An Economic Analysis of the Returns to Canadian Swine Research - 1974-1997

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<u>Abstract</u>

An Economic Analysis of the Returns to Canadian Swine Research - 1974-1997

This paper reports a new set of estimates of the returns to swine research in Canada. These estimates were obtained using Agriculture and Agrifood Canada's Canadian Regional Agricultural Model (CRAM). Positive Mathematical Programming was incorporated into the model for use in this study. The CRAM allows the effects of supply shifts from technological change in the hog industry to interact with product and factor market conditions in the rest of Canadian agriculture. Previous estimates of the returns to Canadian swine research were obtained with a partial equilibrium model that did not allow for intra-sectoral resource use adjustments. Extensive sensitivity analysis was conducted to examine the robustness of the return estimates under variations in some of the key assumptions employed in the analysis. The costs of public and private sector swine research were estimated. Public sector research costs were inclusive of the marginal excess burden of taxation. Overall, the estimated benefits from Canadian swine research were high relative to the estimated costs for the time period considered. The estimated returns obtained in this study were higher than those obtained in an earlier study that used a partial equilibrium approach, but the differences in returns are not solely attributable to this single change in the method used in the analysis.

Introduction

This study presents some new estimates of the returns to Canadian federal swine[7] research. Research expenditures between 1974 and 1997 were considered. Earlier research on this topic by Huot *et al.,* (1989) found high rates of returns to swine research. That study used a single market partial equilibrium approach with an econometrically estimated supply function. A multi-market model is employed in this study.

The Rationale for Government Supported Agricultural Research

The Canadian federal government, provincial governments, universities and colleges and private industry all contribute to agricultural research. Klein (1985) states that "agricultural research has contributed indispensably to increasing food output during the past several decades." Support for publicly funded agricultural research in Canada began with the Department of Agriculture Act and the Experimental Farm Stations Act of 1886. Objectives for agricultural research include economic growth, income distribution, and food security (Alston *et al.*, 1995). Governments in Canada participate in agricultural research by funding basic and applied scientific research projects. Two different rationales have been offered to justify government involvement in agricultural research. Firstly, the product of agricultural research is viewed by some as a public good. A public good has two characteristics. It is non-rival in use and it is costly, even prohibitively costly, to exclude people from its use (Nicholson, 1995). A non-rival good is a good where consumption by one individual does not affect the quantity or quality of consumption of the

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[7] 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.

same good by another individual. Economists have generally argued that goods that fit the definition of public good are subject to the free rider problem[8]. Since exclusion is prohibitively costly, few people will want to contribute to the provision of a public good, hoping that someone else will do so. But if everyone thinks that way, very little of the public good will be provided, even though the non-rival nature of the good may mean that the potential benefits of greater availability considerably outweigh the costs.

In our judgement, contrary to the views of many agricultural economists, agricultural research generally fails to meet the definition of a public good. The products of agricultural research are not generally non-rival. One of the products of research is knowledge, and knowledge, for the purpose of knowing, is non-rival. Once a researcher discovers something, when that knowledge is conveyed to someone else, there is no less knowledge left over for a third person to acquire. However, agricultural research is conducted not to accumulate knowledge for its own sake, but for application. It is at this point that rivalry emerges.

In addition, means of exercising exclusion with respects to the products of agricultural research are increasingly available. These include patents, breeders rights, copyrights, trademarks, trade secrets and other means of protection of intellectual property rights (Zentner, 1985 and White, 1995). Therefore since the products of agricultural research are increasingly excludable and have never really been non-rival, the public good rationale cannot be applied to

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[8]   Coase's (1974) study of the history of the lighthouse industry in the U.K. indicates that economics textbook writers worries about free rider problems may be excessive. Coase documents that private investors built and profitably operated lighthouses in the U.K. We would add that Bill Gates has made a considerable fortune in recent years selling products that are non-rival in consumption and for which exclusion is difficult.

justify government support for agricultural research.

A second rationale for government support for agricultural research is based on the concept of transaction costs. Transaction costs take the form of the resources used up in the process of making a market exchange. This includes that time, effort and other resources devoted to searching for someone who might like to participate in an exchange and to negotiating the terms of that exchange when a potential partner is identified (Coase, 1937). Farmers, anticipating the benefits that they would derive from agricultural research, could create an organization to support that research. They could seek out other farmers with similar interests and negotiate an agreement indicating how much financial support each producer would contribute to the effort. But the structure of primary agriculture in Canada and the spatial distribution of farm firms means that there would likely be substantial transaction costs involved in such a project. Government eliminates transaction costs. It doesn't have to search or negotiate. It makes policy decisions and implements them. This includes a policy decision to collect taxes and to spend part of the proceeds on agricultural research. To the extent that this system economizes on transaction costs, it provides a rationale for government action (Coase, 1960).

In addition to potentially reducing transaction costs, government involvement in agricultural research may also improve coordination through reducing duplication. Without coordination of agricultural research competing firms may duplicate research efforts (Stephan, 1996). Coase (1960), however, pointed out that this advantage cannot be taken for granted. The offsetting counterbalance to the reduction in transaction costs and the improved coordination of effort through government involvement is twofold. Governments can make mistakes and they require resources to operate. As Coase (1960) indicated, the trick is to find the right balance

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between the benefits of reduced transaction costs and improved coordination and the losses of administration costs and mistakes.

Related Literature

Estimation of the returns to public investments in agricultural research began with the work of Schultz (1953) and Griliches (1958). Schultz estimated the rate of return for all agricultural research in the United States between 1910 and 1950 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 1 summarizes the findings of selected studies, focusing on recent Canadian studies[9].

