AN ECONOMIC ANALYSIS OF THE RETURNS TO CANADIAN FEDERAL SWINE RESEARCH: (1974 - 1997)

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Abstract

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This study measures the costs, benefits, and returns from Canadian federal swine research undertaken from 1974 to 1997. Research costs were estimated using Agriculture and Agri-Food Canada's Inventory of Canadian Agricultural Research data and Agriculture and Agri-Food Canada's, *Main Estimates*, publication. The unit value per professional swine researcher was observed to be $407,000 inclusive of technical support, overhead and operating costs, in 1996 dollars.

Research benefits were estimated using the Canadian Regional Agricultural Model (CRAM). The CRAM model is a multi-commodity, multi-regional, non-linear programming model. This model was used in the present study because it allows for the interaction of one commodity with other commodities in the Canadian agricultural sector. Because the CRAM model can incorporate the research impact of one commodity on another commodity, it provides a more complete assessment of commodity research impacts than previous research studies explaining commodity research impacts in isolation.

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Chapter 1

Introduction

1.1 Introduction

This study represents the findings of an economic analysis of the returns to Canadian federal swine[1] research during the 1974 and 1997 period. The Canadian federal government, provincial governments, universities and colleges, and private industry all contribute to agricultural research. Klein and Furtan (1985) state that "agricultural research has contributed indispensably to increasing food output during the past several decades". However, society has not only benefitted from the increase in food output, but from the increased quality and availability of more nutritious food, and from the reduced requirement for input resources (e.g., land) in food production. Quality and productivity improvements in food production that have been derived from technological innovations are dependent on expenditures in various types of agricultural research activities. The agricultural research activities that are referred to in this study include both basic scientific research and applied scientific research that improves the productivity of primary swine producers' and the quality of their output.

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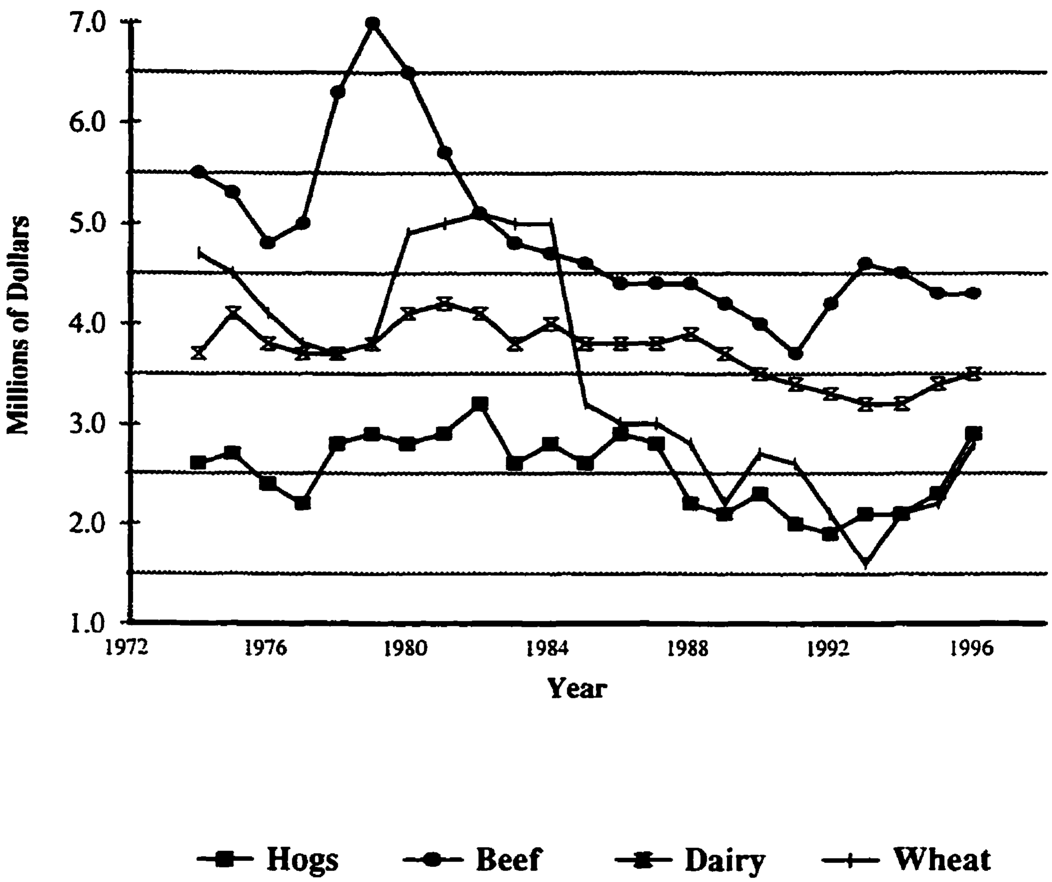
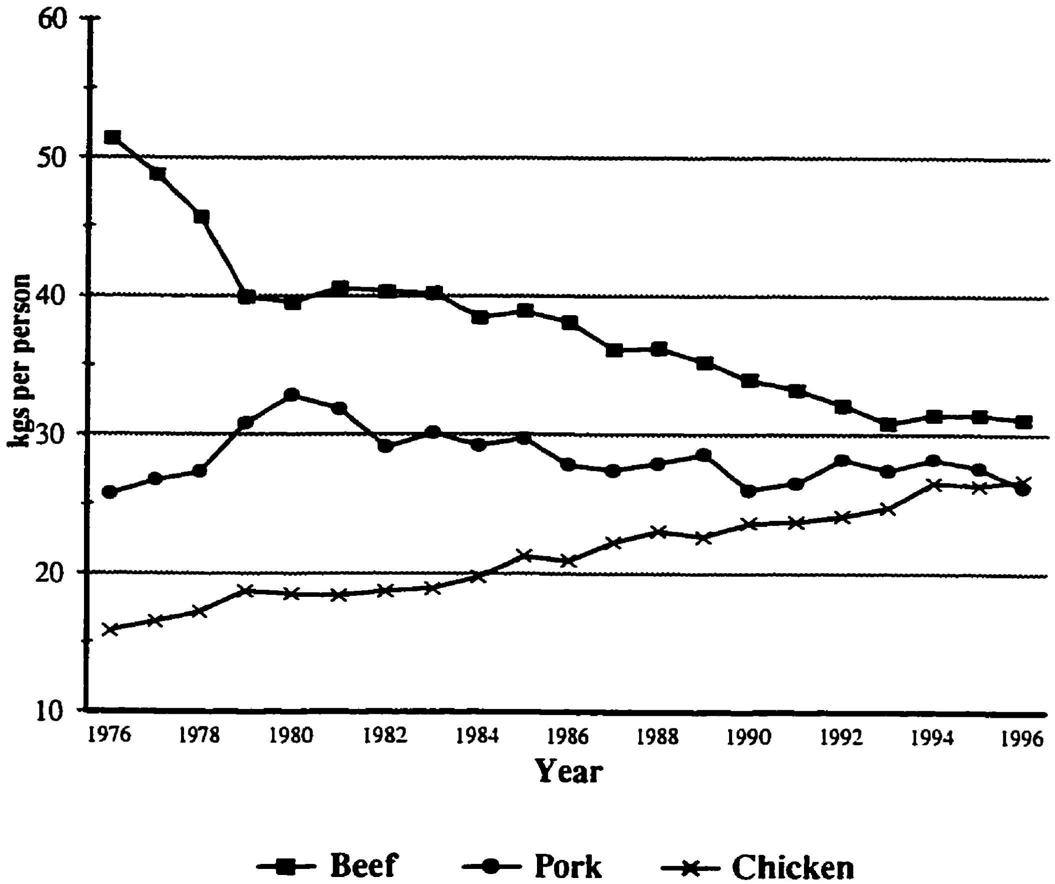
[1] In this study a "swine" is a pig (sow, boar, weaner piglet or market hog). A market hog is produced for meat and meat products.

Figure 1.1 Canadian Farm Cash Receipts for Selected Commodities (Constant 1996 Dollars)



Source: Statistics Canada. (1996). Agriculture Economic Statistics. *Farm Cash Receipts from Farming Operations*. Catalogue Number 21-603-XPE. VariousYears.

Figure 1.2 Canadian Per *Caput* Meat Consumption (1976-1996)[2].



Source: Statistics Canada. Agriculture Division. Livestock Statistics. *Apparent Per Caput Meat Consumption* Catalogue Number 23-603E. Various Years.

2

Per *caput* consumption values represent what is available for consumption on average by the total Canadian population. It does not indicate total food supplies actually consumed by an individual or a specific group of individuals.

1.1.1 The Canadian Hog Industry

The Canadian hog industry is a significant component of the Canadian agricultural sector. In 1996, hog production generated $2.9 billion in gross revenue at the farm level. This represents approximately 21% of the total farm cash receipts generated from livestock production and approximately 10% of the total farm cash receipts generated from all agricultural commodity production in Canada. The 1996 level of hog production generated the third highest farm cash receipts for all agricultural commodities, after cattle and dairy production and followed by wheat production (Statistics Canada, 1996). Figure 1.1 provides a historical review of the farm cash receipts derived from these selected agricultural commodities. Between 1974 and 1996, the average annual percentage change of the aggregate real revenue from hog production was 1.03 percent. In contrast, the average annual percentage change of the aggregate real revenues from beef, dairy, and wheat production were -0.72, -0.15, and -0.79 percent respectively.

Per *caput* consumption of pork has been relatively unchanging in comparison to other commodities. Figure 1.2 provides a historical comparison of pork with beef and chicken. Between 1974 and 1996, pork consumption per *caput* fluctuated between 32.8 kgs and 25.7 kgs, indicating an average annual percentage change of 0.025 percent. Beef consumption per caput has fluctuated between 51.4 and 30.8 kgs, indicating an average annual percentage change of -1.015 percent. Chicken consumption has fluctuated between 26.7 and 15.8 kgs, indicating an average annual percentage change of 0.545 percent.

The Canadian hog industry is an expanding and consolidating industry. This can be observed from the historical increase in the number of hogs produced in Canada, while at the same time the number of individual farms producing hogs has decreased. In 1971, there were approximately 6.7 million hogs produced in Canada. By 1996, the number of hogs produced in Canada had increased to approximately 10.0 million. Within the same time period, the number of farms reporting the production of hogs decreased from 122,481 to 19,850 (Statistics Canada, various years). Therefore, on average the number of hogs produced per year per farm increased from 65 in 1971 to 498 in 1996. The overall increase in the number of hogs produced and the decrease in the number of farms producing hogs is a result of the successful consolidation and specialization of technically efficient and economically competitive swine production operations. Table 1.1 reports the total number of farms producing hogs, the total number of hogs produced, and the average number of hogs produced per farm, by province, in 1996. This table provides an overview of the current distribution and concentration of hog production in Canada.

1.1.2 Public Sector Research

Support for publicly funded agricultural research in Canada was initiated when the Department of Agriculture Act of 1886 and the Experimental Farm Stations Act of the same year were passed by the federal legislature. These were followed by the Act Respecting Contagious Diseases of Animals in 1879 and the Canada Grains Act of 1930. Agriculture and Agri-Food Canada's research is currently managed by the Research Branch, and the Canadian Food Inspection Agency. At the federal level, the National Research Council of Canada also does a significant amount of agricultural research

Table 1.1 Hogs Produced by Province in 1996

Region	Total Number of Farms Producing Hogs	Total Number of Hogs Produced	Average Number of Hogs Produced per Farm per Year
Canada	19,850	9,892,039	498
Newfoundland	31	3,929	127
Prince Edward Island	298	104,669	351
Nova Scotia	201	118,977	592
New Brunswick	213	66,746	313
Quebec	2,938	3,113,452	1,059
Ontario	6,420	2,518,999	392
Manitoba	1,995	1,589,674	797
Saskatchewan	2,672	678,296	254
Alberta	3,871	1,544,144	398
British Columbia	1,211	153,153	126

Source: Statistics Canada. Agricultural Profile of Canada. Table 21.1, *Pigs, by Province.* 1996. Catalogue Number 93-356-XPB.

(Guitard, 1985).

Public sector research is one of several policy instruments used for attaining agricultural sector goals. Objectives for agricultural research include economic growth, income distribution, and food security (Alston *et al.*, 1995). In Agriculture and Agri-Food Canada's *Agricultural Research Review* (1996) the goals stated are; 'to improve the efficiency of swine production and the quality and safety of pork and pork products in support of domestic and export market development.' Growth in agricultural production serves to achieve these goals through the reduction of production costs, the generation of foreign exchange, and improved competitiveness in world markets. Research also has significant income distributional implications among different geographic regions, producers, and between consumers and producers (Alston *et al.*, 1995).

An economic assessment of Canadian swine research provides information for two groups of stakeholders. The first group of stakeholders consists of the research institutions that fund agricultural research. The second group of stakeholders is the Canadian society as a whole (e.g., consumers, producers, taxpayers). Canadian swine production research and supporting activities represent a significant commitment of financial, human, and physical resources by Agriculture and Agri-Food Canada and other Canadian research institutions. As an example of the commitment to swine research, Table 1.2 provides a historical review of Agriculture and Agri-Food Canada's research expenditure trends for swine, beef, dairy, and wheat.

Research expenditures, cash receipts, and the calculated research intensity variable for these four top revenue generating commodities are reported in Table 1.2. The

Table 1.2 Comparison of Research Expenditures (Constant 1996 Dollars)

Categories	Units	Swine	Beef	Dairy	Wheat
1982					
Research Expenditures [1]	Mil$	5.30	16.80	11.80	9.70
Cash Receipts [2]	Bil$	3.20	5.10	4.10	5.00
Research Intensity [3]	%	17.0	33.0	28.0	19.0
1987					
Research Expenditures [1]	Mil$	5.10	11.50	7.30	7.70
Cash Receipts [2]	Bil$	2.80	4.40	3.80	2.90
Research Intensity [3]	%	19.0	26.0	19.0	26.0
1992					
Research Expenditures [1]	Mil$	7.20	14.30	11.90	19.50
Cash Receipts [2]	Bil$	1.90	4.20	3.30	2.10
Research Intensity [3]	%	38.0	34.0	35.0	94.0
1996					
Research Expenditures [1]	Mil$	8.50	15.20	8.00	38.50
Cash Receipts [2]	Bil$	2.90	4.30	3.50	2.80
Research Intensity [3]	%	30.0	35.0	23.0	136

Source:[1] Agriculture and Agri-Food Canada. Research Branch. Finance Office. *Main Estimates*. Various Years.

[2] Statistics Canada. (1996). Agriculture Economic Statistics. Farm Cash Receipts from Farming Operations. Catalogue number 21-603-XPE.

[3] Research Intensity is the ratio of research expenditures to cash receipts ($ of Research Expenditures / $1000 of Farm Cash Receipts) converted to a percentage.

research expenditures and cash receipts reported are in constant 1996 dollars, deflated using the Canadian consumer price index (Statistics Canada, 1996b). The research intensity variable in this table is calculated as the ratio of research expenditures to cash receipts converted to a percentage. Between 1982 and 1996, the research intensity variable for swine research fluctuated between 17% and 38%, whereas, the research intensity variable for beef, dairy, and wheat's research fluctuated between 26% and 35%, 19% and 35%, and 19% and 136% respectively. A quantitative economic evaluation of swine production research activities will provide information to assess the net benefits of this limited resource allocation that is observed through the calculation of the research intensity variable.

Public and private institutions that fund agricultural research must allocate resources among several commodities. It is therefore in their interests to identify research programs that are feasible and that maximize the contribution of the limited resources allocated to the research program. Measurement of the economic returns from alternative research programs provides information to decision makers and planners in the research institutions. The economic information can be used to evaluate the distribution of benefits from previous research programs and decision making systems.

As previously stated, the second group of stakeholders, with respect to agricultural research, is Canadian society. The taxpayers provide the tax base that finances public sector research programs. Presumably, tax payers are interested in receiving the optimal level of benefits from publicly funded programs. Collection and redistribution of income taxes create a cost or deadweight loss to the economy associated with a decrease in private production and consumption. The deadweight loss to the economy is defined as the marginal excess burden of taxation (Dahlby, 1994). Therefore, tax payers demand public institutions to be accountable for research expenditures made to alternative research programs.

1.2 Economic Problem

Canadian swine production research and support activities represent a significant commitment of financial, human, and physical resources by Agriculture and Agri-Food Canada and other Canadian research institutions. A quantitative economic evaluation of swine research activities is important to assess the net benefits of this expenditure. It is important to assess the net benefits of research in order to identify the commodity specific research programs that have maximized the resources allocated to them. Therefore, this study provides a historical assessment of Canadian swine research between 1974 and 1997 and identifies the benefits from these research expenditures. The information derived from this study can be used to evaluate past swine research expenditures and compare the net benefits of swine research with other commodities' research benefits. Also, the information derived from this study can be used to evaluate the effectiveness of the decision making systems research institutions employ when allocating research resources.

1.2.1 Economic Research Problem

Government decision makers require information to determine if public expenditures in agricultural research generated benefits in excess of their costs and if the research resources were allocated efficiently across commodities. One of the economic research problems is to estimate the net benefits from swine research in order to aid in directing future decisions concerning the allocation of limited research resources.

There are various approaches employed to calculate the net benefits from agricultural research. Huot *et al.*, (1989) found high rates of returns to swine research using an econometric approach. The econometric approach used in the Huot study, considered one commodity market in a partial equilibrium model. Thus, the second economic research problem is to estimate the net benefits of swine research with the inclusion an interactive effect with other major Canadian agricultural commodities. To estimate the net benefits of swine research in relation to other major Canadian agricultural commodities a multi-market model will be employed in this study. By considering all major agricultural products simultaneously, the multi-market approach calculates the change in the economic surplus in the agricultural industry as a whole, providing a more complete analysis of the effects of swine research.

1.2.2 Purpose

The purpose of this study is to provide an economic assessment of the returns to Canadian swine research that took place between 1974 and 1997. The study will calculate the research costs and benefits in order to estimate the returns from Canadian swine research expenditures.

1.2.3 Objectives

The objectives of this study are:

1. To identify the past and present areas of emphasis in swine research in Canada.

2. To discuss and select an appropriate economic model by comparing and contrasting the various economic models that are used to estimate the returns from agricultural research.

3. To estimate the costs and benefits of Canadian swine research between 1974 and 1997.

4. To calculate the economic viability of Canadian swine research by using the following criterion of evaluation and to construct a sensitivity analysis:

    i) Net Present Value
    ii) Benefit-Cost Ratios
    iii) Internal Rate of Return

5. To summarize the results of the return on research net benefits.

1.2.4 Organization of Study

To provide background to this study, Chapter 2 gives a brief description of the growth and nature of the Canadian swine industry. It also gives a summary of swine research between 1971 and 1996. Chapter 3 reviews the literature on the economics of agricultural research, outlines some of the approaches used to evaluate public research programs, and discusses the use of the social surplus approach in this study. In Chapter 4 the econometric model used to estimate the Canadian hog supply function and the multi-market model used to estimate the economic surplus of Canadian swine research are presented. The empirical results and sensitivity analysis are reported in Chapter 5. A summary of the results and their implications are presented and discussed in Chapter 6. Lastly, it should be noted that throughout this study a conservative approach has been employed. In other words every opportunity to fully account for all the costs involved in swine research has been taken.

Chapter 2

Summary of Canadian Swine Research

2.1 Review of Swine Research in Canada

The following is a summary of swine research that took place in Canada between 1971 and 1997. Agriculture and Agri-Food Canada's, *Agricultural Research Review* and the Commonwealth Agricultural Bureau (CAB) abstracts were searched for published Canadian swine research studies. In this section research projects examining specific areas of swine production are referenced and research projects that describe the findings of input changes in swine production are summarized.

The majority of research studies that are reviewed have taken place at the federal animal research stations located in Lacombe, Alberta; Brandon, Manitoba; Ottawa, Ontario and Lennoxville, Quebec. Other studies that are reviewed have taken place at Canadian provincial agricultural universities and colleges.

Swine research in Canada between 1971 and 1997 addressed a wide range of problems in the general categories of nutrition, feeding, reproductive physiology, breeding, health, behaviour, management, and marketing. Research was guided by industry demands from both producers and consumers and the structural changes that occurred in the industry (Fredeen *et al.*, 1983). The objectives and goals for agricultural research have been articulated by Agriculture and Agri-Food Canada in its annual

Research Review. Agriculture and Agri-Food Canada's objectives have been to improve the efficiency of swine production and the quality and safety of pork and pork products in support of domestic and export market development.

2.2.1 Nutrition & Feeding

The objectives in nutrition and feeding research have evolved with the changes in industry demands and the structural changes that have occurred in the swine production system. Nutritional research objectives have emphasized improved health, feed conversion efficiency, meat quality, decreasing the length of the reproductive cycle, exploring alternative feed sources, and feed safety concerns.

