt} \tag{A.67}$$

$$P_{pe} = P_{pc} + G_{pe} \tag{A.68}$$

$$P_{pr} = P_{pc} + G_{pr} \tag{A.69}$$

$$P_{li} = P_{lc} + G_{li} \tag{A.70}$$

$$P_{lh} = P_{lc} + G_{lh} \tag{A.71}$$

$$P_{lb} = P_{lc} + G_{lb} \tag{A.72}$$

$$P_{lt} = P_{lc} + G_{lt} \tag{A.73}$$

$$P_{le} = P_{lc} + G_{le} \tag{A.74}$$

$$P_{lr} = P_{lc} + G_{lr} \tag{A.75}$$

$$Q^d_{wc} = Q^s_{wc} \tag{A.76}$$

$$Q^d_{cc} = Q^s_{cc} \tag{A.77}$$

$$Q^d_{pc} + Q^d_{pi} + Q^d_{ph} + Q^d_{pb} + Q^d_{pt} + Q^d_{pe} + Q^d_{pr} = Q^s_{pc} + Q^s_{pi} + Q^s_{ph} + Q^s_{pb} + Q^s_{pt} + Q^s_{pe} + Q^s_{pr} \quad (A.78)$$

$$Q^d_{lc} + Q^d_{li} + Q^d_{lh} + Q^d_{lb} + Q^d_{lt} + Q^d_{le} + Q^d_{lr} = Q^s_{lc} + Q^s_{li} + Q^s_{lh} + Q^s_{lb} + Q^s_{lt} + Q^s_{le} + Q^s_{lr} \quad (A.79)$$

where equation (A.32) to (A.47) are demand functions for peas, lentils, wheat and canola in Canada and all importing countries respectively. Equation (A.48) to (A.63) are supply functions for peas, lentils, wheat, canola in Canada and importing countries respectively. Equation (A.64) to (A.75) are the spatial price differentials for each region to Canada. Equation (A.78) is the market clear condition for world pea market in which the total supply is equal to the total demand. Equation (A.79) is the market clear condition for world lentil market.

A.4.2 Partial Equilibrium Model after the Increase of Pea R&D Investment

In the case of Canadian farmers increase R&D investment in peas in any given year, the knowledge stock of peas in Canada will increase from , K_{pc}, in equation (A.48), to K_{apc}. Consequently, Canadian pea supply function, i.e., equation (A.48) turns into

$$Q^s_{pc} = (\alpha_{pc} + \rho_{pc}\bar{K}_{apc}) + \beta_{pc}P_{pc}(1 - l_{ap}) + \beta_{plc}P_{lc}(1 - l_l) + \beta_{pwc}P_{wc}(1 - l_w) + \beta_{pcc}P_{cc}(1 - l_c) \quad (A.80)$$

where $K_{apc} = K_{pc}(1 + 10\%)$ and l_{ap} is the check-off ratio after the increase of R&D investment.

A.5 Proof of The Proportional R&D Benefits and Costs: Parallel Supply Shift vs Pivotal Supply Shift

Alston et al. [2004] show that in the case of a parallel supply shift, producers have the same incentive to invest in R&D if they are in a small open economy (SOE) or a large open economy (LOE)). Alston et al. [2004] also analyze the case of a pivotal supply shift.

This thesis models a pivotal supply shift that generates the R&D cost and a parallel supply shift that generates the R&D benefit; it also examines the effect of trade status (SOE versus LOE) on farmers' investment incentives in such a model. The pivotal supply shift in the case of R&D cost is empirically important because percentage levies are used in the Canadian pulse industry. Understanding how farmers' investment incentives are influenced in this case may help to shed light on the underinvestment in R&D.

Figure A.1 depicts the welfare effects of R&D investment for a single-product producers, i.e., peas producers in Canada. The supply curve for Canadian peas prior to the introduction of a checkoff is S_0. In the case of per unit levy, as Alston et al. [2004] analyzed, the supply curve parallel shifts from S_0 to S'_1. In the case of percentage levy, as the model in this thesis, the supply curve pivotal shifts from S_0 to S_1. Market clears at h before levy, and clears at e after the levy. Assume all check-off revenue are invested into R&D activities. This thesis assumes that the check-off ratio increases from l_p to l'_p only at $t = 0$, and returns to l_p at the periods of $t = 1$ to $t = 50$, as Figure 5.1 shows. Under this assumption, at period $t = 0$, the supply curve shifts from S_0 to S_1 in the case of pivotal shift, and shifts from S_0 to S'_1 in the case of parallel shift. Then at period $t = 1$, the supply curve shifts back to S_0. This levy-funded R&D investment results in higher productivity and causes a parallel shift of the supply curve from S_0 to S_2 from period $t = 1$ to $t = 50$, and the market clears at k.