Since these early studies, an enormous literature has evolved exploring different methods of analyzing the returns from agricultural research (Ruttan, 1982). The economic surplus approach has been the most common method used to analyze the returns from agricultural research (Alston *et al.*, 1995). This approach characterizes the benefits from research as the changes in consumers' and producers' surpluses that occur as commodity demand or supply curves shift in response to technological change attributable to research. The conceptual framework used to measure the gross benefits from a supply shift from agricultural research is

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[9] Other summaries of returns to research studies can be found in Evenson *et al.*, (1979) and Hueth *et al.*, (1985).

shown in Figure 1. A supply shift leads to reduced commodity prices and an increase in the

quantity produced. 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. Agricultural economists have identified four types of supply

shift (Lindner and Jarrett 1978); a pivotal proportional shift, a divergent proportional shift, a

parallel shift, and a convergent shift. The type of supply shift influences the size of the overall

research benefits as well as the distribution of those benefits between producers and consumers.

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 to capture this effect. 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. 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. Evenson (1968) has argued that the decline in economic

benefits can be attributed to the emergence of new technology that makes old technology obsolete

and to biological adaptation by pests which overtakes the ability of existing technology to sustain

current yields.

Adapting the Economic Surplus Approach for Use with the CRAM Model

Agriculture and Agri-Food Canada's Canadian Regional Agricultural Model (CRAM) was used to calculate estimated research benefits. The CRAM is a static annual spatial optimization model of Canadian agriculture. The CRAM includes all of the major agricultural commodities produced in Canada. The model is disaggregated at the provincial level and allows for interprovincial, interregional 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, the CRAM allocates land among crops and livestock feed production in each region to maximize producers' and consumers' surpluses. The CRAM allows effects such as supply shifts in one agricultural industry to interact with other agricultural product and factor markets. A partial equilibrium model cannot take these intrasectoral adjustments into account. The CRAM was used in an earlier study by Klein *et al* (1994)to examine the effects of these intra-sectoral market adjustments on research benefits in the Canadian beef industry as well as in a study of the returns to potato research (Agriculture and Agrifood Canada, 1996) and in a study of the returns to wheat research (Klein *et al*, 1996).

Canadian production of hogs, cattle, dairy, and poultry is modeled in the CRAM for each of the ten provinces. Livestock animals are fed grains grown in the crops sector of the model including 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

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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 depend 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. The objective of the CRAM model is to maximize the sum of consumers' and producers' surpluses. 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).

Positive Mathematical Programming

Positive Mathematical Programming (Howitt, 1995) was added[10] to the hog component of the CRAM for use in this study. Positive Mathematical Programming is used to eliminate calibration constraints on output in a linear programming model. The marginal cost function in positive mathematical programming consists of a constant component and a shadow value (see Figure 2). When the calibration constraint is removed with Positive Mathematical Programming, a new function is added to costs. This function is calibrated to be equal to the shadow value at

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[10] See Gill *et al* for a more complete discussion of the modifications to the CRAM model.

the level of output set by the now removed calibration constraint. In Figure 2, this new function

is represented as a smooth increasing function of X. The new synthetic marginal cost function is

equal to marginal revenue at X_0. When the programming model is allowed to select an optimal

solution, given the marginal revenue and this new synthetic marginal cost function, it picks X_0.   .

Marginal cost, *MC*, is written as

$$MC = a + l\,(X)$$

The shadow value function could be specified using a number of functional forms. We have

elected to use

$$l\,(X) = aX^b$$

The shadow value is the difference between the (assumed) constant marginal revenue and the

constant component of marginal cost at the level of output permitted by the calibration constraint

in the initial linear programming solution of the model. Rearranging the expression for λ to get

output as the dependent variable yields

$$X = (l\,/\,a)^{1/b}$$

This equation describes how optimal output varies with variations in λ. Setting price equal to

marginal cost means that $\lambda = P\text{-}a$. If a is constant, then variations in λ are a result of variations in

P. The expression for the elasticity of optimal output with respect to λ is

$$h^1 = 1/b$$

The expression for the more familiar own-price elasticity of supply is

$$h^P = (1/b)(P/l)$$

In the present application, b was assumed to be 2, so the own-price supply elasticity is ½ times the ratio of the product price to the initial value of the shadow value. The advantage of this specification is that it allows the incorporation of estimated supply elasticities directly into the Positive Mathematical Programming model.

The Supply Function

A national annual hog supply function was estimated in a manner consistent with modifications made to the CRAM to incorporate Positive Mathematical Programming for the purposes of this study. Huot *et al* (1989) employed a partial - logarithmic functional form to describe the relationship between the dependent and independent variables. One limitation of the partial - logarithmic functional form is that the intercept of the resulting supply function is the origin. 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 better represents the cost structure of the industry. Figure 3 compares the constrained partial-logarithmic supply function to 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.

The partial - logarithmic supply function subject to a constraint on the intercept is represented by equation (1). The coefficient α represents the threshold price below which production falls to zero. 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).

$$Q_t^h = e^{\beta(T)}(P_t^h - \alpha)^\eta (P_{t-2}^b)^\gamma \qquad \textbf{(1)}$$

Where:

Q_t^h	$=$	th quantity of hogs supplied,
$\beta(T)$	$=$	a technology shifter function, see equation (4),
P_t^h	$=$	the price of market hogs,
P_{t-2}^b	$=$	the price of feed barley,
α	$=$	a threshold price,
γ	$=$	the supply elasticity with respect to the price of feed barley,
η	$=$	the supply elasticity with respect to the price of hogs, restricted to 2.