The need for research to improve sow feed diets was identified in the 1970s and the 1980s (see, for example, Dyck 1972, 1974; Friend 1973, 1977; Tremblay *et al.*, 1989). Research in this area explored whether improved nutrition influenced the age of puberty. Focusing on the time interval between postweaning and pregnancy and fetal survival, Friend (1977) found that the body weight of bred gilts at puberty was increased significantly by the addition of soybean oil to the animal's diet, but that it did not significantly effect the average age of puberty. Tremblay *et al.*, (1989) found that the addition of 5 mg/kg of folic acid to commercial sow diets improved the survival rate of fetuses during early gestation and tended to increase the number of fetuses living at 30 days of gestation.

In the mid 1980s to the 1990s sow nutritional feed research reexamined diet formulation methods. With the recognition of differences in metabolizable energy in common feedstuffs, the methods of feed formulation has shifted from nutrients as a percentage of diet to the more accurate nutrients per calorie of diet (Fredeen *et al.*, 1983). The need for increased caloric intake by the sow at breeding, late gestation and lactation, along with decreased caloric intake in early and mid-gestation, lead to the development of different feeding regimes during the reproductive cycle (see, for example, Grandhi *et al.*, 1990; Matte *et al.*, 1992; Girard *et al.*, 1995). Matte *et al.*, (1992) evaluated the folic acid requirements of gestating and lactating bred gilts and found that piglet growth and total litter weight increased with the level of folic acid in the bred gilt's gestation diet. Girard *et al.*, (1995) evaluated the effects of high fibre diets given to sows during gestation. The purpose of the high fibre diets is to avoid excessive weight gain and fat deposition while providing sufficient levels of feed to maintain the sow's total required daily nutrient intake. Girard *et al.*, found that the high fibre diets had beneficial effects on the welfare of sows and on some aspects of their reproductive performance.

Feeding and nutrition of young piglets has changed considerably in Canada in the past twenty-five years. The objectives of piglet nutritional research have been to decrease weaning time and piglet mortality. Modern nursery facilities house weaned piglets at 3 weeks of age, where they can attain a weight of 22kgs by nine weeks of age with a mortality rate of 1-2% (Fredeen *et al.*, 1983). Early weaning is desired in order to decrease the length of the sow's reproductive cycle and lower the piglet mortality rate. The need for artificial rearing of piglets is necessary in cases when the sow has no milk, when there are more piglets than can be nursed, or there are low birth weight, undernourished piglets. Piglet nutrition research through the mid-1980s and the 1990s emphasized identifying alternative protein sources and the early introduction of feed and water (see, for example, Cinq-Mars *et al.*, 1986; Appleby *et al.*, 1992; Castell 1993). Cinq-Mars *et al.*, (1986) examined the use of whey protein concentrate as an alternative feed protein source for weaned piglets. The study found that the piglets fed the whey protein concentrate diet grew faster than the piglets fed a conventional diet. Appleby *et al.*, (1992) examined the effects increased access to creep feed had on individual variation in feeding and growth in piglets. The study found that individual piglets with high creep feed intake showed increased weight gains before weaning. Individual piglets with low creep feed intake before weaning exhibited poor growth after weaning.

The focus of research with respect to the feeding and nutrition of growing and finishing pigs has evolved during the time period considered in this study. The objectives of research in this area was to improve the grower-finisher hog's health and growth rate, and to reduce feed consumption and costs. Pre-1970 research focused on the identification of most of the nutrients required by growing pigs. Current research has focused on refining the requirements of nutrients, establishing maximum and minimum levels for nutrients, and exploring alternative feed sources and protein supplements (see, for example, Castell 1976, 1980, 1994; Grandhi *et al.*, 1980). Castell (1976) compared faba beans with soybean meal as an alternative protein supplement in barley diets for growing and finishing hogs. The study found that the replacement of soybean meal by faba beans as a protein supplement resulted in a significant reduction in the hog's growth rate. Castell (1980) examined the effects of feeding growing and finishing hogs canola seed. The study found that the hog's live performance and carcass measurements were not adversely affected, but the level of canola seed directly influenced the proportions of unsaturated fatty acids in the hog's backfat. Grandhi *et al.*, (1980) examined the differences in average daily gain when growing and finishing hogs were fed either soybean meal or Tower rapeseed meal as protein supplements in corn diets. The study found the hogs fed the Tower rapeseed meal resulted in a lower average daily gain, backfat thickness, and dressing percentage.

2.2.2 Reproductive Physiology

Research with respect to reproductive physiology is concerned with the success of mating and pregnancy maintenance (Friend, 1985). Specifically, reproductive physiology research has examined factors that affect the successful establishment of pregnancy or the attachment of the fertilized ovum to the uterus. Research also has focused on factors affecting the maintenance of the pregnancy and embryonic loss (see, for example, Dufour 1974; Robertson *et al.*, 1980).

Early research in reproductive physiology was concerned with the affect of cold climate conditions on the performance during mating (see, for example, Swierstra 1970, 1972; Dyck 1974b). Concerns for maintaining year around performance levels has diminished with improvements in swine housing facilities. Other research in the 1970s was concerned with inducing the onset of estrus in sows, in order to synchronize the herd and decrease the length of the reproductive cycle (see, for example, Robertson *et al.*, 1974; King *et al.*, 1979). Decreasing the time period between post-weaning and farrowing and the onset of puberty and the first farrowing for gilts also has been a research concern to further reduce the overall reproductive cycle in the sow (see, for example, Fahmy 1981; Dyck 1983).

Artificial insemination techniques have improved due to research examining the collection, processing, storage and breeding method applications (see, for example, Harbison *et al.*, 1987; Sather *et al.*, 1991). Improved artificial insemination techniques have helped to ensure pregnancy, reduced waste, and decrease injury to the sow. Sather *et al.*, (1991) examined the useful shelf life of fresh semen which has typically been determined to be 3 days. Sather *et al.*, found that neither the number of embryos or the embryo survival rate were effected by the age of the semen, although 5 and 7 day old semen resulted in a 18% decrease in the conception rate compared with 3 day old semen. Therefore, the use of fresh boar semen for artificial insemination is limited due to the short storage life. Deep freezing of semen allows longer storage of boar spermatozoa creating managerial advantages when semen processing centres are a long distance from user herds (Harbison *et al* ., 1987). Harbison *et al.*, (1987) compared the use of fresh and thawed semen to determine if there was any effect on the pregnancy and birth rate. They found that the pregnancy rate was reduced by 25% and the number of embryos produced were reduced on average by 3.4 when thawed semen was used.

2.2.3 Breeding

Swine breeding research in Canada has investigated genetic traits of specific swine breeds in order to improve producer flexibility to changing economic conditions. Crossbreeding allows commercial breeders to capitalize on heterosis and combine several desirable traits (Fahmy *et al.*, 1977). Heterosis is defined as the percent increase in performance of the crosses over the mean of the two parents. In order for the crossbreeding to be economically advantageous, the crosses should have a higher performance level than the better parent (Fahmy *et al.*, 1983). Advantages of crossbred sows have been shown to be earlier puberty, higher ovulation and embryo survival, larger litter size, faster progeny growth, more efficient feed utilization, and better carcass quality (see, for example, Fahmy 1970, 1972; Rahnefeld *et al.*, 1970, 1983; McKay *et al.*, 1986; Schaefer *et al.*, 1989; Castell *et al.*, 1993).

Litter size is of primary importance in maximizing sow production and in breeding selection. The normal assumption is that the size of the litter produced is primarily dependent on the female (Rahnefeld *et al.*, 1970). Rahnefeld *et al.*, (1970) examined the direct effect of the sire on the total number of piglets born. Rahnefeld *et al.*, found that there was a significant sire effect on the total number of piglets born, the number of piglets born alive, and the number successfully weaned. Sire differences with respect to litter size were associated with differences in the semen quality of the boars. The significant influence of the sire indicated that sire effects needed to be considered when undertaking breeding studies on litter size and embryonic death loss.

Research emphasis on breeding for leanness in pork carcasses has become of increased importance due to consumer demands for high quality pork and producer demands for higher feed efficiency. Breeding for leanness in pork carcasses leads to a decrease in the costs of production, since fat deposition during growth is less efficient than muscle growth in terms of feed utilization (Castell *et al.*, 1993). Castell *et al.*, stated that concern arose as a result of the emphasis of selection for leanness because of the apparent effect on voluntary feed intake. Reduced feed intake can detrimentally effect a nursing sow's body condition and finishing hog's meat quality. Castell *et al.*, examined the changes in market hogs' performance level resulting from selection emphasizing reduced backfat thickness. Castell *et al.*, found that selection emphasizing reduced backfat thickness has resulted in lower appetites in the crossbred progeny. Castell *et al.*, suggested that changes in feeding management towards higher nutrient density diets and delaying the use of grower diets appeared to overcome the detrimental effects of reduced voluntary feed intake.

More recently, breeding research has explained genetic traits related to stress and body or leg structure. Projects examining traits related to Porcine Stress Syndrome (PSS) are looking for breeds that are less susceptible to high levels of stress. This is to avoid a loss in production due to Pale, Soft and Exudative pork (PSE). PSE pork is meat that is discoloured and has a watery texture. The biochemical process associated with muscle activity, occurring under stressful conditions, gives rise to an accumulation of lactic acid, responsible for PSE.

2.2.4 Health & Growth

Health control and disease prevention have increased in importance due to the structural changes that have occurred in the swine production industry over the last fifty years. Under extensive management conditions, disease control was achieved by medication of affected individual animals. When sporadic diseases occurred the producer either vaccinated or slaughtered the animal or herd. Avoidance of epidemics of common infectious diseases in the herd was achieved by the low density of populations. With the increase in production intensity other pathogens are now considered a threat to the health of the herd. Programs using Minimal Disease (MD) or Specific Pathogen Free (SPF) techniques were introduced in the early 1950s. The MD programs or SPF techniques use aseptic pregnancy delivery procedures to prevent the transmission of pathogens from the sow to the piglet. Atrophic Rhinitis and Enzootic Pneumonia were specifically targeted. To avoid reinfections isolating the herd from the breeding stock is necessary. All-in-all-out management systems separated by a period for thorough disinfection were developed to interrupt disease cycles. In all-in-all-out management systems a single herd is brought into a housing facility at the same time and isolated throughout the entire production cycle, and then all of the animals in the herd are removed at the same time (Fredeen *et al.*, 1983).

With the increase in confinement production, joint and leg structure damage and abrasions have also become more important problems. To avoid productivity losses, research has focused on reducing joint and leg structural damage and abrasions that increase the risk of crippling and infection in the hog. Research has examined different housing structures and materials that may help to reduce the occurrence of injuries (see, for example, Fredeen *et al.*, 1973, 1978; Sather *et al.*, 1982).

With the increased use of growth enhancing hormones in the 1980s, specifically recombinant Porcine Somatotropin (rPST), many research studies began examining how swine react to rPST exposure. Research studies have examined the effects of rPST on joint cartilage, growth, feed efficiency, carcass yield and meat quality (see, for example, Dubreuil *et al.*, 1990; Farmer 1991; Jones *et al.*,1994). Jones *et al.*, (1994) stated that numerous studies published demonstrate that Porcine Somatotropin (PST) and recombinant Porcine Somatotropin (rPST) improves growth and feed efficiency by approximately 10%. Jones *et al.*, found that the majority of production and carcass quality studies on the effects of PST have been obtained with the use of a daily injected product. Jones *et al.*, argued that management and labour complications inherent in the use of daily injections of PST would encourage the development of a prolonged release product. The study tested the effectiveness of a prolonged release rPST system on the growth, efficiency, carcass yield and carcass quality of finishing pigs. They found that the tested prolonged release system for rPST was ineffective in improving growth rates or feed conversion. Small effects were found for carcass characteristics where rPST reduced backfat thickness and increased carcass bone content.

Mycotoxins, feed toxins of fungal origin, were recognized as a serious threat to swine health and growth in the 1980s in Canada. Mycotoxins are produced by molds on plant crops in the field and during storage. When ingested by livestock, decreased animal performance or more deleterious health effects can occur. There have been numerous research studies examining residue levels in swine tissue and the effects of contaminated feed on weight gain and sexual development. The research studies on mycotoxins emphasized work on the toxicology and nutritional effects of the mycotoxins zearalenone and vomitoxin (see, for example, Friend *et al.*, 1984; Foster *et al.*, 1986). Friend *et al.*, (1984) concluded that several studies show evidence that the presence of mycotoxins in swine feed diets can cause a reduction in the animal's feed intake. Friend *et al.*, examined the effects of feeding various levels of contaminated feed to pigs. They found that feed consumption of contaminated wheat feed was reduced 15-17% and 50% for contaminated corn feed. The reduction in feed intake decreased the animal's overall performance and health. Friend *et al.*, stated that the results demonstrate the economic importance to the Canadian swine industry of caution when feeding pigs grain or diets suspected of containing mycotoxins.

2.2.5 Behaviour

The development of behavioural studies arose because of increased concerns with production problems and animal welfare concerns associated with intensification in production. Relationships between the sow and her litter are crucial to the survival and rapid growth of the piglets. The piglets need to be protected from the sow so not to be crushed, but they also need to be given an opportunity to nurse as piglet starvation is a primary cause of death (see, for example, Fraser *et al.*, 1984, 1986; De Passille *et al.*, 1988). Fraser *et al.*, (1986) studied the variation in piglet weights in relationship to suckling behaviour, parity number and farrowing crate design. The purpose of the study was to understand why litter-mate piglets, even with reasonably uniform birth weights will sometimes differ by a factor of three or more in weaning weight. The lack of uniformity can complicate subsequent management, requiring delayed weaning or special treatment for the low weight piglets. Furthermore, lower weight piglets may be suffering from poor nutrition, a major factor leading to piglet deaths. These factors can cause higher management costs and lower sow productivity. Fraser *et al.*, found that within litter variation in 14 day weight was greater in the type of farrowing crate that impeded access to the sow's udder. Total milk intake was not effected, but the distribution of milk between the piglets had a greater variability. The behavioural results show that the farrowing crate with impeded access tended to have an increase of fighting and competition within the litter. Fraser *et al.*, conclude that crate designs can increase variability in piglet weights and may also increase pre-weaning mortality in commercial units.

Research studies that have examined the welfare of pigs in confinement housing have looked at issues regarding the provision of bedding and the amount of available space for the animal (see, for example, Fraser 1985; Phillips *et al.*, 1992). Research emphasis has shifted to identifying animal welfare needs by examining abnormal behaviour and preference testing (see, for example, Gonyou 1994; Fraser *et al.*, 1995). These study's objectives are to identify the causes of pig conflicts, tail biting, and Porcine Stress Syndrome (PSS).

2.2.6 Management & Marketing

Increases in production specialization and scale have lead to the need for improved cost efficiencies in production, and reduced stress management innovations. Animal management research has emphasized studies on feeding, artificial rearing, weaning and finishing (see, for example, Elliot *et al.*, 1978; Fraser *et al.*, 1989). Production management research has emphasized studies on ventilation, manure disposal, pen design and construction material choices (see, for example, Barnett 1981; Farmer *et al.*, 1983; Phillips *et al.*, 1989, 1995).

Fraser *et al.*, (1989) examined the use of water by piglets in the first days after birth. The results suggested that piglets drank appreciable amounts of water on the first days after birth especially if their milk intake was limited. Under these circumstances water intake helped prevent dehydration and promoted survival of piglets with low early milk intake.

Research with respect to marketing, processing and grading procedures has examined the need for increased meat quality. Domestic and international marketing studies have examined consumer acceptability of fat content in pork (see, for example, Fredeen *et al.*, 1975; Jeremiah 1994). Jeremiah (1994) examined consumer responses to pork loin chops with different degrees of muscle quality. Consumers evaluated packages of pork loin chops from three muscle quality groups (pale, soft, exudative (PSE); normal; and dark, firm, dry (DFD)). Jeremiah found that consumers most preferred DFD chops and least preferred PSE chops.

Meat quality studies have examined the affects on pork quality from processing, packaging and storage procedures (see, for example, Jeremiah 1982, 1986; Jones *et al.*, 1993; Schaefer *et al.*, 1989). The economic losses in the swine industry attributed to PSE pork are considered to be high (Schaefer *et al.*, 1989). Therefore, the ability to detect physiological differences in pigs prone to producing PSE and more importantly the ability to detect and remove pigs which are likely to produce PSE pork is desirable and has been identified by the Canadian meat processing industry as a priority for research (Schaefer *et* *al.*, 1989). Stress susceptible pigs or pigs that exhibit malignant hyperthermia as a result of exposure to pre-slaughter stress often display physiological changes including elevated skin temperatures. Schaefer *et al.*, examined the usefulness of infrared thermography in detecting skin surface temperature differences in pigs with stress susceptibility. Their results demonstrated that infrared thermography is highly sensitive in terms of identifying anatomical temperature differences in pigs and identifying stress susceptible pigs.

The Canadian Hog Grading Index was introduced in 1969. This index was based on carcass weight and backfat thickness. Developing a hog grading scheme generated research studies concerned with developing objective measurement techniques through the 1970s to the 1990s. The measurement techniques and lean-fat grading categories have been updated and adjusted with the demand and production quality changes that have occurred in the industry (see, for example, Gillis *et al.*, 1972; Fredeen *et al.*, 1979; Fortin *et al.*, 1980; Sather *et al.*, 1988). The goal of research in this area is to develop a grading scheme that reflects pork quality demands of the domestic and export consumer market.

2.3 Summary

Each research category -- Nutrition and Feeding, Reproduction Physiology, Breeding, Health and Growth, Behaviour, and Management and Marketing -- will be constantly confronted with challenges to adapt quickly to changes in producer needs, consumer preferences, legislation and the biological environment. In the short to medium term production must grow to meet the demand of population growth in both the domestic and export market.

Some of the issues affecting production efficiency and productivity presently are concerns with respect to the loss of yield due to PSE pork and feed mycotoxins. Issues affecting the economic efficiency of producers focus on the loss of revenue due to the variable nature of the cost of feed grains and other inputs. Environmental issues affect swine production through public pressure to regulate air and water pollution originating from swine production facilities. Food safety, specifically problems related to tissue residue from feed rations or medication, has also become a issue of public concern. Ensuring the safety and welfare of livestock is another issue that can affect legislation concerning swine production processes.

The diverse range of research projects all address some aspect of the swine production process. The swine production process consists of a complex set of relationships between biological, technical, and economic factors. The cumulative goal of all the research projects is to contribute to the improvement of the biological, technical and economic efficiency in the swine production process. The aggregate effects of swine research has contributed to the reduction in the growing and reproductive cycles, and increases in sow productivity, feed efficiency, carcass yield and pork quality. These aggregate effects stem from the combined improved production and management technologies that have been produced from swine research. Examples of these technologies include artificial insemination, modern standardized production facilities, improved genetics, all in and all out pig management processes, split sex feeding, phase feeding, pelleted feeds, and three site production facilities.

The research literature review has provided a general overview of the various subjects swine research has encompassed. This review is important since it does give evidence of the type of research that is being completed or has been completed on swine production. However, the information presented in the animal science journals are not appropriate for the calculation of the aggregate economic benefits and costs from swine research. Therefore, in order to calculate the economic returns to swine research an alternative method is described in this paper.

Chapter 3

Summary of the Returns to Agricultural Research Literature

3.1 Introduction

The purpose of this chapter is to discuss the rationale for public expenditures in agricultural research and to review the economic returns to agricultural research literature.

3.2 The Rationale for Public Agricultural Research

Governments in Canada participate in agricultural research by funding basic and applied research projects. Publicly funded projects take place in government research stations, universities and colleges, or in joint ventures with private firms. As mentioned in the first chapter, the objectives of agricultural research include economic growth, income distribution, and food security (Alston *et al.*, 1995). Two different economic perspectives have been articulated in the returns to agricultural research literature as to why governments have taken on the role of pursuing these objectives. The following sections will outline these economic perspectives and discuss the appropriateness of employing them in the justification of public expenditures in agricultural research.

3.2.1 Public Agricultural Research Viewed as a Public Good

Firstly, the product of agricultural research is viewed by some as a *public* or *collective good.* The definition of a public good is a good that once produced, no individual can be excluded from benefitting from its availability and the good is nonrival in consumption (Nicholson, 1995). In theory, a public good is provided by a government for the benefit of all or most of the populace (e.g. education, health care, national defense, law enforcement).

The first characteristic of a public good is concerned with the fact that no individual can be excluded from receiving the benefits from the production of the good. In other words, it is neither economically, technically, or physically feasible to exclude individuals or groups from consuming or benefitting from the produced good.

The second characteristic of a public good is concerned with the idea of nonrivalry. A nonrival good is a good where consumption by one individual does not affect the quantity or quality of consumption of the same good by another individual.