Parallel Supply Shift

Under the condition of parallel shift, in the case of small-country exporter, R&D cost is the difference of the producer surplus before and after the levy, i.e., area $abc - d'ec$ in Figure A.1, and the R&D benefit is the area $fgc - abc$. In the large country case, R&D cost is the area $ahi - d'ec$, and the R&D benefit is area $fkj - ahi$. Alston et al. [2004]'s argument indicates:

$$\frac{abc - d'ec}{fgc - abc} = \frac{ahi - d'ec}{fkj - ahi} \tag{A.81}$$

Pivotal Supply Shift

Under the condition of pivotal shift, in the case of small-country exporter, R&D cost is the difference of the producer surplus before and after the levy, i.e., area $abc - dec$ in Figure A.1, and the R&D benefit is the area $fgc - abc$. In the large country case, R&D cost is the area $ahi - dec$, and the R&D benefit is area $fkj - ahi$.

To examine whether farmers investment incentives change in the large country case versus the small country case, we need to compare the following items, i.e., :

$$\frac{abc - dec}{fgc - abc} \gtreqless \frac{ahi - dec}{fkj - ahi} \tag{A.82}$$

Collecting terms, expression (A.82) can be transformed to

$$\frac{abc - d'ec + d'ec - dec}{fgc - abc} \gtreqless \frac{ahi - d'ec + d'ec - dec}{fkj - ahi} \tag{A.83}$$

Because

$$\frac{abc - d'ec}{fgc - abc} = \frac{ahi - d'ec}{fkj - ahi} \tag{A.84}$$

from equation (A.81). Therefore, to compare the LHS and RHS of equation (A.82) is equivalent to compare the following expression, i.e.,

$$\frac{d'ec - dec}{fgc - abc} \gtreqless \frac{d'ec - dec}{fkj - ahi} \tag{A.85}$$

As Figure A.1 shows, $d'ec - dec > fkj - ahi$, and $d'ec - dec < 0$, therefore,

$$\frac{d'ec - dec}{fgc - abc} > \frac{d'ec - dec}{fkj - ahi} \tag{A.86}$$

Thus,

$$\frac{abc - dec}{fgc - abc} > \frac{ahi - dec}{fkj - ahi} \tag{A.87}$$

Equation (A.87) indicates that the IRR in the large country case is greater than the IRR in the small country case under the condition of pivotal supply shift R&D cost combined with parallel shift R&D benefits.

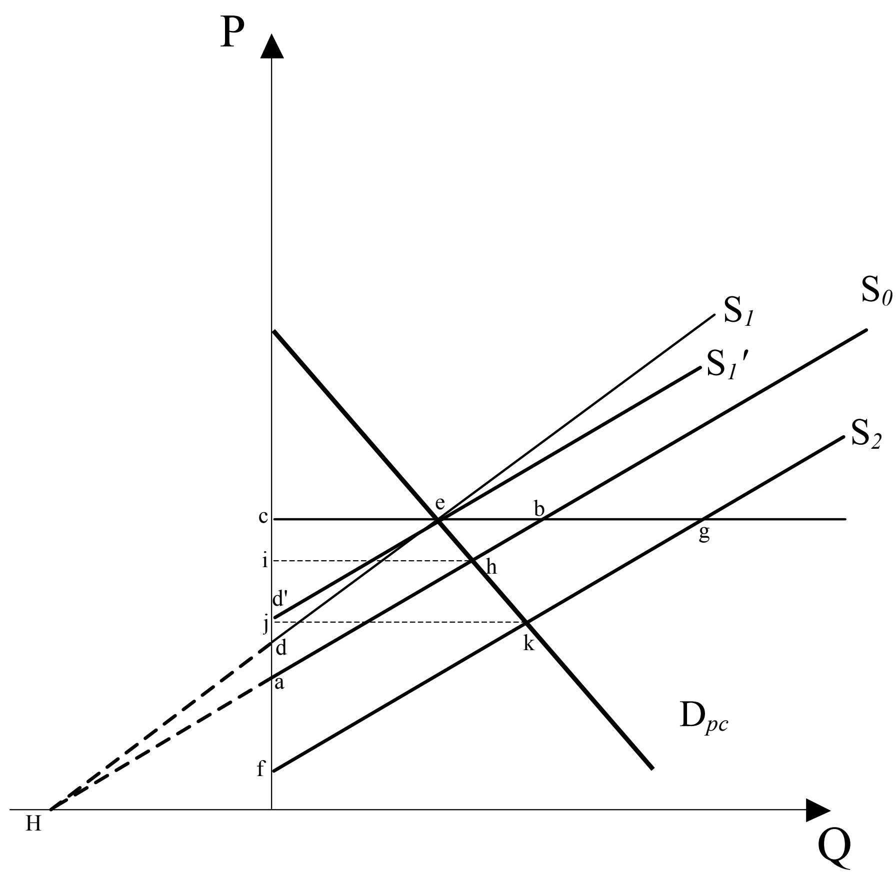

Figure A.1: Welfare Effects: Parallel vs Pivotal Supply Shift

Source: Developed by the author.