Because the own-price supply elasticity imposed as a restriction, equation (1) can be rearranged to obtain equation (2).

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

The price variable (P_{t-2}^b) is lagged two years to represent the adjustment period for the producers' decision making process.

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 supply shifters in Huot *et al* (1989). The structure of this function is represented as

$$\beta(T) = \theta t_t + \varphi D_t + \sum \delta R_{t-i}^{US} + \sum \epsilon R_{t-i}^{Cdn} \tag{3}$$

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

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

and $\theta, \varphi, \delta, \epsilon$ are parameters to be estimated.

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The independent variable t_t is the arithmetic mean of an index of provincial swine research

expenditures (1981=100), an index of provincial swine extension expenditures (1981=100) and

the index of farmer's education level (1981=100). This procedure follows Huot *et al* (1989.

The coefficients on the lagged U.S. (R^{US}_{t-i}) and Canadian federal (R^{Cdn}_{t-i}) swine research

expenditures were assumed to follow a quadratic polynomial pattern with zero end points. This

lag represents the time that elapses between the initial expenditure in swine research and the first

measurable impact of research on aggregate production. Huot *et al* (1989), 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 in this study confirmed this lag structure.

The constrained partial - logarithmic regression results for the Canadian hog supply

function were derived with ordinary least squares (OLS), 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 *et al* (1989).

Table 2 presents the estimated coefficients and elasticities of the variables in the hog

supply function. The coefficients of Canadian federal research expenditures (R^{Cdn}_{t-1}) are

significant at the 95% level. The coefficients of U.S. research expenditures (R^{US}_{t-1}) are significant at the 80% level. The coefficients of the price of barley (P^b_{t-2}) and of the provincial research index (t_t) are significant at the 90% level. The adjusted R-squared is 0.899.

The regression results indicate that the coefficient of the technology index (t_t) is negative. This result is inconsistent with the idea that research, extension services and producers' education level increase 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 United States. 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. The sum of the supply shift elasticities for Canadian federal swine research (R^{Cdn}_{t-1}) is 0.259. Comparable research elasticity results reported in other Canadian studies are presented in Table 3. Our model produced a substantially lower estimate of the research elasticity than Huot *et al* (1989) obtained.

CRAM Solutions

The CRAM is an annual optimization model. It maximizes the sums of producers' and consumers' surpluses for all of the agricultural markets represented in the model for a given set of input output coefficients, final demand conditions, policies and resource availabilities. In order to use it to estimate the gross benefits of research the CRAM was generally solved twice for each year included in the study. The first solution was obtained using the trend values of the input-

output coefficients listed in Table 4. The model was solved first for the base year of 1996, then the seven input-output coefficients were projected backwards to 1995, 1994 and earlier at their trend rates of change. These coefficients were projected forward at these same trend rates for 1997 and beyond. In order to isolate the effects of swine research from changes in policy or in market conditions not attributable to swine research, all other coefficients in the CRAM were left unchanged from their 1996 values. The time period considered in this study covers research expenditures from 1974 to 1997. The estimated lag structure of research impacts on the aggregate supply function implies that solutions for the CRAM were required for the years 1976-2005 inclusive.

After solutions were obtained for each year for historical trend values of the input-output coefficients, solutions were required for each year to reflect what would have happened had Canadian swine research ceased in 1974. The structure of the CRAM does not allow a direct manipulation of aggregate supply. Supply is one of the variables that is derived as part of the optimal solution of the model. The input-output coefficients have to be adjusted iteratively to reflect the impact of the cessation of research. The econometric estimates reported earlier indicated that a 25.9 % reduction in supply was predicted by 1981 if research had stopped in 1974. This supply shift was imposed on the model by linearly interpolating the values of the seven input-output coefficients backwards from 1981 to 1976. After 1981, these coefficients were adjusted to increase at their historical rates of change to reflect the impact of other sources of technological change other than Canadian Federal swine research. After 1997, the last year of research expenditures included in the study, a similar adjustment in the relevant input-output coefficients was imposed to reflect the predicted supply shift if research ceased in that year.

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Figure 4 illustrates how this procedure was used to calculate annual research benefits from

Canadian Federal swine research. In the Figure, the upper solid line represents the optimal value

of the CRAM objective function for each year using the input-output coefficients at their

historical trend values. In terms of Figure 1, this represents the sum of producers' and

consumers' surpluses "with research". This value falls starting in 2000 as a result of the effects of

an assumed cessation of Canadian Federal swine research beginning in 1997. The lower dotted

line represents the optimal value of the CRAM objective function for the values of the input-

output coefficients indicative of Canadian Federal swine research stopping in 1974. The initial

25.9 % reduction in supply takes place between 1976 and 1981. After 1981 the objective

function rises reflecting the impact of other sources of technological change in the industry. The

vertical difference between the upper solid line and the lower dotted line in Figure 4 is the multi-

market analog of the area ABC in Figure 1. It is the difference in the optimal value of the CRAM

objective function with and without research in each year.

The historical values and productivity growth rates of each coefficient are presented in

Table 4. The indexed farm gate price for market hogs 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 were collected at the provincial level between 1971 and 1996. These data were compiled

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.

The inverse of hogs per sow or the number of sows needed to produce a given number of hogs 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 compiled from Agriculture and Agri-Food Canada's 'Livestock Market Review'. Total variable costs for hogs and sows are modeled as a function of the 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 annual growth rates for average hog carcass weight, average hog grading index and average number of hogs produced per sow per farrowing were all positive over the time period considered. Average feed barley and feed protein requirements for hogs and sows also increased. Initially this seems to contradict the idea that swine research saves inputs. However, increased feed barley and 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 increases in the average hog carcass weight, the average hog quality grading index and the average number of hogs produced per sow per farrowing.