Since, public goods possess these two characteristics of nonexclusivness and nonrivialry, there is not a direct link between consumption of a public good and payment for it. This makes it necessary for public goods to be paid for out of a state's general taxation system and not by individual customers buying in the market place. Public goods are also paid for in this manner due to the idea that beneficiaries will attempt to become *free riders.* A free rider will understate his or her demand for the good, in the hope of avoiding his or her share of the cost without affecting the amount he or she obtain. Consequently, these products are currently not marketed in the conventional way and market prices are not determined. This is due to the concern that if these goods were marketed conventionally they would be under-produced.

However, in the case of agricultural research, examples of exclusion and rivalry arguably can be found. Examples of exclusion can be found by examining the products of agricultural research (e.g. feed rations, machinery, veterinary medicine, chemical inputs, and biotechnologically produced inputs). When an innovative agricultural research product is developed the beneficiaries can be excluded from the use of this good either through its retail cost, limited availability, copy rights, and patents. Over time the ability for agricultural research producers to expand the exclusionary nature of their products has increased with the development of well defined markets and property rights (Zentner, 1985 and White, 1995).

Rivalry also occurs when the innovative product is applied to the production process by increasing the economic marginal cost of the product. The marginal cost of an agricultural research product increases when an individual consumes the innovative product. This occurs because of the product's limited availability reduces the quantity and quality available for consumption by other individuals. The economic marginal cost of the agricultural research product also increases when an individual consumes an innovative product. This occurs because more physical resources must be committed to the continued production of the product.

Therefore since agricultural research can be perceived as both exclusionary and rival in nature, its classification as a public good is not accurate. Thus, it is inappropriate to claim that public expenditures in agricultural research are justified in this manner.

3.2.2 Public Agricultural Research Viewed as a Means to Reducing Transaction Costs

A second economic perspective that has been articulated in the returns to agricultural research literature as to why governments have taken on the role of pursuing agricultural research is the concept of reducing economic transaction costs. Transaction costs are the costs involved with searching and negotiating the means of production or in this case the means of research (Coase, 1937). These costs can be reduced when the responsibility of agricultural research production is undertaken by a competent institution or institutions. This assertion is based on the following two concepts.

Firstly, transaction costs limit individual agricultural producers or firms from supporting their own basic and applied research due to the structural nature of the agricultural production sector. The agricultural sector is typically made up of small, atomistic, private farm firms. These agricultural firms lack the necessary technical skills and resources to support their own basic and applied research. However, a publicly or privately funded agriculturally focused research institution possess the size and scope in research to lower these transaction costs. This means a large and diversified organization is often able to efficiently do research at lower transaction costs than a number of smaller individual firms.

Secondly, the logical coordination of agricultural research can serve to lower transaction costs within the agricultural sector. Without coordination of agricultural research competing firms will duplicate one an others research efforts. This increases the transaction costs found in the agricultural sector. Duplication of research is prevented through coordination of research projects across a geographical area. In Canada, the federal government uses a centralized system of coordination over agricultural research in various geographic regions (Klein, 1985). The planned coordination of research limits the social inefficiency resulting from duplication (Stephan, 1996).

Governments have taken on the role of providing research resources for the generation of new knowledge in agricultural production as a means of reducing transaction costs within the agricultural sector. It can be argued that this can be justified due to the incapacity of private farm firms to conduct their own research and the benefits derived from research coordination. This leaves governments with the task of allocating resources in an efficient or socially optimal manner among different agricultural commodity research projects.

3.3 Review of the Returns to Research Studies

Estimation of the returns to public investments in agricultural research began with the work of Schultz (1953) and Griliches (1958). Schultz (1953) quantified the increase in agricultural production in the United States between 1910 and 1950. Schultz (1953) estimated the rate of return for all agricultural research to be between 35% and 170%. Griliches (1958) examined the economic returns from research on hybrid corn in the United States between 1940 and 1955. He estimated the rate of return for hybrid corn research to be between 35% and 40%. A number of studies since the pioneering work of Schultz and Griliches, using a variety of methods, have found very high rates of return, on the order of 40 to 60 percent per year (Economic Research Service, 1996). Table 3.1,

Table 3.1 Summary of Returns to Research Studies: United States & Canada

Study	Commodity	Period	Method	Average Estimated Rate of Return
		United States Studies		
Schultz (1953)	Aggregate	1910-1950	Inputs Saved, Index Number	35-170%
Griliches (1958)	Hybrid Corn	1940-1955	Economic Surplus, Index Number	35-40%
Peterson (1967)	Poultry	1915-1960	Economic Surplus, Index Number	21-30%
		Canadian Studies		
Nagy & Furtan (1978)	Rapeseed	1960-1975	Economic Surplus, Econometric Approach	101%
Farrell, Funk & Brinkman (1984)	Corn Wheat	1984-2003 1984-2003	Economic Surplus, Econometric Approach	20-22% 41%
Brinkman & Prentice (1985)	Aggregate	1950-1980	Inputs Saved, Index Number	54-84%
Farrell & Funk (1985)	Plant Biotechnology	1984-2003	Inputs Saved, Delphi Forcasting	15-40%
Brown-Andison & Brinkman (1986)	Dairy	1968-1984	Economic Surplus, Econometric Approach	115%
Widmer, Fox & Brinkman (1988)	Beef	1968-1984	Economic Surplus, Econometric Approach	66%
Horbasz, Fox & Brinkman (1988)	Sheep	1968-1984	Economic Surplus, Econometric Approach	25%

Table 3.1 Summary of Returns to Research Studies Continued

Study	Commodity	Period	Method	Average Estimated Rate of Return
Zachariah, Fox & Brinkman (1989)	Broilers	1968-1984	Economic Surplus, Econometric Approach	61%
Huot, Fox & Brinkman (1989)	Swine	1968-1984	Economic Surplus, Econometric Approach	50%
Haque, Fox & Brinkman (1989)	Laying Hens	1968-1984	Economic Surplus, Econometric Approach	81-98%
Fox, Roberts, & Brinkman (1992)	Dairy	1968-1998	Economic Surplus, Econometric Approach	109%
Klein, Freeze, Clark, & Fox (1994)	Beef	1968-1984	Economic Surplus, Historical Trend & Mathematical Programming	n/a
Agriculture & Agri-Food Canada (1996)	Potato	1971-1995	Economic Surplus, Delphi Forecasting & Mathematical Programming	28%
Klein, Freeze, & Walburger (1996)	Wheat	1962-1992	Economic Surplus, Historical Trend & Mathematical Programming	27-39%

displays a selection of past returns to research studies, focusing on recent Canadian studies. Other tables listing past returns to research studies can be found in Evenson *et al.*, (1979) and Hueth *et al.*, (1985).

Since these early studies, an enormous literature has evolved exploring different methods of analyzing the returns from agricultural research (Ruttan, 1982). The different methods are divided into two categories: *ex ante* and *ex post* studies[1]. Economists have developed three methods to measure the returns from public expenditures in agricultural research. These three methods are 1) the value of inputs saved approach, 2) the production function approach, and 3) the economic surplus approach. It seems the most common approach employed for analyzing the returns from agricultural research has been the concept of economic surplus in a partial-equilibrium framework (Alston *et al.*, 1995).

3.3.1 The Value of Inputs Saved Approach

The value of inputs saved approach estimates the reduction in the total quantity of inputs required to produce a given level of output from the adoption of technological innovations in the long run. The difference between the value of the actual inputs used and the actual value of inputs that would have been required to produce the current level of output with old technology, is a measure of the benefits of research (Schultz, 1953; and Brinkman and Prentice, 1983). The limitations of the value of inputs saved approach are that it cannot identify the benefits received by consumers and producers and it cannot

---

1

Ex ante is defined as being applied from before an action, and *ex post* is defined as from after an action.

measure the benefits from marginal investments in agricultural research (Fox *et al.*, 1987).

3.3.2 The Production Function Approach

The production function model uses econometric techniques to estimate industry level production functions. Production function models express agricultural output as a function of various inputs, one of which is lagged research expenditures. This enables the estimated value of the marginal product of research to be derived from the estimated production function and the marginal rate of return to research to be calculated. The limitation of this approach is that it cannot identify the benefits derived from research with respect to consumers (Fox *et al.*, 1987).

3.3.3 The Economic Surplus Approach

The economic surplus approach identifies the benefits from research as the changes in consumers' and producers' surpluses, as a result of productivity changes arising from research. The productivity changes generated from research are derived in the form of innovative production techniques and technologies that shift the industry's supply function.

Consumers' surplus is a measure of the area under the demand curve and above the price line. Producers' surplus is the area above the supply curve and below the price line. Consumers' surplus is defined as the benefits received by consumers from paying actual prices for goods that are lower than the consumers would have been prepared to pay. In Figure 3.1, consumers' surplus is represented by the area under the demand function and above the price line, P_0BC. Producers' surplus is defined as the benefits received by producers at a competitive price over and above the price level where they would exit the market. In Figure 3.1, producers' surplus is represented by the area below the price line and above the supply function, P_0BA.

The changes in consumers' and producers' surpluses are created when new technology, generated by agricultural research, shifts the industry's supply function to the right. The sum of the net changes in consumers' and producers' surpluses are used to measure the gross benefits from agricultural research (Fox *et al.*, 1987). The conceptual framework used to measure the gross benefits from agricultural research with the economic surplus approach is portrayed in Figure 3.2. The supply shift leads to reduced commodity prices and an increase in the quantity produced. In Figure 3.2, it is observed that consumers' surplus increases by the area P_0BCP_1.
The reduction in prices reduces producers' surplus by the area P_0BDP_1, but increased quantity produced adds ADC to producer welfare. The sum of the increases in consumers' surpluses and the net change in producers' surplus is the area ABC.

3.3.3.1 Examples of Canadian Studies Employing the Economic Surplus Approach

A series of returns to research studies for different livestock commodities were completed for Canadian agricultural commodities in the mid-1980s. Haque *et al.*, (1989)

Figure 3.1 Consumer and Producer Surplus Framework

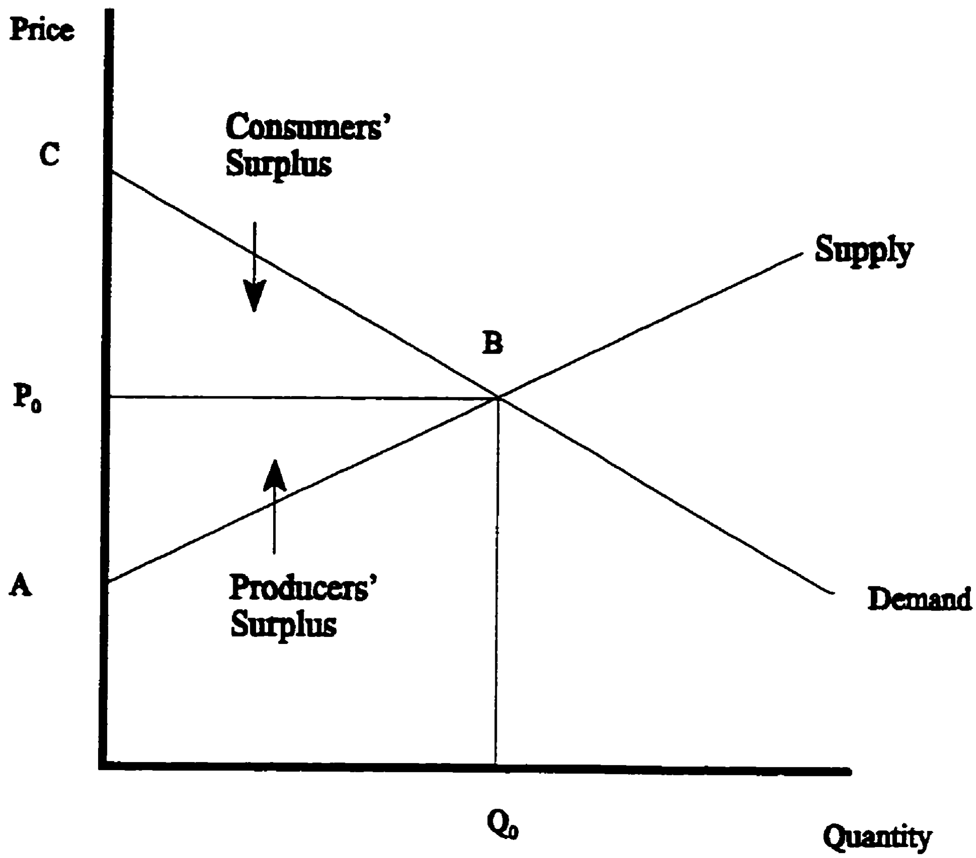
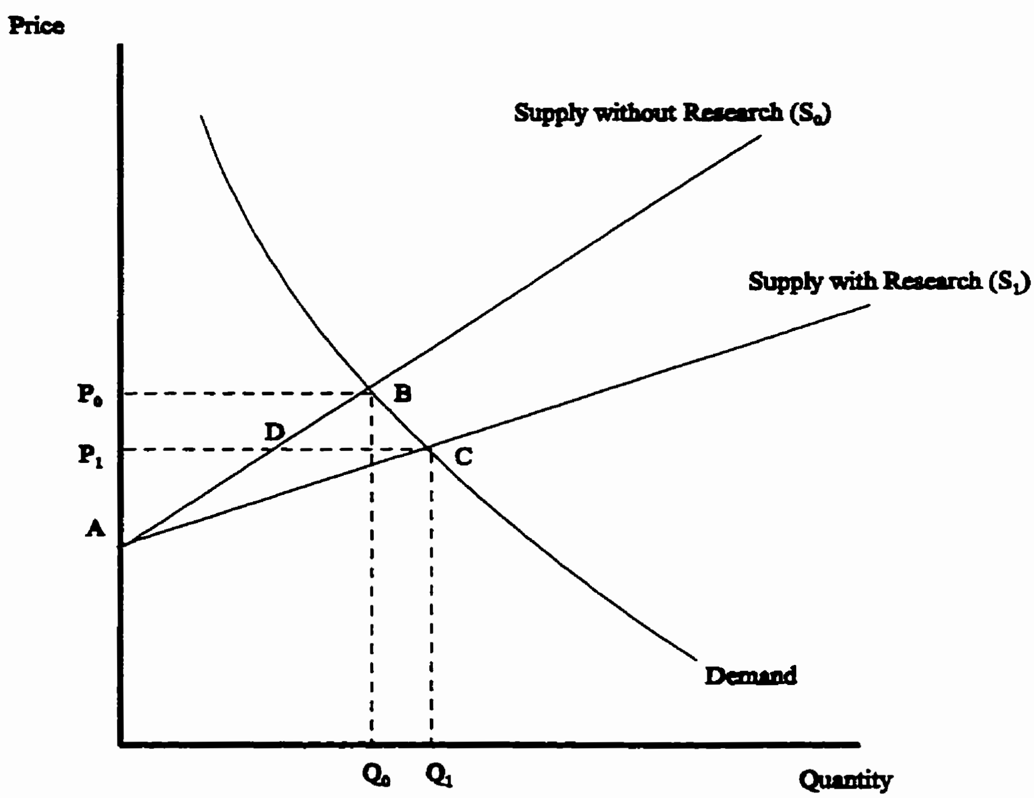


Figure 3.2 Gross Research Benefits from a Shift in the Supply Function



studied laying hens, Widmer *et al.*, (1988) studied beef cattle, Horbasz *et al.*, (1988) studied sheep, Zachariah *et al.*, (1989) studied broilers, Huot *et al.*, (1989) studied swine, and Roberts *et al.*, (1992) studied dairy cattle.

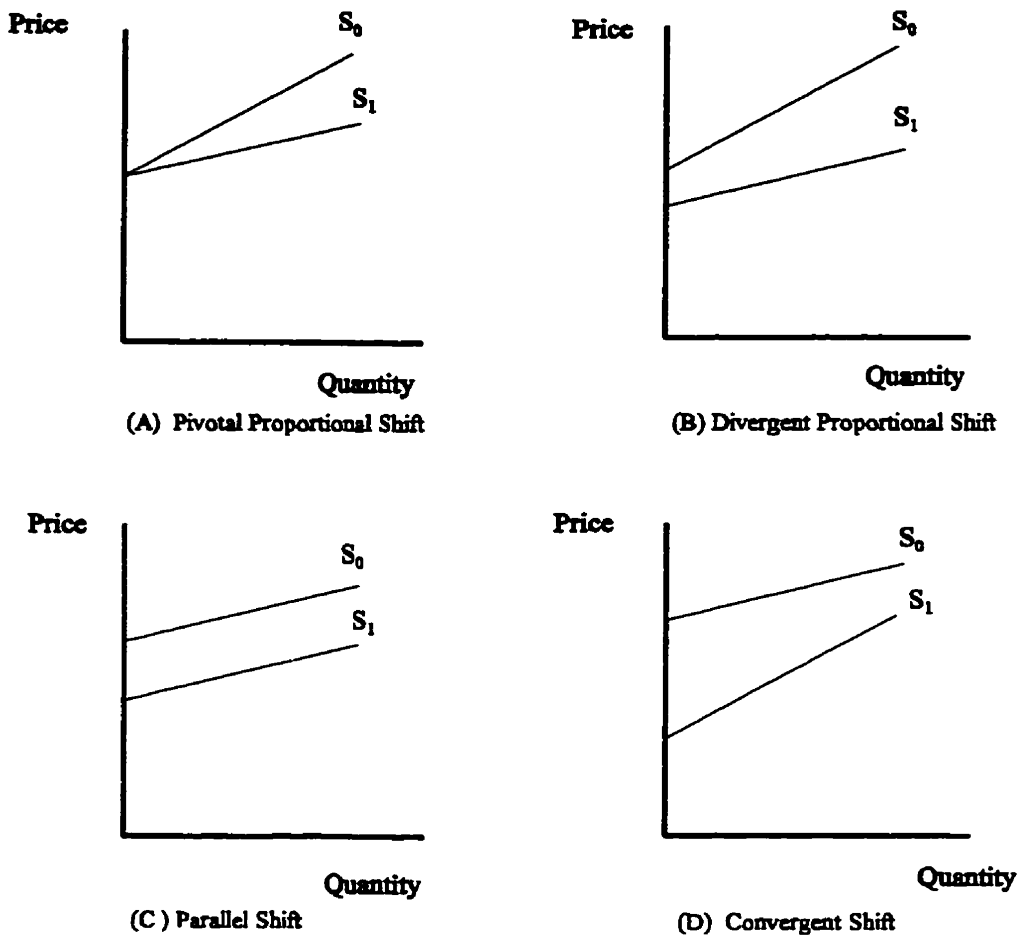
Each study used the economic surplus approach to estimate the change in consumers' and producers' surpluses derived from agricultural research. The change in consumers' and producers' surpluses derived from agricultural research was estimated using an econometric model based on time series data. The model's dependent variable is the commodity's output quantity and the independent variables are the commodity's prices, lagged research and extension expenditures, and producers' level of education. In each study the econometric model estimated the shift in the commodities' aggregate supply function in relation to the defined independent variables.

Each study found relatively high rates of return ranging from 25% in sheep research to 115% in dairy cattle research (Fox, 1995). Table 3.1, summarizes each study's observed time period, examined commodity, estimation technique, and estimated rate of return.

3.3.4 The Nature of the Supply Shift

Agricultural economists have identified four principle ways in which technological change might shift the industry level supply curve for an agricultural commodity (Lindner and Jarrett 1978); a pivotal proportional shift, a divergent proportional shift, a parallel shift, and a convergent shift, (see Figure 3.3). Figure 3.3, uses linear supply functions for simplicity.

Figure 3.3 Types of Linear Supply Shifts



Source: Taken from Lindner and Jarrett (1978).

Panel (A) in Figure 3.3, portrays a pivotal proportional shift that occurs when technological change reduces costs at higher levels of output but does not reduce the minimum threshold price below which no output would be produced. A divergent proportional shift, shown in panel (B), represents the case when research shifts the supply function by reducing costs at higher levels of output and also reduces the minimum threshold price. A parallel shift, shown in panel (C), would occur when research reduces costs by a constant amount at all levels of output. Lastly, panel (D) portrays a convergent shift representing the situation in which research reduces costs at lower output levels to a greater extent than at higher output levels.