The Scenarios

Although the estimated supply function indicated that stopping Canadian Federal swine research would reduce national hog supply eventually by almost 26 %, we wanted to explore the possibility that the federal research elasticity might be overestimated. This was motivated in part by the less than completely satisfactory estimates for the coefficient on the index of education, provincial research and extension. We developed 5 scenarios to represent different ways of

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attributing the estimated 25.9 % supply shift. These scenarios are identified as 1.A, 1.B, 1.C, 2.A and 2.B. A brief summary of the key assumptions employed in each scenario is presented in Table 5. Scenarios 1.A, 1.B, and 1.C attribute the estimated gross annual research benefits to Canadian federal swine research. Scenario 1.A is a direct application of the econometric results reported in Table 2. The 25.9% reduction in supply is attributed entirely to Canadian federal swine research. Scenario 1.B was developed to illustrate 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. This could mean that a 25.9% reduction in the supply of hogs might overestimate the effect of Canadian federal swine research. In this scenario, this shift was reduced to 16.9%[11].

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 adversely affect the productivity of Canadian non-federal swine research. To reflect this possibility, the slope of the line indicating the optimal sum of producers' and consumers' surpluses after 1981 was reduced by 10%. 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%.

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[11] This value was selected because it represented one of the interpolated intermediate adjustments in the input-output coefficients made to produce the 25.9 % shift. Selecting this value economized on the number of CRAM runs that needed to be solved.

Scenarios 2.A and 2.B attribute 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 estimated gross annual research benefits obtained from the solutions of the CRAM should be attributed to federal, provincial, university and college and private sector research efforts. 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. We 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.

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, based on the coefficients reported in Table 2. 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. After this adjustment, all the derived gross annual research benefits are attributed to total Canadian

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public and private research sources.

Scenario 2.B is a modification of scenario 2.A. It was developed to account for the possibility that the estimated coefficient on Canadian swine research might be understated relative to the spill-in effects from U.S. research. To consider this possibility, the growth rate of total consumers' and producers' surpluses after 1981 was reduced by 10%.

Nine versions of the CRAM were solved for each scenario. These variations included low, medium, and high productivity growth rates as well as low, medium and high price levels for hogs. Results from these solutions were analysed with three discount rates, so that 27 sets of return estimates were obtained for each scenario. The version that represents the base solution employs the average or medium historical growth rates for the swine input and output coefficients and the actual 1996 input and output prices. 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. Five scenarios were considered therefore one hundred thirty-five sets of estimated returns to research were obtained.

Research Costs

The Inventory of Canadian Agricultural Research (ICAR) database is the most comprehensive source of information on agricultural research activity in Canada. A list of all projects directly associated with swine research in Canada was compiled with the assistance of the Inventory of Canadian Agricultural Research staff. Projects specifically focusing on swine research were included in the selection process along with projects where swine was one of a

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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. These professional person years were used to estimate the amount

of research effort committed to swine research over the observed time period. Since the level of

activity of Canadian private swine research is generally not reported in the Inventory, an estimate

was required. Ruttan and Pray (1987) have observed that data on private sector research in the

United States are limited. 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) stated

that private sector agricultural research expenditures have now surpassed those of the public

sector in the United States. Likewise, White (1995) concluded that private research spending was

approximately equal to government spending in 1950, but that private sector expenditures have

grown more rapidly than public sector expenditures since that date so that current private sector

expenditures for agricultural research are approximately double the level of public sector

expenditures.

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)

estimated Ontario private sector agricultural research to be 22% of public sector agricultural

research expenditures between 1950 and 1970.   The estimate of the size of Canadian private

sector swine research used in this study was based on the expert opinion of 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.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 previous Canadian studies. Table 6 summarizes our estimates of the annual

total professional person years for Canadian swine research for the various institutional

categories. The total Canadian public and private swine professional person years were used to

calculate research costs in Scenarios 2.A and 2.B.

The Inventory of Canadian Agricultural Research database does not contain cost estimates

for individual swine research projects. Therefore, a general method was employed to calculate a

homogeneous research unit cost for the calculated professional person years. Treasury Board's

Agriculture and Agri-Food Canada's Research Branch *Main Estimates* (1996) report estimated

annual total costs of various research activities. These costs include fixed, variable, professional

and technical person year costs. Based on these data, the total cost of each professional person

year for swine research is $407,000. 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.

The marginal excess burden of taxation was applied to the costs of government research.

The marginal excess burden of taxation is defined as the deadweight loss to the economy that is

created through taxation. This additional cost has often 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, 1985 and 1995 and Economic Research Service, 1996).   Alston *et al.*, (1990) estimated the

marginal excess burden of taxation in the United States to be in the range of 20% to 50%.

Browning (1987) estimated the marginal excess burden of taxation for the U.S. to be in the range

of 10% to 300%. Ballard *et al* report estimates of the marginal excess burden of taxes in the

United States from 17% to 56%. Findlay *et al.*, (1982) estimated the marginal excess burden of

taxation in Australia to be in the range of 23% to 65%.   Dahlby (1994) estimated the marginal

excess burden to be 66% at the provincial level and 38% at the federal level for income taxes in

Canada. We applied Dalhby's estimates for the federal marginal to swine research costs at

Agriculture and Agri-food Canada and to college and university research costs. The provincial

marginal excess burden estimate was applied to provincial research expenditures. Table 7

summarizes our estimates of Canadian swine research costs between 1974 and 1997.

Estimated Returns to Swine Research

        Table 8 summarizes the base solution results for the five scenarios. These results were

calculated using the medium price variation, the medium productivity growth rate variation and a

5% real discount rate. Table 9 reports the range of estimated returns to hog research for each of

the five scenarios. Estimated net present values ranged from $4.3 billion to $20.8 billion,

benefit/cost ratios ranged from 3.2 to 40.4 and internal rates of return from 37.21% to 145.02%.

The results reported in Table 10 describe how a 1% change in the discount rate, market hog price

and productivity growth rate affect the net present value and the benefit cost ratio. These results

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are expressed as elasticities.   Changes in the market hog price has the greatest impact on the net present value for each scenario. On average, a 1% change in the discount rate decreases the net present value by 0.09%. A 1% change in the input-output productivity growth rates increases the net present values by 0.84%. Our results are compared to three other return to research studies conducted with the CRAM in Table 11.

Discussion

Overall, Canadian federal swine research expenditures were found to have generated high rates of return for the time period considered in this analysis. 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 ratio of the base solutions for past Canadian federal research is found to range between 6.40 to 22.40.   The return estimates reported in this paper are based on econometric estimates of the relationship between Canadian Federal swine research expenditures and the supply of market hogs. Further investigation of this relationship is needed to test the robustness of the model and the econometric methods. In addition, because of the lack of private sector swine research expenditures a heuristic estimate was employed. Other researchers have suggested even higher levels of private sector swine research expenditures than the values assumed in this study. Wherever possible, we 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.

The value of the approach taken in this study derives from the multi-market structure of the modeling approach. By allowing for adjustments in related agricultural markets when

technology shifts the supply function for market hogs, the estimated benefits of research are more easily defended than those obtained with a partial equilibrium approach. In addition, the results reported in this paper are more easily compared with estimates of returns to research for potatoes (Agriculture and Agri-food Canada, 1996), for beef (Klein *et al*, 1994) and for wheat (Klein *et al*, 1996), since all were derived using the CRAM.
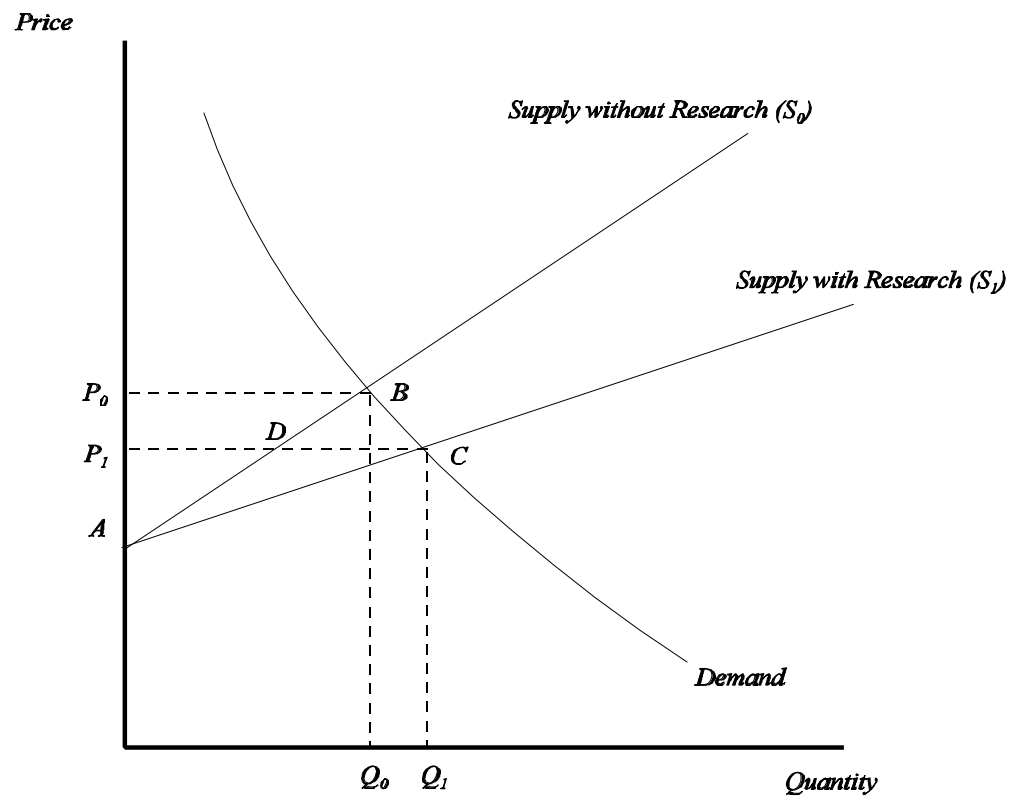
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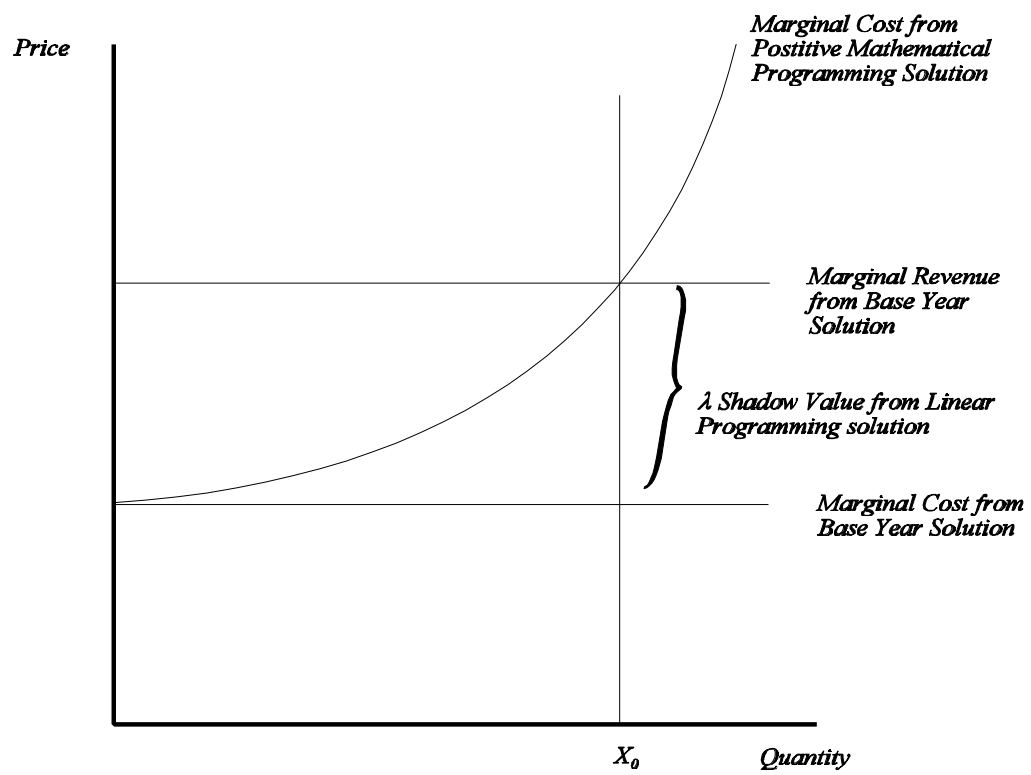
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Figure 1   Gross Research Benefits from a Shift in the Supply Function