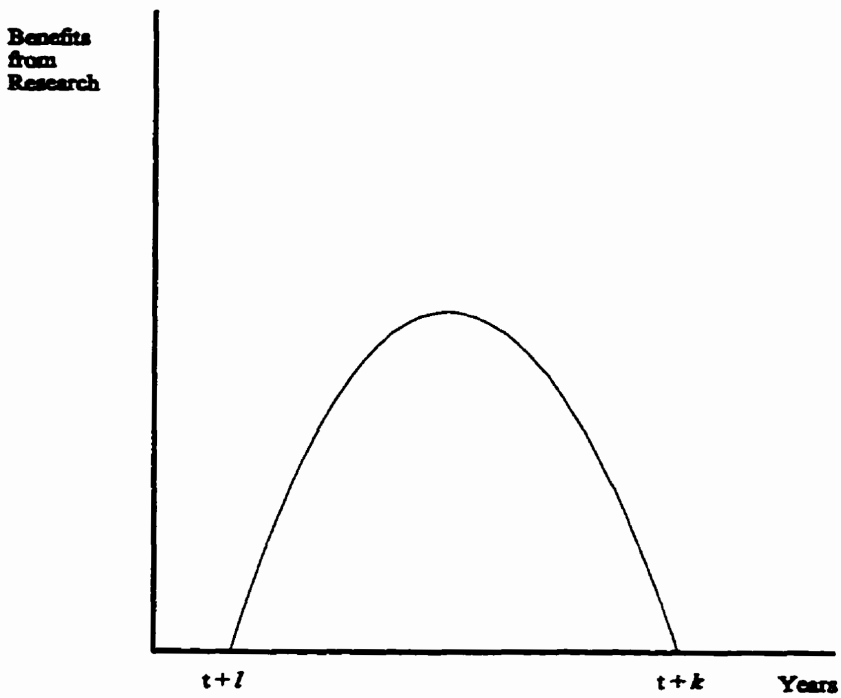
The type of supply shift is determined by the functional form of the supply function. A linear functional form produces parallel shifts and a partial - logarithmic functional form produces a proportional shift (Fox *et al.*, 1987).

3.3.5 The Lag Structure of Agricultural Research

The effect of agricultural research expenditures on the output of agricultural commodities is subject to time lags. The lag represents the time that elapses between the initial expenditure in research and the first measurable impact of research on aggregate production. Cline (1975) developed a quadratic polynomial distributive lag model that captures this effect. Figure 3.4, portrays the lag model.

A period of time is needed to develop a new technology, a new management

Figure 3.4 The Quadratic Polynomial Lag Model



technique, genetically improve an animal, for extension activities to have an effect, and for producers to adopt the newly developed technology. The first measurable impact of research on aggregate research benefits is represented by *l*, in Figure 3.4. As the new technology is adopted by farmers the contribution of research to economic benefits increases. Economic benefits will continue to increase as more producers adopt the new technology. At some point the economic benefits from research expenditures will begin to decline and eventually become exhausted. This happens after *k* years in Figure 3.4. Evenson (1968) argued that the decline in economic benefits occurs because the technology may become irrelevant through replacement technologies or maintenance decay.

3.3.6 Limitations of Estimating Economic Surplus with an Econometric Model

The limitations of estimating the changes in economic surplus, derived from research, with an econometric model have been identified by Klein *et al.*, (1994), Klein *et al.*, (1996) and Moschini *et al.*, (1997). Klein *et al.*, state the main limitation of the econometric approach relates to the problem of aggregation. Previous studies employing the econometric approach have focused on single commodities for large regions or whole countries. Since agricultural markets are closely linked, a change in one market may affect conditions in other commodity or agricultural input markets, such as the beef or feed industry.

Moschini *et al.*, (1997) also addresses this point, stating that the validity of econometrically estimated economic surplus measures presupposes optimality conditions in the entire economy. Thus, competitive pricing conditions are assumed in every market and every market is accounted for. Moschini *et al.*, (1997) extends this point, stating that the competitive price assumption may not be valid due to the inseparability of research benefits between public and private research expenditures.

In order to address these issues a multi-market modeling approach where all major agricultural products are considered simultaneously has been employed in recent returns to research studies (see, for example Klein *et al.*, 1994, 1996 and Agriculture and Agri-Food, 1996). By considering all major agricultural products simultaneously, the multi-market approach estimates the change in consumers' and producers' surpluses in the agricultural industry as a whole. Klein *et al.*, (1994) and Klein *et al.*, (1996) state that this method provides a more complete analysis of the effects of agricultural research in relationship to all other agricultural commodities in Canada.

The following chapter will describe the estimation of the industry's aggregate supply function and its application to the multi-market model that is employed in this study.

Chapter 4

Methods

4.1 Introduction

This chapter describes the method used in this study to estimate the returns to Canadian public swine research. First, the factors that could, in principle, influence the rate of technical change in the Canadian hog industry will be reviewed. Then the econometric estimates of the Canadian hog supply function that reflect the impact of historical research expenditures, as well as other factors, on aggregate hog supply will be discussed. Then there will be a discussion on how the results of this econometric analysis were incorporated into the multi-market model, titled the Canadian Regional Agricultural Model (CRAM). Finally, there will be an explanation of how the sum of consumers' and producers' surpluses are calculated using the Canadian Regional Agriculture Model (CRAM).

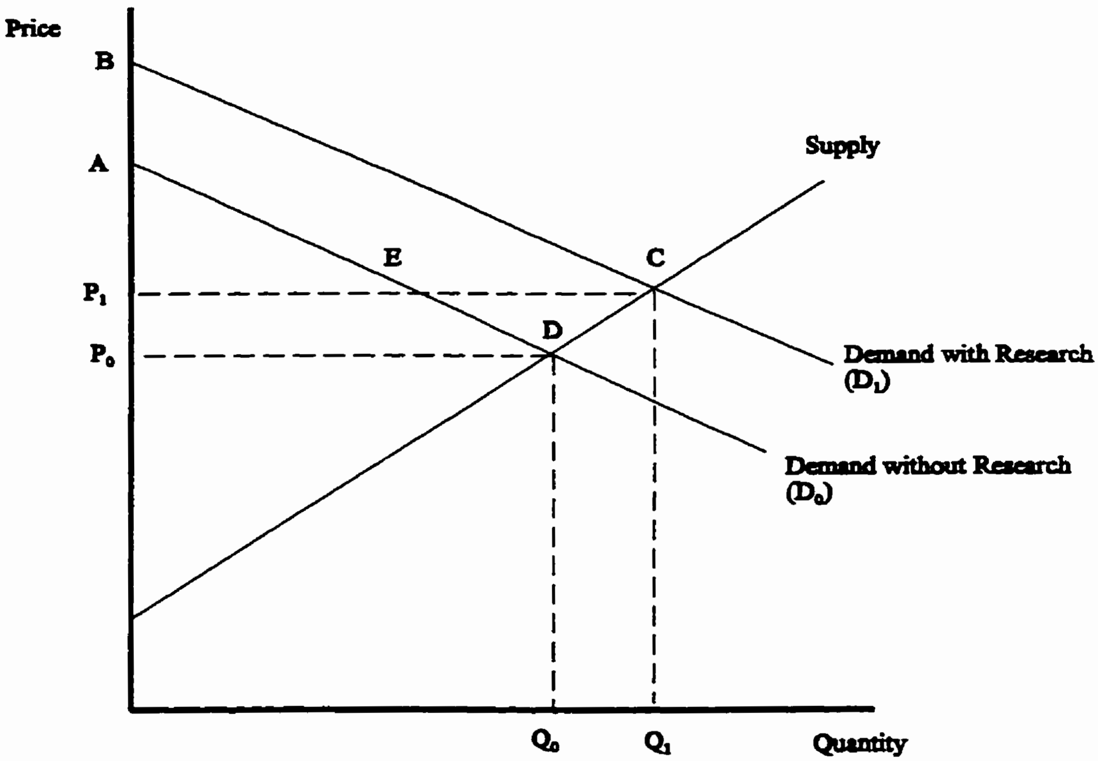
4.2 Factors Influencing Technical Change

Evenson *et al.*, (1979) argue that research leading to technological innovation is the primary source of increases in productivity in agriculture. In principle, technological innovation through swine research could influence the level and efficiency of production, the quality of the product or lead to improved management techniques. The rate of technical change in the Canadian hog industry can be related to research expenditures from the Canadian federal, provincial, and university and college research institutions. In addition, research expenditures from private sector research in Canada and spill-in effects from international research, producers' education and experience, and information transfer through extension services can also play a role in determining the rate of technical change in the Canadian hog industry.

Technical change can be defined in terms of the production function, the cost function or the profit function. In terms of the production function, technical change is defined as the ability to produce an increased level of output with a given quantity of inputs or as the ability to produce the same level of output with a smaller quantity of inputs. In terms of the cost function, technical change decreases the cost of producing a given level of output for a fixed set of input prices. In terms of the profit function, technical change is represented as an increase in profits for a given level of input and output prices. Regardless of whether technological change is conceptualized in terms of production functions, cost functions, or profit functions, research generating technical change will shift the industry supply function down and to the right at some point along its length. If consumer demand conditions remain constant, this shift generally results in a decrease in the output price and an increase in the quantity produced.

Technological change can also shift the consumer demand curve. A shift in the demand curve can occur if agricultural research leads to improved product quality. Improved product quality generally leads to an increase in consumer demand shifting the demand curve to the right. Figure 4.1 portrays the gross benefits from quality improving

Figure 4.1 Gross Research Benefits for a Shift in Demand



research. The parallel linear demand shift leads to increased commodity prices and an increase in quantity produced. In Figure 4.1 it is observed that producers' surplus increases by the area P_0DCP_1. The increase in prices reduces consumers' surplus by the area P_0DEP_1, but increased quantity produced adds AECB to consumer surplus. The sum of the increases in producers' surpluses and the net change in consumers' surplus is the area ADCB. Area ADCB represents the gross benefits from product quality improving research.

In the Canadian hog industry the value of a hog carcass is determined through the Canadian hog grading index. The Canadian hog grading index is a quality measuring mechanism that is used to determine the quality graded index carcass price premium or discount. Therefore, the indexed hog carcass price contains the perceived value of pork quality demanded by consumers. This enables the measurement of the value of Canadian swine research contributing to quality improvements in the product to be included in the estimated shift in the Canadian hog supply function. In this study the Canadian hog supply function is defined as a function of Canadian federal research expenditures, United States federal and state research expenditures, Canadian provincial research expenditures, extension expenditures, producers' education level, the market price of hogs, and the market price of feed barley. This relationship is described in its most general form in equation (4.1).

$$Q_t^h = f(R_{t-i}^{Cdn}, R_{t-i}^{US}, R_t^{Pro}, R_t^{Ext}, E_t, P_{t-j}^h, P_{t-l}^b) \qquad \textbf{(4.1)}$$

Where:

Q_t^h = quantity of hogs supplied,

$R^{Cdn}{}_{t-i}$ = swine research expenditures by the Canadian federal government,

$R^{US}{}_{t-i}$ = swine research expenditures by the Untied States federal and state governments,

$R^{Pro}{}_t$ = swine research expenditures by the Canadian provincial governments,

$R^{Ext}{}_t$ = extension expenditures by the Canadian provincial governments,

E_t = swine producers' education level,

$P^h{}_t$ = price of market hogs,

$P^b{}_{t-l}$ = price of feed barley, lagged l years.

4.2.1 Estimation of the Canadian Hog Supply Function

The purpose of estimating the Canadian hog supply function in this study is to estimate the effect of Canadian public swine research expenditures on national supply. The observed estimated change in output in the absence of swine research expenditures will be incorporated into the multi-market Canadian Regional Agricultural Model.

A previous study examining the returns to research for the Canadian swine industry was conducted by Huot (1987). Huot used econometric methods to estimate the impact that swine research had on the Canadian hog supply function. The aggregate supply function for hogs was estimated with quantity supplied as a function of the same independent variables defined in equation 4.1. The estimated elasticity for the various research expenditure variables describes the impact of research expenditures on the output supplied. The estimated elasticity of Huot's study and a selection of other returns to research studies can be found on Table 4.1.

Huot (1987) employed a partial - logarithmic functional form to describe the relationship between the dependent and independent variables. One limitation of the partial - logarithmic functional form as used by Huot (1987) is that the intercept is forced through the origin. This is illustrated in Figure 4.2.

Fox *et al.*, (1990) suggest constraining the partial - logarithmic supply function to create a positive threshold price below which production falls to zero. Estimation subject to an output price constraint is used to ensure a desired intercept value that represents the actual structure of the industry. In this study a constrained partial - logarithmic functional form is employed using the same independent variables and time series data as in the study conducted by Huot. Using the same independent variables and time series data as employed by Huot allows for a direct comparison of the two approaches.

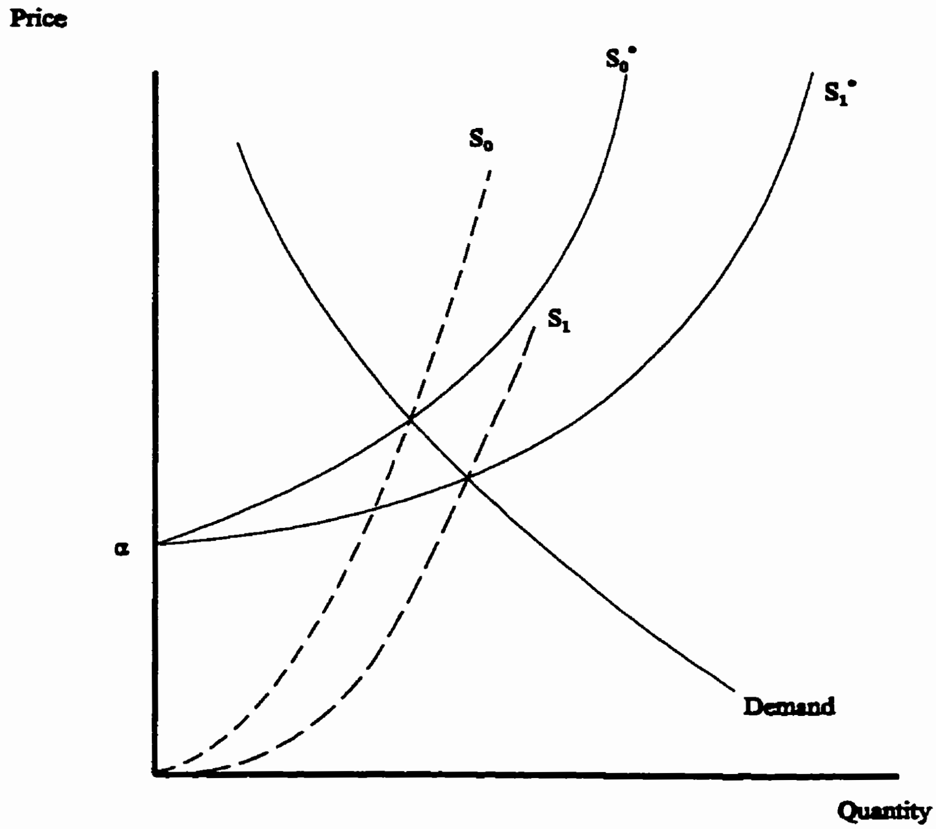
Figure 4.2 portrays the constrained partial-logarithmic supply function, compared with the unconstrained partial - logarithmic functional form. S_0* represents the constrained partial - logarithmic supply function without Canadian swine research and S_1* represents the constrained partial - logarithmic supply function with research. S_0 represents the unconstrained partial - logarithmic supply function without Canadian swine research and S_1 represents the unconstrained partial - logarithmic supply function with Canadian swine research.

Table 4.1 Summary of Canadian Federal Research Elasticities for Different Commodities

Study	Commodity	Period	Method	Canadian Federal Research Elasticity
Agriculture & Agri-Food Canada (1996)	Potato	1971-1994	Delphi Forecasting Estimate	0.33[1]
Klein, Freeze, Clark, & Fox (1994)	Beef	1968-1984	Historical Productivity Trend	0.21
Huot, Fox, & Brinkman (1987)	Swine	1968-1984	Econometric Model: Partial Logarithmic Function	0.53
Zachariah, Fox, & Brinkman (1987)	Broiler	1968-1984	Econometric Model: Partial Logarithmic Function	0.27
Haque, Fox, and Brinkman (1987)	Egg	1968-1984	Econometric Model: Linear Function	0.55
Brown-Andison & Brinkman (1987)	Dairy	1968-1984	Econometric Model: Partial Logarithmic Function	0.51
Widmer, Fox, & Brinkman (1987)	Beef	1968-1984	Econometric Model: Linear Function	0.38
Horbasz, Fox, & Brinkman (1987)	Sheep	1968-1984	Econometric Model: Linear Function	0.24

[1] Estimated research elasticity represents the effect on output from all Canadian public research.

Figure 4.2 Comparison of the Unconstrained Partial - Logarithmic Supply Function with the Constrained Partial - Logarithmic Supply Function



The partial - logarithmic supply function subject to a constraint on the intercept is represented by equation (4.2). The coefficient α represents the threshold price below which production falls to zero, (see, Figure 4.2). The present model set α at 60% of the market price based on the assumption that all current producers would exit the market at this price. The assumption is based on the findings that the top 20% by profitability of Ontario grower to finisher swine producers had approximate total variable costs equal to 60% of their total revenue (OMAFRA, 1995). Therefore, if the market price dropped to the threshold price, the top producers would exit the market and all current hog production would drop to zero.

$$Q_t^h = e^{\beta(T)}(P_t^h - \alpha)^{\eta}(P_{t-2}^b)^{\gamma} \tag{4.2}$$

Where:

Q_t^h = quantity of hogs supplied,

β(T) = technology shifter function, see equation (4.4),

P^h_t = price of market hogs,

P^b_{t-2} = price of feed barley,

α = threshold price,

γ = estimated supply elasticity with respect to the price of feed barley,

η = supply elasticity with respect to the price of hogs, restricted to 2.

The partial - logarithmic supply function used in this study restricts the supply elasticity ($\eta = 2$) with respect to the hog price. Therefore, equation (4.2) is restated as equation (4.3). The restriction on the supply elasticity with respect to the hog price is necessary to be consistent with the positive mathematical programming procedure used in the CRAM model. The rationale for placing the restriction on the supply elasticity with respect to the hog price is specified in the positive mathematical programming procedure which is discussed in further detail in section 4.4.1.

$$\frac{Q_t^h}{[(P_t^h-\alpha)^{\frac{1}{\eta}}]}=e^{\beta(T)}(P_{t-2}^b)^\gamma \tag{4.3}$$

The price variable (P^b_{t-2}) is lagged two years to represent the adjustment period for the producers' decision making process. The adjustment period includes the development of future output plans, the implementation of these plans, and the time period for the new level of output to be actually produced.

The $\beta(T)$ is the technology shifter function. The level of technology, (T), depends on provincial and university swine research expenditures, provincial extension expenditures, producers' education, Canadian federal swine research expenditures, and U.S. swine research expenditures. These variables are identified as research sources that impact on the level of output defined in Huot (1987), (see Equation 4.4).

$$\beta(T)=\theta t_t+\varphi D_t+\sum \delta R_{t-i}^{US}+\sum \varepsilon R_{t-i}^{Cdn} \tag{4.4}$$

Where:

t_t = the average of the indices of provincial and university swine research, extension expenditures, and producers' education level,

D_t = a dummy variable given for the years 1975 to 1977 to capture the decrease in swine production,

R^{US}_{t-i} = estimated swine research expenditures by the Untied States federal and state governments,

R^{Cdn}_{t-i} = estimated swine research expenditures by the Canadian federal government,

$\theta, \varphi, \delta, \varepsilon$= parameters to be estimated.

The independent variable t_t is the arithmetic mean of three variables: an index of provincial swine research expenditures (1981=100), an index of provincial swine extension expenditures (1981=1), and the index of farmer's education level (1981=1). The three variables were weighted together in the study done by Huot (1987) due to the observation of positive correlation between the three variables.

The coefficients on the lagged U.S. (R^{US}_{t-i}) and lagged Canadian federal (R^{Cdn}_{t-i}) swine research expenditures were assumed to follow a quadratic polynomial pattern with zero end points (see Figure 3.4). This lag represents the time that elapses between the initial expenditure in swine research and the first measurable impact of research on aggregate production. This is *l* years in Figure 3.4. A period of time is needed to develop a new technology, a new management technique, genetically improve an animal, for extension activities to have an effect, and for producers to adopt the newly developed technology. As the new technology is adopted by farmers the contribution of research to productivity increases. Productivity will continue to increase as more producers adopt the new technology. At some point the productivity gains from research investments will begin to decline and eventually become exhausted. This happens after *k* years in Figure 3.4.

Evenson (1968), argued that the decline in productivity gains occurs because the technology may become irrelevant through replacement technologies or maintenance decay. Huot (1987), found the lagged response of supply to Canadian federal swine research began three years after the research expenditures had been made and ended five years later. Estimation of the constrained partial - logarithmic hog supply confirmed the estimated lag structure (see the estimated coefficients for Canadian federal swine research in Table 4.2). This lag structure represents a relatively short response period suggesting that swine research is adopted into production practices at the producer level relatively quickly.

4.3 Constrained Partial - Logarithmic Regression Results

The constrained partial - logarithmic regression results for the Canadian hog supply function were derived with ordinary least squares (OLS). The use of ordinary least squares is justified since all of the independent variables may be regarded as exogenous. The variables used in the model are the lagged barley price (P^{b}_{t-2}), the hog price (P^{h}_{t}), the provincial technology index (t_t), the dummy variable (D_t), the Canadian federal swine research expenditures (R^{Cdn}_{t-i}), and the United States federal and state swine research expenditures (R^{US}_{t-i}). The time period in which the variables are observed is between 1962 and 1984. The time period observed and all the variables used in this estimation of the Canadian hog supply function with the constrained partial - logarithmic functional form are the same as the time period and variables used in the estimation of the Canadian hog supply function with the unconstrained partial - logarithmic functional form conducted by Huot (1987). Applying the same time period and variables maintains consistency and allows for a comparison of the estimated results.

Table 4.2 presents the estimated coefficients and elasticities of the variables in the selected equation. The level of significance for the coefficient on the Canadian federal research expenditures (R^{Cdn}_{t-1}) is significant at the 95% level. The level of significance for the coefficient on the U.S. research expenditures (R^{US}_{t-1}) is significant at the 80% level. The level of significance for the coefficients on the price of barley (P^{b}_{t-2}) and the provincial research index (t_t) are significant at the 90% level. The computed adjusted R-squared value or coefficient of multiple determination is found to be approximately 90%. The R-squared value represents the percent of variation in the dependent variable associated with the variation in the independent variables defined in the regression equation. The computed F-statistic value is found to be approximately 16. The F-statistic value represents the ratio of the dependent variables' variance associated with the regression equation and the variance associated with random disturbances. In other words, is the variance associated with the regression equation "larger" than the variance associated with random disturbances. When the computed F-statistic is compared with the appropriate critical F-value, it is observed that the computed F-statistic is larger and falls in the upper 5% range. This means that the variables in the regression equation do explain the

Table 4.2 Swine Restricted Supply Function Results

Dependent Variable = See Equation (4.2).

Explanatory Variables	Estimated Coefficients	t - statistic	Estimated Elasticity
Constant	6.2728	4.4416	
Logarithm of Barley Price (P^B_{t-2})	-0.4899	-2.1752	-0.5253
Technology Index (t_t)	0.1501	-2.0565	-0.2544
Dummy Variable (1975-1977)=1	-0.0046	-0.3665	
Canadian Federal Swine Research (R^{cdn}_{t-i})			
t-3	0.0522	3.3297	0.0401
t-4	0.0835	3.3297	0.0615
t-5	0.0939	3.3297	0.0662
t-6	0.0835	3.3297	0.0566
t-7	0.0522	3.3297	0.0343
sum	**0.3653**		**0.2587**
U.S Swine Research (R^{US}_{t-i})			
t-3	0.0036	1.5664	0.0243
t-4	0.0057	1.5664	0.0421
t-5	0.0064	1.5664	0.0460
t-6	0.0057	1.5664	0.0396
t-7	0.0036	1.5664	0.0242
sum	**0.0250**		**0.1762**

Functional Form: Constrained Partial - Logarithmic   Range of Data: 1962 - 1984

Adjusted R^2: 0.8985   F-Statistic: 16.13   Durbin-Watson: 1.5248 variation in the dependent variable.

The regression results show that the elasticity coefficient for the technology index (t_t) is negative. This result is arguably inconsistent with the assumption that research, extension services, and producer's education level will increase the level of the industry's output. This inconsistency suggests that the effects of provincial and university research, extension services, and producers' education level may be confounded with the effects of Canadian federal research or research spill-ins from the U.S. This is a common problem in applied economic research because many economic variables in time series data sets tend to fluctuate simultaneously (Johnson *et al.*, 1987). The implications of this problem are explored in the construction of five different scenarios used to calculate the returns to Canadian swine research in section 5.1.

The sum of the lagged regression results for the Canadian federal swine research (R^{Cdn}_{t-l}) elasticity coefficient is 0.2587. This describes the change in the Canadian hog supply function with respect to a change in Canadian federal swine research expenditures over the lagged time period. Assuming a 100% reduction in Canadian federal swine research, hog production would be reduced by approximately 25.9% over the estimated polynomial lag structure (i.e. after 8 years).

The next section will describe the Canadian Regional Agricultural Model (CRAM) and how the method of Positive Mathematical Programming was incorporated into the model. The following section will also describe how the sum of the Canadian federal estimated swine research expenditure elasticities were incorporated into the CRAM model.

4.4 The Canadian Regional Agricultural Model (CRAM)

The Canadian Regional Agricultural Model (CRAM) is a static spatial optimization model of Canadian agriculture. CRAM models all the major agricultural crops and livestock grown in Canada. CRAM is disaggregated at the provincial level and allows for interprovincial, inter-regional, and international trade. Existing government agricultural policies and programs are incorporated into the model. Based on land availability, government policies, production costs, commodity prices, transportation costs, and consumer tastes and preferences, CRAM allocates land among crops and livestock feed in each region to maximize producers' and consumers' surpluses. The CRAM model optimizes the production of Canadian agricultural commodities within the constraints of available agricultural resources and the final demands for the products.

Canadian production of hogs, cattle, dairy, and poultry is modelled in the CRAM model for each of the ten provinces. Pork primal cuts are produced in the hog sector of the model. Livestock animals are fed grains grown in the crops sector of the model: stored forage, pasture, barley, and corn for beef and dairy animals; barley for hogs; and wheat for poultry. Protein supplements are treated as a cash cost. Based on relative prices and nutritional characteristics of feedstuffs, feeder animals can be fed different ratios of feed grains and forages. The model also chooses the optimal rate of growth of feeder animals, within specified constraints (Klein *et al.*, 1994).

Domestic demand is specified for beef, pork, dairy products, eggs, broilers, and turkeys. Excess supplies can be exported. Both meat and livestock animals can be transported to other provinces and to export locations. The prices for farm products are dependent on the quantity produced and offered for sale, as well as on demand for the product. These effects are represented in the CRAM model through a series of stepped demand functions established for the major categories of final agricultural products (Klein *et al.*, 1994).

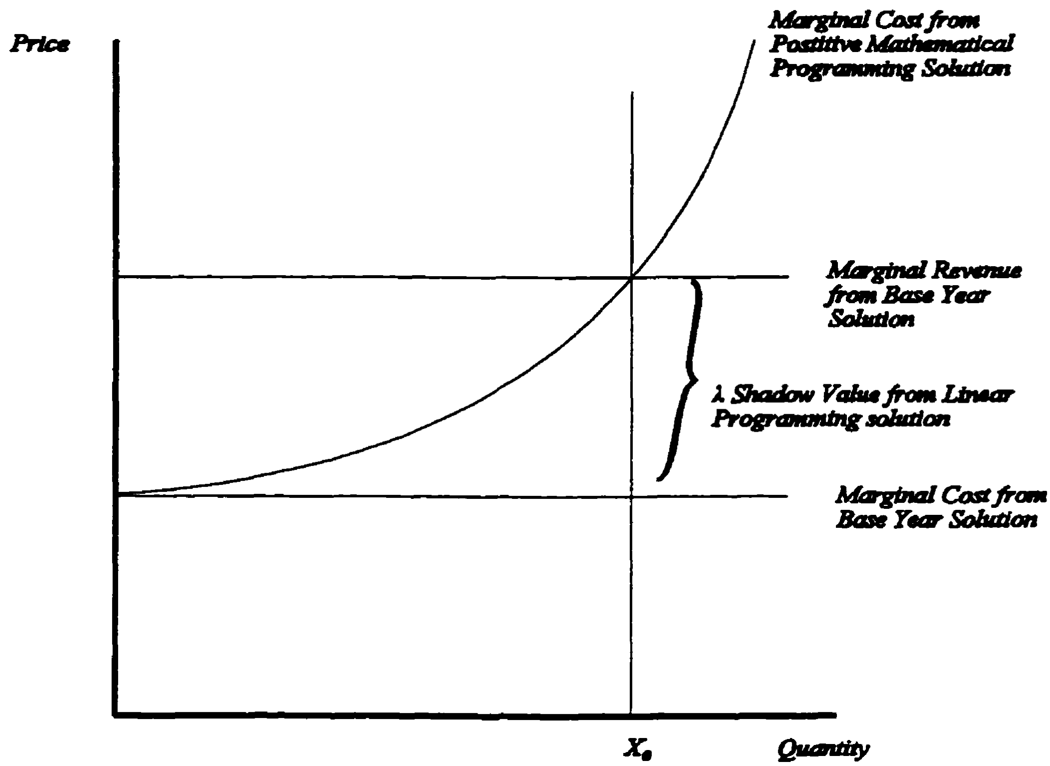
Since Canada trades all categories of grains and oilseeds, as well as beef and hogs, Canadian producers face import and export prices for these commodities. The small country assumption is used in the CRAM model. Therefore, changes in Canadian production will not effect world price levels. Domestic prices must then be between an export price floor and an import price ceiling. The downward-sloping demestic demand functions in the CRAM model for wheat, barley, canola, beef, and pork represent price levels between the floors and ceilings (Klein *et al.*, 1994).

The objective of the CRAM model is to maximize the sum of consumers' and producers' surpluses. Consumers' surplus is increased when the price of food falls due to greater production. Producers' surplus is measured as the difference between gross agricultural income and costs of production plus transportation (Horner *et al.*, 1992 and Klein *et al.*, 1994).

4.4.1 Positive Mathematical Programming in the Canadian Regional Agricultural Model

Positive Mathematical Programming (PMP) was introduced into the hog sector of the CRAM model for this study. The resulting model is flexible in its response to productivity changes and priors on the supply elasticities can be specified (Howitt, 1995).

Figure 4.3 CRAM Supply Function Derived using Positive Mathematical Programming



Positive Mathematical Programming allows the calibration constraints to be eliminated so that the CRAM model can solve for an optimal level of output in the base year of the model (1996).

Without Positive Mathematical Programming, given the gross returns and average costs per grower hog space, the base year production level must be constrained by calibration constraints in the linear programming model to generate the actual output level (X_0). This produces a shadow value (λ) that is the difference between the linear marginal revenue function and linear marginal cost function at the actual output level, (see Figure 4.3). Without constraining the linear marginal cost function optimal production would be undefined.

To link the Positive Mathematical Programming procedure to the CRAM model a quadratic marginal cost function is specified for grower hogs. The specified marginal cost function consists of variable costs, feed costs, and the observed shadow value (λ). Marginal variable costs and feed costs are assumed to be independent of the level of output and the shadow value is assumed to vary as a quadratic function of output. Therefore, the marginal cost function is specified as a quadratic function where the elasticity of the price of hogs (η) is assumed to be equal to 2. As a result, the total variable cost function, which is the integral of the marginal cost function, is a cubic function of output. This results in a cubic optimization problem that equates marginal cost with marginal revenue at the base year's actual output level. The Positive Mathematical Programming procedure now incorporates a non-linear supply response into the CRAM model. Since a value of, $\eta = 2$, has been assumed, an estimate employing the restricted supply function defined in equation (4.3) can now be calculated.

4.4.2 Modelling Technical Change in the Canadian Swine Industry in CRAM with Positive Mathematical Programming

The CRAM model is used to calculate the sum of consumers' and producers' surpluses for Canadian swine research that took place between 1976 and 1997. The objective function of the model maximizes the sum of consumers' and producers' surpluses by optimizing the allocation of land among crops and livestock feed in each region in Canada for all agricultural commodities. To model technical change in the Canadian swine industry in the CRAM model with Positive Mathematical Programming specific input and output productivity coefficients were used.

To determine the sum of consumers' and producers' surpluses with swine research the objective function in the CRAM model was solved. Equation (4.5) is the portion of the CRAM model's objective function that refers to Canadian hog production. The input/output coefficients that are used in this portion of the CRAM model's objective function are 1) the quality indexed price of a hog, 2) the variable costs of raising a hog, 3) the inverse of hogs per sow or the number of sows needed to produce a given number of hogs, and 4) the variable costs of maintaining a sow.

$$P_t^h(T)(Q_t)-[C_t^h(T)(Q_t)+(\psi(T))(C_t^s(T)(Q_t))] \qquad \textbf{(4.5)}$$

Where:

Q_t = The quantity of market hogs sold in a given year.

(T) = Represents the parameter as a function of technology, T.

P_t^h = The indexed farm gate price of a market hog net of shipping costs. The indexed farm gate price of a market hog is determined by the quality index and the average carcass weight measure.

C_t^h = The costs of maintaining one market hog space for one year includes; total variable costs, feed barley costs, and feed protein costs.

Ψ = The inverse of (S_t / Q_t), the market hogs per sow productivity ratio. Number of sows needed to produce a given number of hogs.

C_t^s = The cost of maintaining one sow space for one year includes; total variable costs, feed barely costs, and feed protein costs.

In order to isolate the effects of technical change in the Canadian swine industry the input/output coefficients -- i.e. the quality graded indexed price of a hog, the variable costs of raising a hog, the inverse of hogs per sow or the number of sows needed to produce a given number of hogs, and the variable costs of maintaining a sow-- were adjusted by their productivity growth rates each year in the CRAM model. All other parameters in the CRAM model were held constant at 1996 levels. Therefore, the CRAM model is solved and optimizes for each year observed in the study under the terms of 1996 production policies and prices. This allows the results of the study to be interpreted as the effects of technical change on output derived from Canadian swine research expenditures.

4.4.2.1 Estimation of the Input and Output Coefficients

To satisfy the data requirements of the hog component in the CRAM model, time series data were collected for each input/output coefficient. This section will describe how the data for each coefficient were collected and derived. The historical values and productivity growth rates of each coefficient are presented in Table 4.3. The input/output coefficients are 1) the quality graded indexed price of a hog, 2) the inverse of hogs per sow or the number of sows needed to produce a given number of hogs, 3) the variable costs of raising a hog, 4) the variable costs of maintaining a sow, 5) the feed requirement to produce a market hog, 6) the feed requirement to maintain a sow, 7) the protein requirement to maintain a market hog, and 8) the protein requirement to maintain a sow.

First, the output coefficient, i.e. the indexed farm gate price for market hogs (P^h_t), is a function of the 1996 domestic hog base price and the annual average hog grading index. The data for the annual average hog grading index was collected at the provincial level between 1971 and 1996. These historical time series data sets were collected from Agriculture and Agri-Food Canada's 'Livestock Market Review'. The average hog grading index was adjusted on the basis of the 1996 Canadian Hog Carcass Grading Settlement System.Second, the input variable, the inverse of hogs per sow or the number of sows needed to produce a given number of hogs (Ψ), is a function of the average number of hogs produced per sow and the total number of hogs produced. The production data for both the average number of hogs produced per sow and the total number of hogs produced were collected at the provincial level between 1971 and 1996. These historical time series data sets were collected from Agriculture and Agri-Food Canada's 'Livestock Market Review'.

Table 4.3 Canadian Swine Historical Input and Output Coefficients

Year	Average Hog Carcass Weight[1] (kgs)	Average Hog Grading Index[1]	Average Number of (Hogs/ Sow/ Farrowing)	Average Feed Barley Requirement (metric tons/hog space/year)	Average Feed Protein Requirement (metric tons/hog space/year)	Average Feed Barley Requirement (metric tons/sow space/year)	Average Feed Protein Requirement (metric tons/sow space/year)
				Market Hogs		Sows	
1971	74.6	99.6	--	1.1489	0.1686	0.8973	0.1316
1976	74.6	101	11.98	1.1456	0.1543	0.8511	0.1203
1981	77.2	101.4	11.67	1.0128	0.1364	0.9217	0.1187
1986	79	102.5	9.53	0.8963	0.138	1.1076	0.1635
1991	81.2	104.3	13.78	0.8418	0.1654	1.0326	0.1957
1996	84.1	105.9	13.08	0.7377	0.1694	0.9672	0.1926
Average Annual Growth Rates	0.4	0.18	1.32	-1.55	0.72	0.58	2.2

Source: [1] Agriculture and Agri-Food Canada. Production and Marketing Branch, Livestock Division. *Livestock Market Review*. Various Years.

Third, the input coefficients for total variable costs of both hogs (C_t^h) and sows (C_t^s), are a function of total number of hogs produced, average feed barley and feed protein requirements, 1996 feed prices, and 1996 variable costs. The 1996 variable costs are derived from the sum of veterinary, insurance, marketing, labour, maintenance, supplies, manure disposal, taxes, and utility costs. The data for average feed barley and feed protein requirements for both hogs and sows were collected at the provincial level between the years 1971 and 1996.

From Table 4.3 it is observed that the average hog carcass weight increased from 74.6kgs per animal in 1971 to 84.1kgs per animal in 1996, a 0.40% average annual rate of increase. The average hog grading index increased from 99.6 in 1971, (adjusted on the basis of the 1996 Canadian Hog Carcass Grading Settlement System), to 105.9 in 1996, a 0.18% average annual rate of increase. The average number of hogs per sow productivity measure represents the sum of total hogs marketed plus total weaner pigs and hogs exported, divided by the year's opening stocks of sows and bred gilts. The average number of hogs per sow productivity measure increased form 11.98 in 1976 to 13.08 in 1996 a 1.32% average annual rate of increase. The average feed barley requirement per hog space decreased from 1.1498 tonnes per hog space per year in 1971 to 0.7377 tonnes per hog space per year in 1996 a negative 1.55% average annual rate of decrease. The average feed protein requirement per hog space increased from 0.1686 tonnes per hog space per year in 1971 to 0.1694 tonnes per hog space per year in 1996 a 0.72% average annual rate increase. The average feed barley requirement per sow space increased from 0.8973 tonnes per sow space per year in 1971 to 0.9672 tonnes per sow space per year in

1996 a 0.58% average annual rate increase. Finally, the average feed protein requirement per sow space increased from 0.1316 tonnes per sow space per year in 1971 to 0.1926 tonnes per sow space per year in 1996 a 2.20% average annual rate increase.

The derived output coefficients' average annual productivity growth rate for the average hog carcass weight variable, average hog grading index variable, and average number of hogs produced per sow per farrowing variable are all increasing over the observed time period. This represents quantity and quality improvements based on swine research. The derived input coefficients' average annual productivity growth rate on the average feed barley variable and feed protein requirement variable for hogs and sows are all increasing, except the coefficient on the average feed barley variable requirement for hogs. Initially this appears contradictory to the idea that swine research contributes to input saving technologies and innovations. However, increased feed barley for sows, and increased feed protein requirements for hogs and sows represent improved feeding regimens that contribute to the increased quantity and quality of swine products. The improved quantity and quality is reflected in the output variables through the increase in the average hog carcass weight, the average hog quality grading index, and the average number of hogs produced per sow per farrowing.

4.4.3 Solving the CRAM Model for the With Research and Without Research Solution

The CRAM model solves for the sum of consumers' and producers' surpluses for all Canadian agricultural markets annually. This section describes how the sum of consumers' and producers' surpluses were derived with and without swine research for the base solution. The base solution is where the sum of consumers' and producers' surpluses are derived using the actual 1996 base year prices, the defined input and output coefficients, and their respective average annual productivity growth rates. The results of the estimations are reported in section 5.5 along with a sensitivity analysis.

The first step in solving for the sum of consumers' and producers' surpluses with Canadian public swine research is for the CRAM model to solve for the base year, 1996. The portion of the objective function in the CRAM model that represents Canadian hog production (Equation 4.5) maximizes the sum of consumers' and producers' surpluses for 1996 prices, policies, and the 1996 values of the input/output coefficients. The following steps describe how the sum of consumers' and producers' surpluses for each year in the model were derived by adjusting the input/output coefficients by their average annual productivity growth rate relative to their 1996 output levels.