Price

Supply without Research (S_0)

Supply with Research (S_1)

P_0 *B*

D

P_1 *C*

A

Demand

Q_0 Q_1 *Quantity*

Figure 2   Optimal Output Determination with Positive Mathematical Programming

Price

Marginal Cost from Postitive Mathematical Programming Solution

Marginal Revenue from Base Year Solution

λ Shadow Value from Linear Programming solution

Marginal Cost from Base Year Solution

X_0 *Quantity*

**Figure 3   Comparison of the Unconstrained Partial - Logarithmic Supply Function
with the Constrained Partial - Logarithmic Supply Function**
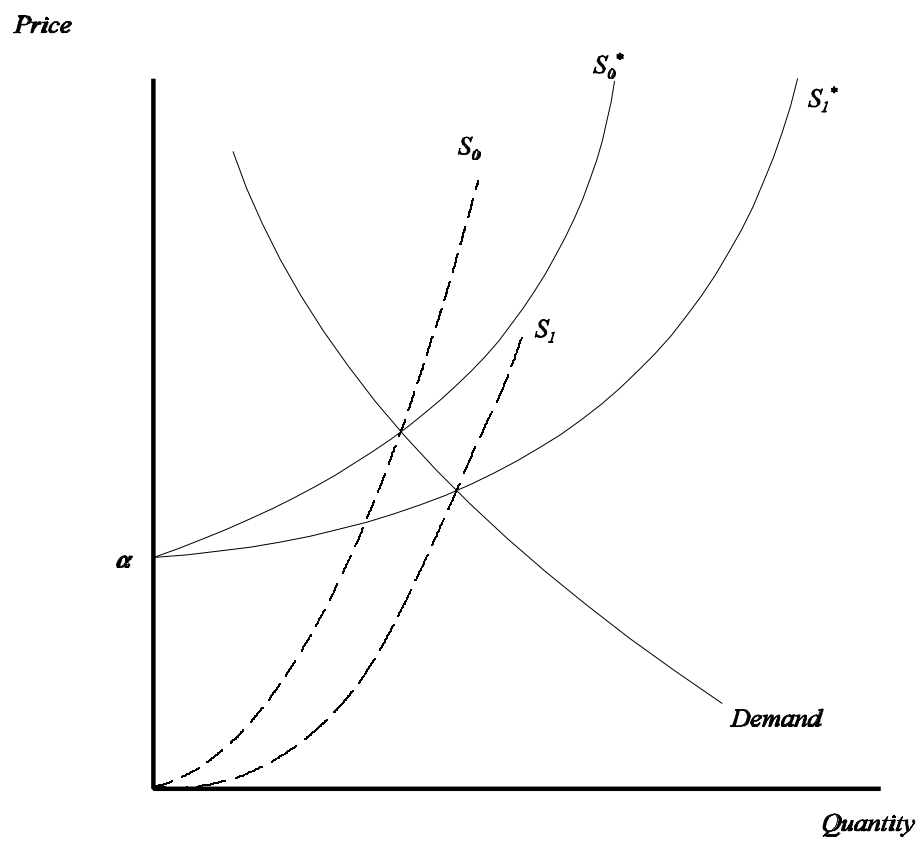
Figure 4   **Sum of Consumers' and Producers' Surpluses With and Without Swine Research between 1976 and 2005**

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1976   1981   1996   2000   2005   Year