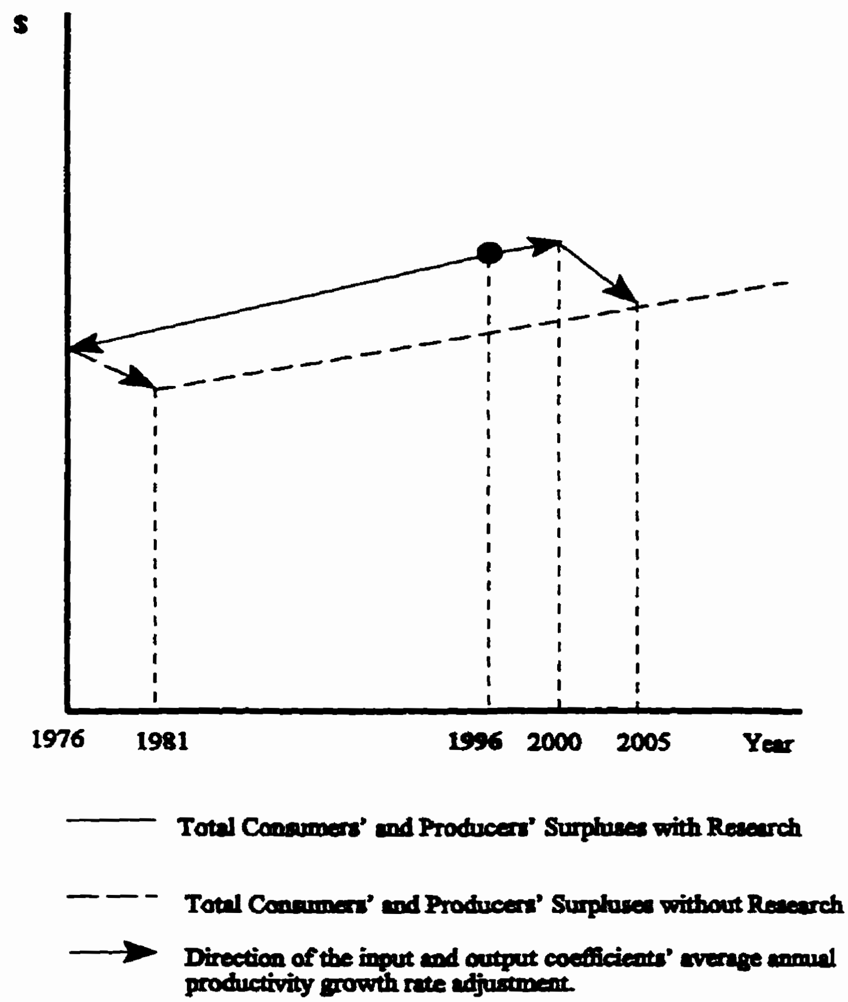
The second step in solving for the sum of consumers' and producers' surpluses with Canadian public swine research was for the CRAM model to solve for all the other years included in this study. Therefore, each year between 1976 and 1995 and between 1997 and 2000 had to be individually solved for by the CRAM model. Historical data for each input/output coefficient for the period 1976 to 1996 and the average annual productivity growth rate for each coefficient was derived. The input/output coefficients used in the CRAM model's objective function are the quality graded indexed price of a hog, the variable costs of raising a hog, the inverse of hogs per sow or the number of sows needed to produce a given number of hogs, and the variable costs of maintaining a sow.

To calculate the sum of consumers' and producers' surpluses between 1976 and 1995 each input/output coefficient in the objective function was projected backward from 1996 at its average annual productivity growth rate. Figure 4.4 illustrates the direction of adjustment with respect to the input/output coefficients. First, the CRAM model solved the sum of consumers' and producers' surpluses for the base year 1996. Then the input/output coefficients were projected backward one year by their average annual productivity growth rate to 1995. The CRAM model then solved for the sum of consumers' and producers' surpluses for 1995. This procedure was then repeated for every year between 1995 and 1976.

To calculate the sum of consumers' and producers' surpluses between 1997 and 2000 each input and output variable in the objective function was projected forward from 1996 at their average annual productivity growth rate. First, the CRAM model solved the sum of consumers' and producers' surpluses for the base year 1996. Then the input and output variables were projected forward one year by their average annual productivity growth rate to 1997. The CRAM model then solved for the sum of consumers' and producers' surpluses for 1997. This procedure was then repeated for every year between 1997 and 2000.

The third step in solving for the sum of consumers' and producers' surpluses with Canadian public swine research was for the CRAM model to solve for each year between 2001 and 2005. Public swine research was assumed to be terminated at the end of 1997, but research would continue to effect production up to 2005 according to the estimated lag structure. By 2005 the 100% reduction in Canadian swine research in 1997 results in a

Figure 4.4 Sum of Consumers' and Producers' Surpluses With and Without Swine Research between 1976 and 2005



25.9% reduction in supply relative to the year 2000.

The CRAM model cannot simulate the 25.9% reduction in supply directly. This adjustment is made by changing the input/output coefficients to reflect the loss in productivity due to the absence of research. Therefore, to calculate the reduction in the sum of consumers' and producers' surpluses, the input/output coefficients' average annual productivity growth rates were weighted by the annual percentage change required to achieve the estimated reduction in supply over the lagged five years. The input/output coefficients' average annual productivity growth rates were weighted by 4%, 10.2%, 16.8%, 22.5%, and 26% respectively for each year over the five year lag. Then the CRAM model was solved for the sum of consumers' and producers' surpluses for each year between 2001 and 2005 with the adjusted input/output coefficients.

The fourth step in determining the gross annual research benefits was to calculate the sum of consumers' and producers' surpluses that would of occurred if swine research had ceased at the start of 1974. The estimated lag structure indicates that the supply of hogs would not be affected for three years, or until 1977. Then between 1977 and 1981, the estimated 25.9% reduction in the hog supply function relative to the year 1976 occurs. To calculate the reduction in consumers' and producers' surpluses between 1977 and 1981, the input/output coefficients were adjusted by the same procedure that was discussed previously for the years 2001 to 2005.

The last step in determining the gross annual research benefits was to calculate the sum of consumers' and producers' surpluses between 1982 and 2005 under this scenario when swine research was assumed to cease in 1974. The values for the sum of consumers' and producers' surpluses between 1982 and 2005 were based on assumptions regarding what other research sources would contribute to consumers' and producers' surpluses in the absence of Canadian public swine research. Five different scenarios were defined and are described in the next chapter.

The difference between the sum of consumers' and producers' surpluses derived with swine research and the sum of consumers' and producers' surpluses derived without swine research gives the gross annual research benefits for each of the different scenarios. In Figure 4.3 the gross annual research benefits can be observed as the difference between the top solid line and the bottom slashed line.

Chapter 5

Analysis and Results

5.1 Analysis of Swine Research Costs and Benefits

The purpose of this chapter is to discuss the calculation and results of all the Canadian swine research costs between 1974 and 1997 and the lagged benefits between 1974 and 2005. The first part of this chapter will discuss the five different scenarios used in the interpretation of the estimated gross annual research benefits. This section will also discuss the different analytical variations defined within each scenario. The second part of this chapter will discuss the calculated Canadian swine research effort and the associated costs. The last part of the chapter will present the results of the analysis on the returns to Canadian swine research.

5.2 Overview of the Different Scenarios

In total there are five different scenarios examined in this study (see Table 5.1). The scenarios provide alternative solutions to the calculated gross annual research benefits, derived from the difference between the calculated Canadian Regional Agricultural Model (CRAM) results and the calculated sum of consumers' and producers' surpluses derived in the absence of Canadian public swine research.

Table 5.1 Overview of the Five Scenarios

Scenarios					
	(1) Gross Annual Research Benefits Attributed to Canadian Federal Research			(2) Gross Annual Research Benefits Attributed to All Canadian (Public & Private) Research	
	Scenario 1.A	**Scenario 1.B**	**Scenario 1.C**	**Scenario 2.A**	**Scenario 2.B**
Benefits	Gross Annual Research Benefits are attributed to Canadian federal swine research (1976-1997). This scenario is based on the estimated supply function from the econometric results. See Figure 5.1.	Scenario 1.B is the same as 1.A except the size of the supply shift is reduced by 35% to 16.9%. See Figure 5.2.	Scenario 1.C is the same as 1.A except it assumes a relationship exists between federal and non-federal research productivity. In 1.C, the without federal research solution reflects the contribution of Canadian federal research to the productivity of other Canadian swine research. See Figure 5.3.	Gross Annual Research Benefits are attributed to all Canadian swine research (1976 - 1997). The without Canadian research solution reflects the impact of U.S. research spill-ins. See Figure 5.4	In scenario 2.B the without research solution is modified to reflect the possibility that the size of U.S. research spill-ins are overstated in the econometric results used in scenario 2.A. See Figure 5.5
Costs	Costs of research are only Canadian federal expenditures (plus excess burden of taxation 38%).	The costs are the same as in Scenario 1.A.	The costs are the same as in Scenario 1.A.	Costs of research are Canadian federal (plus excess burden of taxation 38%) plus provincial (plus excess burden of taxation 66%)plus universities and colleges (plus excess burden of taxation 38%) plus private industry expenditures, (estimated to be 40% of all Canadian PPYs).	The costs are the same as in Scenario 2.A.

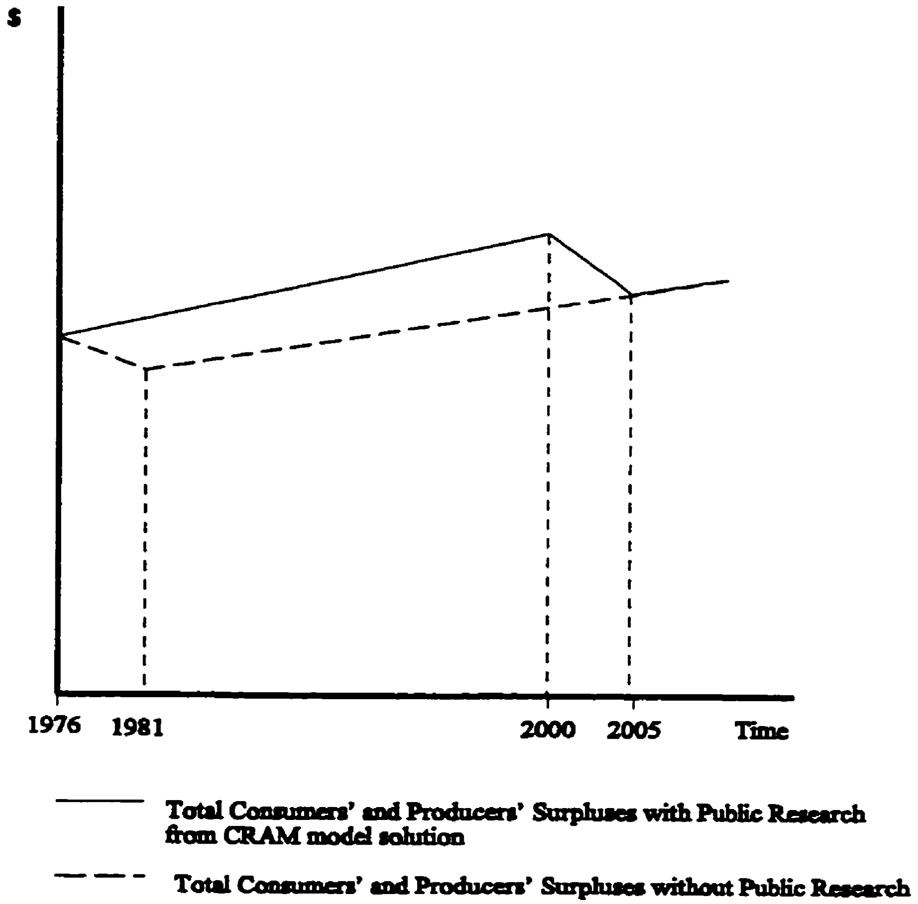
5.2.1 Scenarios 1.A, 1.B, and 1.C: Research Benefits Attributed to Canadian Federal Swine Research

Scenario 1.A, 1.B, and 1.C attribute the gross annual research benefits to Canadian federal swine research. The gross annual research benefits are measured as the difference between the consumers' and producers' surpluses calculated by the CRAM model and the consumers' and producers' surpluses that are calculated with out federal research. It is assumed in scenario 1.A, 1.B and 1.C that if Canadian federal swine research were terminated, swine research from provincial, universities and colleges, the U.S., and private industry sources would continue. In these scenarios a direct interpretation of the econometric results was applied. The econometric results are presented in section 4.3, where it was estimated that a 25.9% reduction in the Canadian hog supply function would occur with the complete termination of Canadian federal swine research.

5.2.1.1 Description of Scenario 1.A

Scenario 1.A is a direct interpretation of the econometric results derived in section 4.3, where a 25.9% reduction in supply is attributed to the complete termination of Canadian federal swine research. For scenario 1.A, the total consumers' and producers' surpluses calculated for the "with-research" solution by the CRAM model is represented with the solid line between 1976 and 2005 in figure 5.1. The with-research solution assumes that swine research was terminated in 1997. The estimated research lag period indicates that the hog supply function would not be affected for three years after the termination of swine research. Then the 25.9% reduction in the hog supply function was

Figure 5.1 Scenario 1.A: Gross Annual Research Benefits from Canadian Federal Swine Research (1976 - 2005)



simulated between 2001 and 2005 relative to the output level in the year 2000. This creates a reduction in the sum of consumers' and producers' surpluses over the remaining estimated lag period between 2001 and 2005.

The total consumers' and producers' surpluses calculated for the "without-research" solution are represented with the slashed line (see, Figure 5.1). This line digresses from the with-research solution after 1976, simulating the effect of a 100% reduction in Canadian federal swine research expenditures in 1974. The 100% reduction in Canadian federal swine research expenditures causes the estimated 25.9% reduction in the supply of hogs over the last five years of the estimated lag period relative to the level of output in 1976. In order to derive the total consumers' and producers' surpluses between 1981 and 2005 that would of occurred without Canadian federal swine research, the 1981 CRAM model calculation was linearly extrapolated forward to the 2005 CRAM model calculation. These results represent the total consumers' and producers' surpluses without Canadian federal research that were assumed to be derived from the effect of research contributions from provincial, universities and colleges, and U.S. spill-ins. Research contributions from provincial, universities and colleges, and U.S. spill-ins were assumed to contribute to the Canadian hog industry's productivity growth.

The total gross annual research benefits for scenario 1.A is the difference between 1) the consumers' and producers' surpluses calculated by the CRAM model and 2) the consumers' and producers' surpluses that were calculated without Canadian federal swine research.

5.2.1.2 Description of Scenario 1.B

Scenario 1.B was developed to illustrate the impact on the calculated gross annual research benefits from a reduction in Canadian federal swine research which in turn causes an impact on the supply of hogs. The rationale for the development of scenario 1.B is due to the possibility that the historical data used in the econometric model may be confounded, resulting in multicollinearity between the economic variables defined in the hog supply function.

To explore the possibility that a 25.9% reduction in the supply of hogs might overestimate the effect of Canadian federal swine research, this 25.9% value was reduced by 35% to 16.8%. The 16.8% change in the supply of hogs relative to the level of output in 1976 was chosen because it is an actual CRAM model solution that was calculated for 1979 the sixth year of the estimated lag period. This value was then assumed to represent the sum of consumers' and producers' surplus in 1981 the last year in the estimated lag period. The values for total consumers' and producers' surpluses between 1976 and 1981 were then linearly extrapolated forward from 1976 to 1981.

The same procedure was repeated relative to the level of output in 1997 when Canadian federal swine research was assumed to be terminated. The 16.8% change in the supply of hogs relative to the level of output in 2000 was chosen because it represents an actual CRAM model solution that was derived for 2003 the sixth year of the estimated lag period. This value was then assumed to represent the sum of consumers' and producers' surplus in 2005 the last year in the estimated lag period. The values for total consumers' and producers' surpluses between 2000 and 2005 were then linearly extrapolated forward

Figure 5.2 Scenario 1.B: Adjusted Gross Annual Research Benefits from Canadian Federal Swine Research (1976 - 2005)

——— Total Consumers' and Producers' Surpluses with Federal Research from CRAM model solution

— — – Total Consumers' and Producers' Surpluses without Federal Research (1.A)

········· Adjusted Total Consumers' and Producers' Surpluses without Federal Research (1.B) from 2000 to 2005.

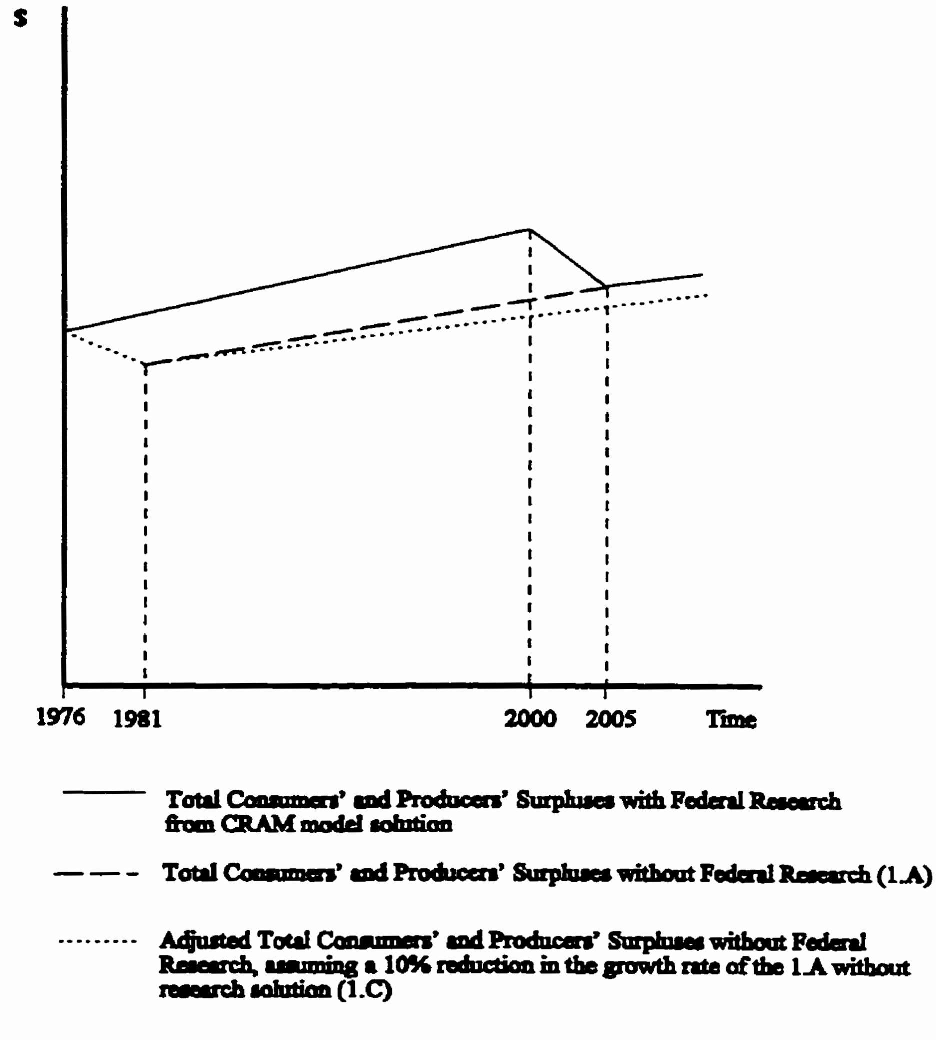
For scenario 1.B, the total consumers' and producers' surpluses associated with Canadian federal swine research between 1976 and 2005 are represented by the solid line in figure 5.2. The total consumers' and producers' surpluses associated without Canadian federal research are represented by the dotted line. The lines digress from each other starting in 1976, simulating the effects of a 100% reduction in Canadian federal swine research expenditures. The 100% reduction in Canadian federal swine research expenditures in this scenario was assumed to cause an estimated 16.8% reduction in the supply of hogs over the last five years of the estimated lag period relative to the level of output in 1976 and 2000.

Total consumers' and producers' surpluses without Canadian federal swine research are derived by linearly extrapolating the 1981 CRAM model calculation forward to the 2005 CRAM model calculation. Total consumers' and producers' surpluses without Canadian federal research are assumed to represent the effect of research contributions from provincial, universities and colleges, and U.S. spill-ins. Figure 5.2 provides a comparison between the areas representing the gross annual research benefits for scenario 1.A and 1.B.

5.2.1.3 Description of Scenario 1.C

Scenario 1.C, was developed to illustrate the possible relationship between Canadian federal swine research and Canadian non-federal swine research. Scenario 1.C assumed that the complete termination of Canadian federal swine research would

Figure 5.3 Scenario 1.C: Adjusted Gross Annual Research Benefits from Canadian Federal Swine Research (1976 - 2005)



adversely affect the productivity of Canadian non-federal swine research. In this scenario it is assumed that a 10% reduction in the growth rate of the total consumers' and producers' surpluses derived without Canadian federal swine research would occur. Figure 5.3 illustrates the estimated gross annual research benefits that would occur as a result of Canadian federal swine research when it is assumed that a synergetic relationship exists between Canadian federal and Canadian non-federal swine research.

In Figure 5.3 the total consumers' and producers' surpluses associated with Canadian federal swine research between 1976 and 2005 are represented by the solid line. The total consumers' and producers' surpluses associated without Canadian federal swine research are represented by the slashed line. The lines digress from each other starting in 1976, simulating the effect of a 100% reduction in Canadian federal swine research expenditures. A 100% reduction in Canadian federal swine research expenditures would cause an estimated 25.9% reduction in the supply of hogs over the last five years of the estimated lag period relative to the output level in 1976. After 1981, the original growth rate of total consumers' and producers' surpluses for the without-research solution in scenario 1.A was decreased by 10%. The 10% reduction in the total consumers' and producers' surpluses growth rate represents the assumed reduction in research productivity that Canadian non-federal swine research suffers when Canadian federal swine research is completely terminated.

In Figure 5.3, it is observed that permanent gross annual research benefits are derived after 2005. The permanent gross annual research benefits were attributed to Canadian federal research and were included in the net benefit calculations for this scenario. The permanent gross annual research benefits represent the effects Canadian federal research has on swine production productivity into the future.

5.2.2 Scenarios 2.A and 2.B: Research Benefits Attributed to all Canadian Public and Private Research

Scenario 2.A and 2.B attributes the gross annual research benefits to the combination of all Canadian public and private swine research. These scenarios were developed to examine the possibility that the research benefits generated from Canadian federal swine research cannot be separated from the research benefits generated from other Canadian swine research sources. If this assumption is correct then the gross annual research benefits should be attributed to federal, provincial, university and colleges, and private sector research sources.

5.2.2.1 Description of Scenario 2.A

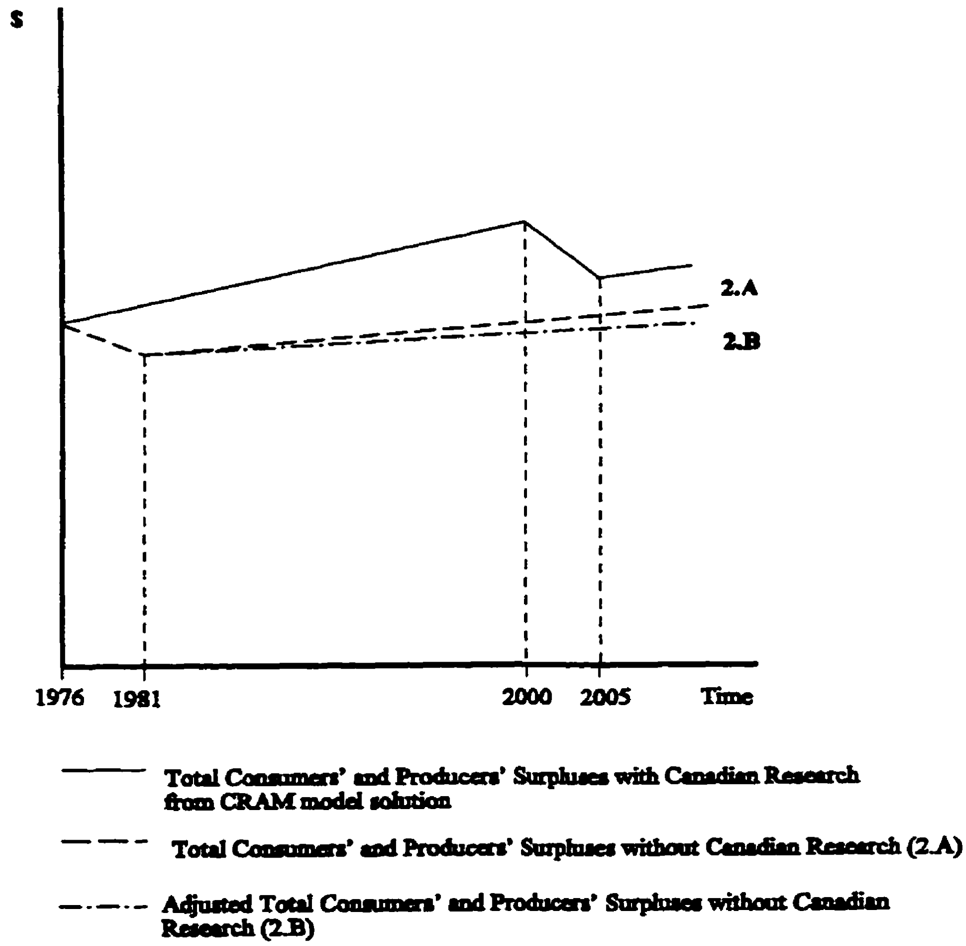
Scenario 2.A assumes that the total consumers' and producers' surpluses maximized by the CRAM model are derived from all Canadian research sources. To account for the full range of Canadian swine research inputs, the benefit and cost calculations incorporate the research costs for federal, provincial, universities and colleges and private sector research. The gross annual research benefits calculated in scenario 2.A are measured as the difference between total consumers' and producers' surpluses with Canadian research and total consumers' and producers' surpluses without Canadian research.

It is assumed in scenario 2.A that if all Canadian swine research were terminated, research from the U.S. would still continue and would generate research spill-ins that would benefit Canadian producers. Therefore, total consumers' and producers' surpluses without Canadian research are measured as the level of consumers' and producers' surpluses derived from U.S. research spill-ins only.

The relative effect of U.S. research on the Canadian hog supply function must therefore be estimated. The sum of both the estimated elasticity coefficients of Canadian Federal and U.S. research expenditures were estimated and the results were presented in Table 4.2. To estimate the relative effect of U.S. research spill-ins the ratio of the sum of elasticities for U.S. research to the sum of the elasticities of Canadian Federal and U.S. swine research was calculated. This represents the relative effect of U.S. research spill-ins. The effect of U.S. research spill-ins, was found to represent 41.5% of the growth rate of the without Canadian federal research solution in scenario 1.A. Therefore, the growth rate of consumers' and producers' surpluses in the without research solution derived in scenario 1.A was reduced by 41.5% between 1981 and 2005. This represents the spill-in effect of U.S. research. After this adjustment, all the derived gross annual research benefits are attributed to total Canadian public and private research sources.

Figure 5.4 illustrates the estimated gross annual research benefits that occur as a result of all Canadian public and private research sources. The total consumers' and producers' surpluses associated with all Canadian research is graphed with the solid line. The total consumers' and producers' surpluses associated without Canadian research is

Figure 5.4 Scenario 2.A & 2.B: Gross Annual Research Benefits from all Canadian Swine Research (1974 -2005)



graphed with the slashed line. The difference between the top solid line and the middle slashed line represents the gross annual research benefits attributed to all Canadian research. In Figure 5.4, it is observed that permanent gross annual research benefits are derived after 2005. The present value of the permanent gross annual research benefits were attributed to Canadian swine research and were included in the net benefit calculations for this scenario. The permanent gross annual research benefits represent the effects Canadian swine research has on swine production productivity in the future.

5.2.2.2 Description of Scenario 2.B

Scenario 2.B is a modification of scenario 2.A. It is developed to account for the possibility that some of the effects of Canadian swine research were included in the econometric coefficient measuring the effects of the U.S. swine research. In this scenario the growth rate of total consumers' and producers' surpluses attributed to the U.S. research spill-ins calculated for scenario 2.A were reduced by 10%. The estimate of 10% is used to illustrate the potential impact from the possibility that the effects from the U.S. swine research spill-ins were overstated in the econometric analysis.

In Figure 5.4 the bottom dotted and slashed line represents the 10% reduction in the growth rate of consumers' and producers' surpluses without Canadian swine research. The difference between the top solid line and the bottom dotted and slashed line represents the gross annual research benefits attributed to all Canadian public and private swine research.

5.2.3 Overview of the Different Variations

Twenty-seven variations of the results were derived for each scenario. These variations consider low, medium, and high productivity growth rates; low, medium, and high price levels; and three different discount rates. In each scenario, the base solution is represented by the medium productivity growth rate, the medium price level, and a 5% discount rate.

In total, nine different versions for the sum of consumers' and producers' surpluses were solved by the CRAM model for each scenario. The version that represents the base solution employs the average historical growth rates for the swine input and output coefficients and the actual 1996 input and output prices. This version of the model is defined as the medium productivity and medium price version.

The eight other versions of the model were calculated by adjusting the average historical growth rates and prices. High and low price levels were established by raising or lowering the 1996 prices by 10%. Medium productivity growth rates were originally determined by the average historical growth rate for the input and output coefficients in the CRAM model's objective function. Starting in 1996, the input and output coefficients were projected back to 1976 using their average historical productivity growth rate. To derive the high and low productivity growth rates, the projected medium 1976 value was used as the starting year. The input and output coefficients' year to year growth rates were then projected forward at 110% and 90% of their average historical growth rate.

The nine different versions for the sum of consumers' and producers' surpluses are derived from the combinations of low, medium, and high average historical growth rates and low, medium, and high output prices. The results from the nine different versions are evaluated with three different real discount rates. The three real discount rates used in the study are 3%, 5%, and 7%. The discount rates were chosen to be consistent with previous Agriculture and Agri-Food Canada studies and to reflect the range of real interest rates that occurred over the period of this study.

The nine different variations for the sum of consumers' and producers' surpluses derived from the CRAM model when evaluated with three different discount rates produces twenty-seven variations for each scenario. There are five scenarios developed in this study each containing twenty-seven variations. Therefore, one hundred thirty-five sets of results are reported.

5.3 Canadian Public and Private Research Effort

The purpose of this section is to describe the calculation of the research effort made by the Canadian public and private swine research institutions. The first part will describe the calculation of the Canadian public swine research effort. The second part will describe the calculation of the Canadian private swine research effort. Finally, the last part will describe the calculation of the unit cost of Canadian swine research and apply the unit cost to the respective levels of swine research effort.

5.3.1 Calculation of the Canadian Public Swine Research Effort

The Inventory of Canadian Agricultural Research (ICAR) database is the most comprehensive source of information on agricultural research activity in Canada. With the assistance of the Inventory of Canadian Agricultural Research staff, a list of all projects directly associated with swine research in Canada was complied. Projects specifically focusing on swine research were included in the selection process along with projects where swine was one of a group of livestock or red meat commodities being researched. In the commodity-grouped projects, the research effort for swine was derived by dividing the total professional person years (PPY) by the number of commodities involved in the project.

The Inventory of Canadian Agricultural Research data includes an estimate of professional person years for each project that is submitted from Agriculture and Agri-Food Canada, the provincial governments, and the universities and colleges. These professional person years were used in this study to describe the amount of research effort committed to swine research over the observed time period. Table 5.2 lists the total professional person years for each public research institution. The total Canadian public swine research professional person years are used in scenario 1.A, 1.B, and 1.C to calculate the total net benefits derived from Canadian public swine research.

5.3.2 Estimation of the Canadian Private Swine Research Effort

Due to the fact that the level of activity of Canadian private swine research is generally not reported in the Inventory of Canadian Agricultural Research, an estimation of the level of the Canadian private swine research effort was required. First, a brief review of previously estimated private sector agricultural research contributions is

Table 5.2 Annual Public Professional Person Years for Swine Research in Canada (1974 - 1997)

Year	Agriculture & Agri-Food Canada	Provincial Governments	Universities & Colleges	Total Canadian Public PPYs
1974	13.90	2.53	29.32	45.76
1975	14.47	2.63	31.40	48.50
1976	15.04	2.73	33.48	51.25
1977	14.59	1.73	28.72	45.04
1978	14.39	1.85	30.90	47.14
1979	14.19	1.96	33.08	49.23
1980	17.43	2.51	31.96	51.90
1981	19.80	3.33	37.41	60.54
1982	22.17	4.14	42.86	69.17
1983	20.15	4.31	51.98	76.44
1984	18.14	4.48	61.09	83.71
1985	17.86	4.00	66.75	88.61
1986	20.74	3.87	67.10	91.71
1987	21.79	4.40	57.57	83.76
1988	20.80	4.31	60.72	85.83
1989	18.10	4.54	66.84	89.48
1990	29.57	4.70	47.49	81.76
1991	29.85	5.97	82.74	118.56
1992	24.21	4.92	87.91	117.04
1993	28.39	4.66	93.62	126.67
1994	21.70	4.04	63.74	89.48
1995	24.68	2.83	44.22	71.73
1996	21.57	2.58	49.35	73.50
1997	22.33	1.69	38.05	62.06
Annual Average	20.24	3.53	51.6	75.38
Average Distribution	27%	5%	68%	100%

Source: Agriculture and Agri-Food Canada. *Inventory of Canadian Agricultural Research.* Various Years.

Note: 1974-1976 and 1997 are linearly extrapolated from the existing data. 1978, 1981, and 1983 are linearly interpolated from the existing data.

provided. This review serves to evaluate the authenticity of this study's estimated private sector agricultural research effort.

Ruttan and Pray (1987) state, that due to the lack of quantitative data on private sector research our knowledge of their contribution towards output is quite limited. Therefore, many estimations have been made on the level of effort made by private agricultural research firms in the last fifty years in North America.

Crosby (1987) estimated that U.S. private sector agricultural research expenditures were approximately 66% of public sector research expenditures between 1970 and 1985. The United States Department of Agriculture's, Economic Research Service (1996) has stated that in the U.S. private sector agricultural research expenditures have now actually surpassed that of public sector agricultural research. Likewise, White (1995) states that U.S. public and private expenditures for agricultural research were both approximately at the same level in 1950, but that private sector expenditures have grown more rapidly than public sector expenditures. Now, White (1995) and Frisvold *et al.*, (1998) state that private sector expenditures for agricultural research are approximately double the level of public sector expenditures in the U.S.

With respect to Canada, Guitard (1985) estimated Canadian private sector agricultural research to be 15% of public sector research expenditures in the 1980s. Brinkman *et al.*, (1985) conducted a market survey and calculated Ontario private sector agricultural research to be 22% of Ontario public sector agricultural research expenditures between 1950 and 1970. All of these studies were concerned with farm level production improving research and not agri-food processing research. A comparison of the estimated levels of private sector agricultural research from these studies shows a great deal of variability. There is also a considerable difference in the estimated levels of private sector agricultural research between the U.S. and Canadian studies.

For this study Canadian private sector swine research was estimated by Dr. R. Hacker, a swine researcher from the Department of Animal and Poultry Science at the University of Guelph, and the Program Director of animal science research at the University of Guelph. Dr. R. Hacker estimated current private off-farm swine research to be 40% of the calculated Canadian public swine research professional person years. This estimate is based on an informal accounting of Canadian private sector professional swine researchers. This estimate falls between the estimates from the U.S. and Canadian studies. If the previous Canadian studies had underestimated the level of private sector agricultural research they would have overestimated the net benefits and rates of return from public research expenditures. Therefore, the 40% estimated level of Canadian private sector research is appropriate for this study because it falls approximately in the middle of the range defined by the U.S. and Canadian studies. Secondly, the 40% estimated level of Canadian private sector research is appropriate because it is consistent with the conservative approach followed in this study.

Table 5.3 lists the annual total professional person years for Canadian public swine research, the estimated total professional person years for Canadian private swine research, and the sum of professional person years for Canadian public and private swine research. The total Canadian public and private swine professional person years will be used in scenario 2.A and 2.B for the calculation of total Canadian public and private swine

Table 5.3 Annual Public and Private Professional Person Years for Swine Research in Canada (1974 - 1997)

Year	Total Canadian Public PPYs	Total Canadian Private PPYs	Total Canadian Public & Private PPYs
1974	45.76	18.30	64.06
1975	48.50	19.40	67.90
1976	51.25	20.50	71.75
1977	45.04	18.02	63.06
1978	47.14	18.86	66.00
1979	49.23	19.69	68.92
1980	51.90	20.76	72.66
1981	60.54	24.22	84.76
1982	69.17	27.67	96.84
1983	76.44	30.58	107.02
1984	83.71	33.48	117.19
1985	88.61	35.44	124.05
1986	91.71	36.68	128.39
1987	83.76	33.50	117.26
1988	85.83	34.33	120.16
1989	89.48	35.79	125.27
1990	81.76	32.70	114.46
1991	118.56	47.42	165.98
1992	117.04	46.82	163.86
1993	126.67	50.67	177.34
1994	89.48	35.79	125.27
1995	71.73	28.69	100.42
1996	73.50	29.40	102.90
1997	62.07	24.83	86.89

Note: 1) Total Canadian public professional person years (PPYs) is taken from Table 5.1.
2) Total Canadian private professional person years (PPYs) is calculated at 40% of the total Canadian public professional person years. This estimation was provided by Dr. R. Hacker, Department of Animal and Poultry Science, University of Guelph.

research costs.

5.4 Calculation of Canadian Research Costs

The Inventory of Canadian Agricultural Research database does not contain cost or expenditure information with respect to the individual swine research projects. Therefore, a general method was employed to calculate a homogeneous research unit cost for the calculated professional person years.

Agriculture and Agri-Food Canada's Research Branch *Main Estimates* (1996) publication calculates annual total costs allocated by research activity. The total costs allocated by research activity include all the fixed, variable, professional and technical person year costs incurred during this study's base year 1996. The research activities include resource conservation research, crop research, animal research, and food research. Animal research is broken down into beef, dairy, swine, poultry, and sheep. The number of professional person years associated with each sub-activity is provided. Accounting for all fixed, variable, professional, and technical costs, a total cost of $407,000 is associated with each professional person year for swine.

Since other public research institutions and private research institutions do not provide comprehensive cost and expenditure information, the Agriculture and Agri-Food Canada estimate was assumed to be a representative unit cost for all the observed professional person years. Therefore, the Agriculture and Agri-Food Canada's unit research cost was used to calculate the Canadian swine research expenditures in scenario 1.A, 1.B, 1.C and scenario 2.A and 2.B.

The first step in calculating the total swine research costs for the Canadian federal government, the provincial governments, the universities and colleges, and for the private research sector was to multiply their annual professional person years by the unit cost ($407,000) respectively. This generates total research expenditures by the public sector and the private sector in constant 1996 prices.

The second step in calculating total swine research costs for the Canadian federal government, the provincial governments, and the universities and colleges sector was to incorporate an estimate of the marginal excess burden of taxation. The marginal excess burden of taxation is defined as the deadweight loss to the economy that is created through taxation. Government research expenditures which are financed by taxation create an additional expense in the collection and reallocation of funds. This is called the marginal excess burden of taxation. This additional cost has generally been ignored in past studies on the returns to agricultural research. Excluding the marginal excess burden of taxation results in an overestimation of the estimated net benefits and returns to public research (Alston *et al.*, 1990; Fox, 1995 and Economic Research Service, 1996). Therefore, the marginal excess burden of taxation should be included in the unit cost of research to capture the complete cost of the research expenditure. Since the private sector's research expenditures are not financed through taxation, the marginal excess burden of taxation is not included in the calculation of total private swine research expenditures.

There is a growing literature that has estimated the size of the marginal excess burden of taxation in Canada (Ballard *et al.*, 1985; Alston *et al.*, 1990 and Dahlby, 1994).

Studies examining the marginal excess burden of taxation have produced a range of estimates. Alston *et al.*, (1990) estimated the marginal excess burden of taxation in the United States to be in the range of 20% to 50%. Based on various combinations of assumptions about contributory factors, Browning (1987) estimated the marginal excess burden of taxation to be in the range of 10% to 300%. Lastly, Findlay *et al.*, (1982) estimated the marginal excess burden of taxation in Australia to be in the range of 23% to 65%.

With respect to Canada, Dahlby (1994) measured the distorting effects of increasing taxation by calculating the marginal cost of public funds or marginal excess burden from taxing labour income. Dahlby states that the marginal cost of public funds will exceed 1.0 if the reallocation of resources in the economy in response to the tax increase leads to a reduction in total net output. Dahlby estimated the average marginal cost of public funds for the basic personal income tax rate of Canadian provincial governments' to be 1.66 in 1993. The marginal cost of public funds for the Canadian federal government's basic personal income tax rate was estimated to be 1.38 in 1993. Therefore, the marginal excess burden of tax revenue is 66% of provincial research expenditures and 38% of the federal government's research expenditures, per dollar of tax collected respectively.

These estimates for the marginal excess burden of taxation where applied to the appropriate professional person years in the calculation of the total Canadian federal government, the total provincial governments, and universities and colleges expenditures on swine research. The federal government's estimated marginal excess burden of

Table 5.4 Calculated Canadian Public Swine Research Expenditures (1974 - 1997)

Year	Total Canadian Federal Swine Research Expenditures	Total Canadian Provincial Swine Research Expenditures	Total Canadian University & College Swine Research Expenditures	Total Canadian Public Swine Research Expenditures
	($000s, expressed in constant 1996 prices)			
1974	7,808	1,710	16,471	25,988
1975	8,127	1,776	17,638	27,541
1976	8,446	1,842	18,805	29,094
1977	8,195	1,169	16,131	25,494
1978	8,082	1,250	17,355	26,687
1979	7,970	1,324	18,580	27,874
1980	9,790	1,696	17,951	29,436
1981	11,121	2,250	21,012	34,382
1982	12,452	2,797	24,073	39,322
1983	11,317	2,912	29,195	43,424
1984	10,189	3,027	34,312	47,527
1985	10,031	2,702	37,491	50,225
1986	11,649	2,615	37,687	51,951
1987	12,239	2,973	32,335	47,546
1988	11,683	2,912	34,104	48,698
1989	10,166	3,067	37,541	50,775
1990	16,608	3,175	26,673	46,457
1991	16,766	4,033	46,472	67,271
1992	13,598	3,324	49,376	66,297
1993	15,946	3,148	52,583	71,677
1994	12,188	2,730	35,800	50,718
1995	13,862	1,912	24,837	40,610
1996	12,115	1,743	27,718	41,576
1997	12,540	1,142	21,371	35,053

Notes: 1) Total Canadian public expenditures are the sum of the Canadian federal, the provincial, and the universities and colleges research expenditures.
2) All research expenditures are calculated with Agriculture and Agri-Food Canada's *Main Estimates* (1996) derived unit cost of $407,000.
3) All research expenditures are inclusive of the estimated marginal excess burden of taxation.