———————   *Total Consumers' and Producers' Surpluses with Research*

– – – –   *Total Consumers' and Producers' Surpluses without Research*

————➤   *Direction of the input and output coefficients' average annual productivity growth rate adjustment.*
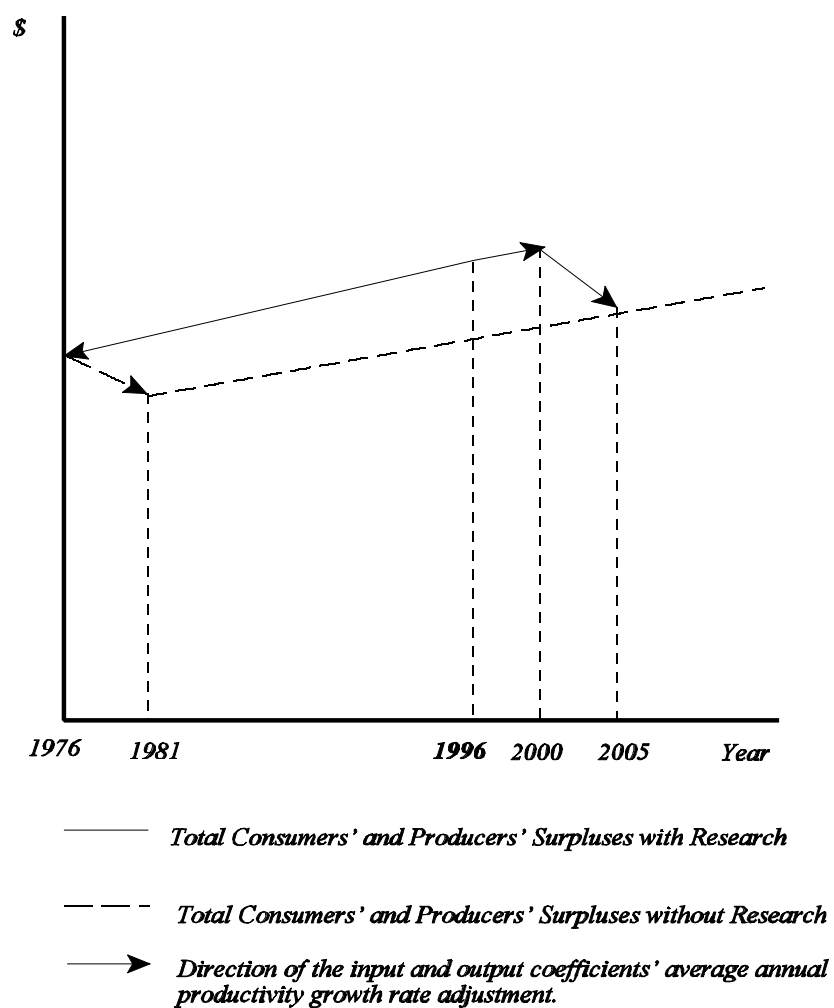
Table 1   **Summary of Selected Returns to Research Studies: United States & Canada**

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 Forecasting	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%

Table 1 (Continued) Summary of Returns to Research Studies

Study	Commodity	Period	Method	Average Estimated Rate of Return
Horbasz, Fox & Brinkman (1988)	Sheep	1968-1984	Economic Surplus, Econometric Approach	25%
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)	Potatoes	1971-1995	Economic Surplus, Delphi Forecasting & Mathematical Programming	28%
Klein, Freeze, & Walburger (1996)	Wheat	1962-1992	Economic Surplus, Historical Trend & Mathematical Programming	27-39%

Table 2 **Hog Supply Function Estimates**

Explanatory Variables	Estimated Coefficients	t - statistic	Estimated Elasticity
Constant	6.27	4.44	
Logarithm of Barley Price (P^B_{t-2})	-0.490	-2.18	-0.525
Technology Index (t_t)	0.150	-2.06	-0.254
Dummy Variable (1975-1977)=1	-0.00460	-0.367	
Canadian Federal Swine Research (R^{cdn}_{t-i})			
t-3	0.0522	3.33	0.0401
t-4	0.0835	3.33	0.0615
t-5	0.0939	3.33	0.0662
t-6	0.0835	3.33	0.0566
t-7	0.0522	3.33	0.0343
sum	**0.365**		**0.259**
U.S Swine Research (R^{US}_{t-i})			
t-3	0.00360	1.57	0.0243
t-4	0.00571	1.57	0.0421
t-5	0.00643	1.57	0.0460
t-6	0.00571	1.57	0.0396
t-7	0.00360	1.57	0.0242
sum	**0.0250**		**0.176**

Functional Form: Constrained Partial - Logarithmic   Range of Data: 1962 - 1984
Adjusted R^2: 0.899   F-Statistic: 16.1   Durbin-Watson: 1.52

Table 3   **Summary of Canadian Federal Research Elasticities for Different Commodities**

Study	Commodity	Period	Method	Canadian Federal Research Elasticity
Agriculture & Agri-Food Canada (1996)	Potatoes	1971-1994	Delphi Forecasting Estimate	0.33[12]
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)	Broilers	1968-1984	Econometric Model: Partial Logarithmic Function	0.27
Haque, Fox, and Brinkman (1987)	Eggs	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

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

Table 4　　　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.

Table 5   **Description 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.	Scenario 1.B is the same as 1.A except the size of the supply shift is reduced by 35% to 16.9%.	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.	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.	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.
Costs	Canadian federal expenditures (plus excess burden of taxation 38%).	The same as in Scenario 1.A.	The same as in Scenario 1.A.	Canadian federal expenditures (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 same as in Scenario 2.A.