Table 5.5 Calculated Canadian Public & Private Swine Research Expenditures (1974 - 1997)

Year	Total Canadian Public Swine Research Expenditures	Total Canadian Private Swine Research Expenditures	Total Canadian Public & Private Swine Research Expenditures
	($000s, expressed in constant 1996 prices)		
1974	25,988	7,449	33,438
1975	27,541	7,896	35,437
1976	29,094	8,343	37,437
1977	25,494	7,333	32,827
1978	26,687	7,674	34,362
1979	27,874	8,015	35,889
1980	29,436	8,449	37,886
1981	34,382	9,856	44,238
1982	39,322	11,261	50,583
1983	43,424	12,444	55,869
1984	47,527	13,628	61,155
1985	50,225	14,426	64,650
1986	51,951	14,930	66,881
1987	47,546	13,636	61,182
1988	48,698	13,973	62,672
1989	50,775	14,567	65,342
1990	46,457	13,311	59,767
1991	67,271	19,302	86,572
1992	66,297	19,054	85,351
1993	71,677	20,622	92,298
1994	50,718	14,567	65,285
1995	40,610	11,678	52,288
1996	41,576	11,966	53,542
1997	35,053	10,103	45,156

Notes: 1) Total Canadian public and private expenditures are the sum of the total Canadian public and private research expenditures.
2) All research expenditures are calculated with Agriculture and Agri-Food Canada's *Main Estimates* (1996) derived unit cost of $407,000.
3) All research expenditures are inclusive of the estimated marginal excess burden of taxation, except the private research expenditures.

taxation was applied to the professional person years of the universities and colleges. This was assumed simply because of the complex nature of combined research funding from federal and provincial sources for a single researcher at the university and college level. Table 5.4 lists the total annual swine research expenditures for the Canadian federal government, the provincial governments, and the universities and colleges. Table 5.4 also lists the annual sum of all Canadian public swine research expenditures between 1974 and 1997. Table 5.5 lists the total annual Canadian public and private swine research expenditures between 1974 and 1997.

5.5 Analysis of Net Benefits from Canadian Swine Research

Publicly funded research projects are amenable to economic analysis. This is one method in which government institutions can evaluate *ex post* their allocation of agricultural research resources. The economic analysis of Canadian swine research expenditures in this study employs the following measurements: the net present value (NPV), the benefit/cost ratio, and the internal rate of return (IRR).

This study uses a multi-year framework that measures the benefits and costs in real dollar terms. Two factors that influence the value of the benefits and costs therefore must be accounted for. First, research benefits and costs are separated in time. Expenditures in research today generate benefits in the future. Therefore, time preference or discounting need to be taken into account. Past expenditures in research need to be discounted to reflect their real value at the time of investment. Three different discount rates (3%, 5%, and 7%) were applied for each scenario and variation. The discount rates were chosen to maintain consistency with previous Agriculture and Agri-Food Canada studies on the economic benefits of agricultural research. The discount rates also represent the range of real interest rates that occurred over the period of this study (Agriculture and Agri-Food Canada, 1996).

Secondly, government policies and agricultural input and output prices have changed over the observed time period. This creates a problem with respect to the calculated benefits of research being confounded with the effects and incentives created from government policies or market price changes. This problem is removed by setting all prices in the analysis to 1996 price levels.

5.5.1 Summary of Results from the Analysis of Net Benefits from Canadian Swine Research

In Table 5.6 a summary of the economic analysis is presented. Table 5.6 presents the base solution results of scenario 1.A, 1.B, 1.C, 2.A and 2.B. These base solution results are calculated using the medium price variation, the medium productivity growth rate variation, and the 5% discount rate variation. The following sections describe the method of calculating the net present value, the benefit/cost ratio, and the internal rate of return. Lastly, the range of results from each scenario and variation are presented.

5.5.1.1 Description of the Calculation for the Net Present Values

The net present value calculates the present value of the total benefits minus the

Table 5.6 Summary of the Economic Analysis of Canadian Swine Research for each Scenario's Base Solution

Scenario	Net Present Value ($000)	Benefit Cost Ratio	Internal Rate of Return (%)
1.A Gross Annual Research Benefits Attributed to Canadian Federal Research	9,667,390	22.4	124.23
1.B 1.A adjusted for illustration of a reduction in the effect Federal swine research has on the supply of hogs	7,617,466	17.8	108.10
1.C 1.A adjusted for illustration of a Federal and non-Federal research productivity relationship	10,656,100	24.6	124.27
2.A Gross Annual Research Benefits Attributed to All Canadian Research	11,786,042	6.4	53.75
2.B 2.A adjusted for illustration of a possible confounding effect between Canadian and U.S. research contributions	12,100,259	6.6	53.81

Note: 1) The base solutions are calculated using a 5% discount rate discounted to the base year 1996, medium productivity growth rates, and medium price variations.

2) All the benefit measurements are calculated using real 1996 prices.

present value of total expenditures. The net present value may be expressed as:

$$NPV=\sum \frac{GARB_t}{(1+r)^t}-\sum \frac{ResearchCosts_t}{(1+r)^t} \tag{5.1}$$

Where:

$GARB_t$ = gross annual research benefits in the ith year, where 1974 and 2005 represent the first and last years,

$Costs_t$ = total costs or expenditures in the ith year, calculated with real 1996 prices, where 1974 and 1997 represent the first and last years,

r = real discount rate, the discount rates employed are 3%, 5%, and 7%,

t = number of years discounted to the defined base year, the base year in this analysis is 1974.

A positive net present value indicates that an investment is worthwhile for a particular discount rate. The calculation of the net present value is considered an appropriate tool to employ when ranking similar projects by order of net economic benefit. Each project is discounted at the same rate and the resulting calculations can be compared in absolute terms. For this study, there are no direct comparisons made with other projects. The net present value simply provides an overall sense of the impact that swine research has on the industry and sector.

5.5.1.2 Description of the Calculation of the Benefit / Cost Ratios

The benefit/cost ratio is the discounted value of the sum of the gross annual research benefits divided by the discounted value of the sum of the annual costs or expenditures. The benefit/cost ratio may be stated as:

$$B/C = \frac{\sum \frac{GARB_t}{(1+r)^t}}{\sum \frac{ResearchCosts_t}{(1+r)^t}} \tag{5.2}$$

The benefit/cost ratio is considered an appropriate analysis tool to use when measuring the average economic benefit returned from the costs incurred. If the project evaluation assumes that the alternative research projects have constant returns to scale, the benefit/cost ratios can be used to rank the projects by the incremental value of the next dollar invested.

5.5.1.3 Description of the Calculation for the Internal Rate of Returns

The internal rate of return is the value for r (expressed in percentage terms) which reduces the net present value to zero. The internal rate of return may be stated as:

$$0 = \sum_{t=0}^{T} \frac{GARB_t - Costs_t}{(1+\rho)^t} \tag{5.3}$$

Where:

ρ = the internal rate of return

The internal rate of return can be used to compare alternative research projects and provide an overall sense of the research investment. The internal rate of return can be compared with alternative investment instruments, such as the bank rate. The disadvantage of the internal rate of return is that it assumes all economic benefits from a research project can be reinvested at the same rate of earning. As well, complex research projects where the net cash flow is negative more than once may produce non-unique internal rates of return. In this study the flow of benefits and expenditures are not complex. Therefore, an internal rate of return is obtainable for the different scenarios.

5.5.2 Calculated Range for the Returns on Research Expenditures for each Solution

Table 5.7 provides a summary of the range or maximum and minimum boundaries of the calculated returns for each of the five scenarios. The range of returns encompass all the variations for each of the previously defined productivity growth rates, price levels, and discount rates. When considering all the scenarios together, the maximum and minimum boundaries of the calculated net present values are $4.3 billion to $20.8 billion. The maximum and minimum boundaries of the calculated benefit/cost ratios are 3.2 to 40.4. Lastly, the maximum and minimum boundaries of the calculated internal rates of return are 37.21% to 145.02%.

5.5.3 Sensitivity Analysis of the Variations in each Scenario

This section presents the results of the sensitivity analysis. The sensitivity analysis examines how the variations in the CRAM model and the variations on the CRAM model's output affect the calculated economic benefits. The variations in the CRAM

Table 5.7 Summary of the Range for the Returns on Research Expenditures for each Solution

Scenario	Net Present Value ($000)	Benefit Cost Ratio	Internal Rate of Return (%)
1.A Gross Annual Research Benefits Attributed to Canadian Federal Research.	5,534,979 - 15,456,009	13.3 - 34.1	98.46 - 145.02
1.B 1.A adjusted for illustration of a reduction in the effect Federal swine research has on the supply of hogs.	4,388,500 -12,410,815	10.7 - 27.5	84.44 - 130.78
1.C 1.A adjusted for illustration of Federal and non-Federal research productivity relationship.	6,380,250 - 16,894,710	14.2 - 40.4	98.51 - 145.05
2.A Gross Annual Research Benefits Attributed to All Canadian Research.	5,866,133 - 19,454,181	3.2 - 12.1	37.21 - 67.63
2.B 2.A adjusted for illustration of possible confounding effect between Canadian and U.S. research contributions.	6,288,616 - 20,885,382	3.4 - 12.9	37.39 - 67.71

model were the high, medium, and low variations of the market hog price and the productivity growth rates for the defined input-output variables. The variations on the CRAM model's output were the 3%, 5%, and 7% variations in the discount rate.

The sensitivity analysis describes how a 1% change in the discount rate, market hog price, and productivity growth rate affects the calculated net present value and the benefit cost ratio, while all other variables are held constant. The result of this calculated relationship is referred to as an elasticity. An elasticity is calculated by deriving the percentage change in the independent variable divided by the percentage change in the dependent variable. Table 5.8 summarizes the average net present value and average benefit cost ratio elasticities for each scenario.

From Table 5.8 it is observed that a 1% change in the market hog price variable has the greatest impact on the net present value for each scenario, where, on average, a 1% change in the price of market hogs would increase the net present value by 4.5%. On average, a 1% change in the discount rate decreases the net present value by -0.09%. Lastly, on average a 1% change in the input-output productivity growth rates increases the net present values by 0.84%.

The calculated elasticities in this study identify the strength of the economic relationships. The economic relationships that are examined are between the discount rate, market hog prices, and the input-output productivity growth rates with the overall net present value of Canadian swine research.

Table 5.8 Sensitivity Analysis for each Scenario's Base Solution

Scenarios	1.A	1.B	1.C	2.A	2.B	Average Elasticity of the Net Present Values from each Scenario
Variables	Average Elasticity of the Net Present Values					
Discount Rate	-0.14	-0.23	-0.07	-0.004	-00.2	-0.089
Market Hog Prices	4.11	4.01	4.10	5.41	5.25	4.576
Productivity Growth	0.54	0.62	0.64	1.20	1.20	0.840
	Average Elasticity of the Benefit Cost Ratios					Average Elasticity of the Benefit Cost Ratios from each Scenario
Discount Rate	-0.18	-0.17	-0.24	-0.36	-0.37	-0.264
Market Hog Prices	3.88	3.72	3.89	4.26	4.20	3.99
Productivity Growth	0.52	0.59	0.62	1.00	1.07	0.748

Chapter 6

Conclusions

6.1 Summary and Implications

The purpose of this final chapter is to summarize this study and discuss the implications of the results. The first section will summarize the purpose of this study and the methods used to acquire the final results. The second section will discuss the implications of the calculated results. The last section will discuss some of the possible limitations of the study and further research possibilities.

6.2 Summary of the Purpose and Methods

This study has employed a economic surplus approach to estimate the net benefits from swine research expenditures in Canada between 1974 and 1997. With an examination of the actual swine research literature review and the input/output coefficients it is possible to assume that there is a relationship between Canadian swine research expenditures and the improved quality and productivity observed in the industry. However, this observation does not indicate the relative benefits or costs associated with the allocation of research resources from both the public and private sector. Therefore, the purpose of this study was to employ a multi-product model entitled the Canadian Regional Agricultural Model to measure the economic net benefits derived from Canadian federal swine research in relation to other Canadian agricultural commodities.

The Canadian Regional Agricultural Model employed a positive mathematical programming technique. The positive mathematical programming technique enabled the model to optimize the sum of consumers' and producers' surpluses based on the observed actual level of output in the study's base year without any constraints defined in the model.

To calculate the gross annual research benefits, the economic surplus derived in the absence of Canadian swine research needed to be estimated. To accomplish this, the Canadian hog supply function was estimated to describe the relationship between Canadian federal swine research expenditures and the supply of hogs. It was then estimated that in the absence of Canadian federal swine research the supply of hogs would be reduced by 25.9%.

The next step was to calculate the net benefits. The net benefits were calculated by deducting the gross federal swine research expenditures from the gross annual research benefits. Five scenarios were developed to account for any possible confounding effects resulting from Canadian provincial, private, and U.S. swine research.

6.3 Implications

The purpose of this study was to derive quantitative economic information that would serve in the evaluation of the economic viability of past Canadian federal swine research expenditures. It is observed from the findings presented in chapter 5 that past Canadian federal swine research has derived high rates of return. The net present value of the base solutions for past Canadian federal research is found to range between $7.6 to $12.1 billion constant 1996 dollars. The benefit/cost ration of the base solutions for past Canadian federal research is found to range between $6.40 to $1.00 to $22.40 to $1.00 constant 1996 dollars.

These results suggests that the previous annual allocations of research resources from Agriculture and Agri-Food Canada's Research Branch to swine research programs were economically viable. However, this does not mean that all future allocations of research resources will be equally viable.

The objectives of this study were also to derive quantitative economic information of the returns to Canadian federal swine research using a multi-market model. The purpose of using this method was to generate results that would be comparable to other studies that have employed a multi-market model. Currently, three other studies have employed the CRAM model and similar methods to quantify the returns to research in the beef, potato, and wheat industries (Klein *et al.*, 1994; AAFC, 1996; Klein *et al.*, 1996). Table 6.1 presents the findings from each of these studies. It would now be possible to include this study in a comparative analysis with the other previously completed studies.

6.3.1 Other Implications

The calculated returns from Canadian federal swine research expenditures are interpreted as the economic benefits attributed to Canadian federal swine research in relation to other Canadian agricultural commodities. The economic benefits represent the sum of the value that consumers save and the value that producers gain. For example,

Table 6.1 **Comparison of the Economic Benefits and Costs Found in Other Returns to Agricultural Research Studies that Employed the CRAM Model**

	Swine Research	**Beef Research**[1]	**Potato Research**[2]	**Wheat Research**[3]
NPV (Billions of 1996 dollars)	7.6 - 12.1	2.9 - 15.2	3.8 - 8.9	0.2 - 4.1
B / C (1996 dollars)	6 - 22	43 - 75	5 - 18	11 - 60
Research Unit Cost $ / P.P.Y (1996 dollars)	407,000	n/a	360,000	357,680

Sources: [1] Klein *et al.*, 1994.
[2] A.A.F.C., Policy Branch, 1996.
[3] Klein *et al.*, 1996.

increases in technical efficiency derived through livestock research has reduced the total level of inputs and costs required to produce a market hog, thus increasing consumers' and producers' surpluses. This can be observed in the calculated input coefficients listed in Table 4.3. One example of the reduced demand for inputs is illustrated by the calculated feed requirement for growing hogs (tonnes of feed barley / hog space / year). The volume of feed barley per hog space decreased by an annual average of 1.55%.

There are also other observable benefits from productivity improving swine research. For example, the land requirements or total number of hectares required to produce the required level of hog feed has been reduced. To calculate the total feed barley land requirement, the total number of hogs produced in 1996 (9,892,039) was multiplied with the required feed barley per hog space per year (tonnes/hog space/year)[1], divided by the average number of hogs per hog space per year[2]. This produces the total amount of feed barley required per year (tonnes/year). Then this figure is divided by the average per hectare yield (tonnes/hectare)[3]. This produces the total amount of land (hectares) required to produce the total amount of feed barley. For the different comparisons discussed below the required feed barley per hog space per year and the

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[1] Hog feed barley requirement in 1996 = 0.7377 tonnes/hog space/year.
Hog feed barley requirement in 1976 = 1.1489 tonnes/hog space/year.
(Table 4.3).

[2] Average number of hogs per hog space per year = (365 days / 150 days) = 2.4

[3] Average barley yield in 1996 = 3.0 tonnes/hectare.
Average barely yield in 1976 = 2.2 tonnes/hectare.
(Statistics Canada. Agricultural Division. Crops Section. *Cereals and Oilseeds Review.* March 1998. Catalogue #22-007-XPB.)

average per hectare yield were adjusted accordingly.

To produce the actual number of hogs observed in 1996, while applying the 1996 level of hog feed requirements and the 1996 barley yield levels, approximately 1,013,522 hectares of land are required. This calculation is called A. To produce the actual number of hogs observed in 1996, while applying the 1976 level of hog feed requirements and the 1976 barley yield levels, approximately 2,152,455 hectares of land are required. This calculation is called B. The difference between these two calculations (B-A = 1,138,933 ha) represents the total number of additional hectares that would have been required for the purpose of feeding the actual number of hogs produced in 1996, if the changes in crop yields and hog feed rations between 1976 and 1996 had not occurred.

To produce the actual number of hogs observed in 1996, while applying the 1976 level of hog feed requirements and the 1996 barley yield levels, approximately 1,578,467 hectares of land are required. This calculation is called C. The difference between calculation C and A (C-A = 564,945 ha) represents the total number of additional hectares that would have been required for the purpose of feeding the actual number of hogs produced in 1996, if the changes in hog feed rations between 1976 and 1996 had not occurred.

Lastly, to produce the actual number of hogs observed in 1996, while applying the 1996 level of hog feed requirements and the 1976 barley yield levels, approximately 1,382,075 hectares of land are required. This calculation is called D. The difference between calculation D and A (D-A = 368,553 ha) represents the total number of additional hectares that would have been required for the purpose of feeding the actual number of hogs produced in 1996, if the changes in feed barley yields between 1976 and 1996 had not occurred.

6.4 Limitations of the Study

This last section will address some possible limitations of this study. First, the study employed a multi-market framework that was structured in the Canadian Regional Agricultural Model. This model allowed for multi-market interaction between the major Canadian agricultural industries. However, the multi-market model does not consider any industries outside of the agricultural sector. A multi-market model that linked all industries would be considered ideal for this type of study.

Second, this study's calculated rates of return to swine research expenditures includes the impact of changes in other industries in the Canadian agricultural sector. However, the rates of returns from this study may still be overestimated due to the critical assumption in the multi-market model of perfect optimization or profit maximization and cost minimization.

Third, this study developed an econometric model to estimate the strength of the relationship between the independent variable, Canadian federal swine research expenditures, and the dependent variable the supply of market hogs. Further manipulation of this model has produced varying results with respect to the estimated elasticity for Canadian federal swine research. This finding suggests an overall weakness in the robustness of the model and the econometric methods.

Lastly, because of the unavailability of private sector swine research expenditures a heuristic estimate was employed. Other studies suggested even higher levels of private sector swine research expenditures. Therefore, the calculated rates of return may be overestimated.

Despite the previously discussed limitations, the study attempted to adhere to a conservative method, where the costs were overestimated and the benefits were underestimated. This method still produced rates of return for Canadian swine research comparable to previous studies.

Further studies may be interested in linking other sectorial mathematical programming models to the Canadian Regional Agricultural Model. This would increase the robustness of the calculated rates of return from agricultural research by including the implications on other sectors of the Canadian economy from these expenditures. Further studies may also be interested in linking bio-physical resource models to the Canadian Regional Agricultural Model. This procedure would allow for the observation of how different allocations of research expenditures affects the bio-physical resources (e.g. soil) employed in agriculture overtime.

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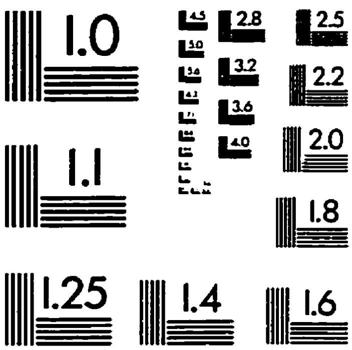
IMAGE EVALUATION TEST TARGET (QA-3)



150mm

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