Table 6   **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	Total Canadian Private PPYs	Total Canadian Public & Private PPYs
1974	13.90	2.53	29.32	45.76	18.3	64.06
1975	14.47	2.63	31.40	48.50	19.4	67.9
1976	15.04	2.73	33.48	51.25	20.5	71.75
1977	14.59	1.73	28.72	45.04	18.02	63.06
1978	14.39	1.85	30.90	47.14	18.86	66
1979	14.19	1.96	33.08	49.23	19.69	68.92
1980	17.43	2.51	31.96	51.90	20.76	72.66
1981	19.80	3.33	37.41	60.54	24.22	84.76
1982	22.17	4.14	42.86	69.17	27.67	96.84
1983	20.15	4.31	51.98	76.44	30.58	107.02
1984	18.14	4.48	61.09	83.71	33.48	117.19
1985	17.86	4.00	66.75	88.61	35.44	124.05
1986	20.74	3.87	67.10	91.71	36.68	128.39
1987	21.79	4.40	57.57	83.76	33.5	117.26
1988	20.8	4.31	60.72	85.83	34.33	120.16
1989	18.10	4.54	66.84	89.48	35.79	125.27
1990	29.57	4.70	47.49	81.76	32.7	114.46
1991	29.85	5.97	82.74	118.56	47.42	165.98
1992	24.21	4.92	87.91	117.04	46.82	163.86
1993	28.39	4.66	93.62	126.67	50.67	177.34
1994	21.70	4.04	63.74	89.48	35.79	125.27
1995	24.68	2.83	44.22	71.73	28.69	100.42
1996	21.57	2.58	49.35	73.50	29.4	102.9
1997	22.33	1.69	38.05	62.06	24.83	86.89
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: (1) 1974-1976 and 1997 are linearly extrapolated from the existing data.
        (2) 1978, 1981, and 1983 are linearly interpolated from the existing data.
        (3) 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.

Table 7   **Estimated 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	Total Canadian Private Swine Research Expenditures	Total Canadian Public & Private Swine Research Expenditures
($000s, expressed in constant 1996 prices)						
1974	7,808	1,710	16,471	25,988	7449	33438
1975	8,127	1,776	17,638	27,541	7896	35437
1976	8,446	1,842	18,805	29,094	8343	37437
1977	8,195	1,169	16,131	25,494	7333	32827
1978	8,082	1250	17,355	26687	7674	34362
1979	7,970	1,324	18,580	27874	8015	35889
1980	9,790	1,696	17,951	29436	8449	37886
1981	11121	2,250	21012	34,382	9856	44238
1982	12452	2,797	24,073	39322	11261	50583
1983	11317	2,912	29195	43,424	12444	55869
1984	10189	3027	34,312	47,527	13628	61155
1985	10,031	2702	37,491	50,225	14426	64650
1986	11,649	2615	37,687	51,951	14930	66881
1987	12,239	2973	32,335	47,546	13636	61182
1988	11,683	2912	34,104	48,698	13973	62672
1989	10,166	3067	37,541	50,775	14567	65342
1990	16,608	3175	26,673	46,457	13311	59767
1991	16,766	4033	46,472	67,271	19302	86572
1992	13,598	3324	49,376	66,297	19054	85351
1993	15,946	3148	52583	71,677	20622	92298
1994	12,188	2,730	35,800	50,718	14567	65285
1995	13,862	1,912	24,837	40,610	11678	52288
1996	12,115	1,743	27,718	41,576	11966	53542
1997	12,540	1,142	21,371	35053	10103	45156

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 8   Summary of Estimated Returns by Scenario - 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	$9,667,390.00	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	$7,617,466.00	17.8	108.1
1.C 1.A adjusted for illustration of a Federal and non-Federal research productivity relationship	$10,656,100.00	24.6	124.27
2.A Gross Annual Research Benefits Attributed to All Canadian Research	$11,786,042.00	6.4	53.75
2.B 2.A adjusted for illustration of a possible confounding effect between Canadian and U.S. research contributions	$12,100,259.00	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.

Table 9   Summary of the Range of Return Estimates by Scenario

Scenario	Net Present Value ($000)	Benefit Cost Ratio	Internal Rate of Return (%)
1.A Gross Annual Research Benefits Attributed to Canadian Federal Research.	$5,534,979.00 to $15,456,009.00	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.	$4,388,500.00 to $12,410,815.00	10.7 - 27.5	84.44 - 130.78
1.C 1.A adjusted for illustration of Federal and non-Federal research productivity relationship.	$6,380,250.00 to $16,894,710.00	14.2 - 40.4	98.51 - 145.05
2.A Gross Annual Research Benefits Attributed to All Canadian Research.	$5,866,133.00 to $9,454,181.00	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.	$6,288,616.00 to $20,885,382.00	3.4 - 12.9	37.39 - 67.71

Table 10 Sensitivity Analysis Results

Scenarios	1.A	1.B	1.C	2.A	2.B	Average Elasticity Across Scenarios
Variables	**Average Elasticity of the Net Present Values**					
Discount Rate	-0.14	-0.23	-0.07	0	-0.2	-0.089
Market Hog Prices	4.11	4.01	4.1	5.41	5.25	4.576
Productivity Growth	0.54	0.62	0.64	1.2	1.2	0.84
	Average Elasticity of the Benefit Cost Ratios					Average Elasticity Across Scenarios
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	4.2	3.99
Productivity Growth	0.52	0.59	0.62	1	1.07	0.748

Table 11 **Comparison of the Estimated Returns to Swine Research with Other Studies that Employed the CRAM**

	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 Ratio (1996 dollars)	6 - 22	43 - 75	5 - 18	11 - 60
Research Unit Cost $ / P.P.Y (1996 dollars)	$407,000.00	n/a	$360,000.00	$357,680.00

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