Underinvestment in Producer-Funded Agricultural R&D: The Role of the Horizon Problem

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Agricultural research and development (R&D) investment has become an increasingly important policy issue as food prices increased and food security problems emerged over the last decade. An important source of agricultural R&D funding is the producer check-off, which is increasingly being used to fund applied agricultural research. Existing studies of producer-funded agricultural R&D indicate there are high private rates of return to agricultural R&D investment by farmers, and thus farmers are underinvesting in R&D. Since a farmer's time horizon is typically less than the period of time over which the benefits of agricultural R&D take place, the horizon problem has been identified as a possible factor in this underinvestment. This paper shows that the horizon problem is unlikely to be the only cause of the underinvestment when the internal rate of return is large. Instead, shortened producer horizons only emerge as the main source of underinvestment when the internal rate of return is low. As a result, other factors, including behavioral determinants, need to be looked at as contributors to the underfunding of agricultural R&D.

Les investissements en recherche et développement agricoles sont devenus un important enjeu politique étant donné l'augmentation des prix des aliments et les problèmes de sécurité alimentaire de la dernière décennie. Une importante source de financement pour la recherche et le développement dans le domaine agricole sont les programmes de contribution des producteurs, ces derniers étant de plus en plus sollicités pour financer la recherche agricole appliquée. Certaines études portant sur la recherche et le développement agricoles financés par les producteurs indiquent un haut taux de rendement privé des investissements en recherche et développement agricoles par les producteurs. Ces derniers y investissent donc moins. Puisque l'échéancier de l'agriculteur est typiquement moins long que celui pendant lequel les avantages liés à la recherche et au développement dans le domaine agricole s'échelonnent, le problème de l'horizon a été identifié comme facteur potentiel au sous-investissement. Il est probable, selon cet article, que le problème de l'horizon ne soit pas la seule cause du sous-investissement lorsque le taux interne de rendement s'avère grand. Plutôt, les échéanciers réduits des agriculteurs apparaissent seulement comme les sources principales de sous-investissement lorsque le taux de rendement interne est bas. Il en résulte que d'autres facteurs, incluant les déterminants comportementaux, doivent être examinés à titre de contributeurs au sous-investissement de la recherche et du développement en agriculture.

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INTRODUCTION

Agricultural research and development (R&D) investment has become an increasingly important policy issue as food prices increased and food security problems emerged over the last decade. Agricultural R&D is the primary driver of agricultural productivity and is largely carried out by three groups—the public sector, private companies, and agricultural producers (Alston et al 2009). In spite of its high rate of return, the growth rate of public research funding in developed countries has fallen over the last 40 years, a slowing that corresponds to a lowering of the growth rates of yield and of land and labor productivity over the last 20 years (Alston et al 2009). This slowdown in the growth of funding has been important in Canada, where total real public agricultural R&D funding fell from $Cdn 520.7 million in 1981 to $Cdn 474.3 million in 2000 (Alston et al 2010).[1]

While public funding was falling in Canada, private investment increased dramatically, particularly in industries such as canola where hybrids and patents provide strong property rights and hence strong investment incentives. Consequently, private funding has become a larger component of total agricultural R&D investment in Canada; its share in total research funding has increased from 17% in 1981 (Alston et al 2010) to 39% in 2007 (Gray and Weseen 2008).

Producer-funded R&D financed by producer check-offs is the third important source of agricultural R&D and is used in a number of commodities to fund applied agricultural research such as disease management, genetic improvement, and weed control.[2] Check-off programs have developed for a variety of reasons, including a response by agricultural producers to lower public funding and a concern that private R&D may lead to higher seed prices. From a social welfare perspective, it is argued that producer check-offs are a desirable way to fund agricultural R&D because taxing producers directly is more efficient

[1] The data provided by Alston et al (2010) are the most recent available. Since, however, the share of R&D provided by private industry grew during the early 2000s (see figures presented below), it is likely that the share of R&D undertaken by the public sector fell during this period, suggesting that public funding for agricultural R&D in Canada remains relatively low.

[2] Comprehensive and up-to-date data on the relative importance of producer-funded R&D are not available. The snapshots that are obtainable indicate a substantial role for producer-funded R&D in certain regions and for certain commodities. For instance, the Saskatchewan Pulse Growers (SPG), which is the focus of the analysis in this paper, is by far the largest funder of R&D in the Saskatchewan pulse industry. As an example, in 2015, SPG raised $18.3 million from levies and had R&D expenditures of $10.0 million (net of the funding provided to the SPG by the federal and provincial governments) (SPG 2015). The Saskatchewan government contributed roughly $0.7 million in funding (ADF 2015), while the federal government provided at least $0.2 million in funding (SPG 2015). In the absence of any additional funding sources (private sector funding in the pulse industry is quite low), an upper estimate of the percentage of R&D funding in the Saskatchewan pulse industry that was carried out by the SPG is 90%. To provide another example, consider the Grains Research Development Corporation (GRDC) in Australia. As outlined in its 2012 strategic plan (which is the latest one), GRDC funding, which is financed by a levy on grain growers in Australia, financed 23% of the R&D in the Australian grains sector in 2007–08 (the strategic plan noted that more recent numbers were not available). This was equal to the share financed by private investors (GRDC 2012). Only the state governments financed a greater share (at 32%).

than taxing the general population (Alston et al 2003).

The return for producers from check-offs has been estimated to be high. For example, it has been estimated that the average benefit–cost ratio (BCR) for Canadian producer-funded R&D is 4.4 in the case of wheat and 12.4 for barley (Scott et al 2005). For Saskatchewan pulse producers, the BCR for producer-funded R&D is 15.8, while the average internal rates of return (IRRs) are 39.0% and 39.5% in the short run and long run, respectively (Gray et al 2008). Since these BCRs and IRRs are high compared to what would be expected if R&D investments were being made to maximize producer welfare, the implication is that farmers are underinvesting in check-off–funded agricultural R&D.

There are a number of explanations as to why collective organizations, such as commodity groups, underinvest in value-enhancing activities such as R&D. Some of these explanations focus on the manner in which individuals within these organizations make decisions (e.g., risk aversion). Other explanations focus on the organization and the way it structures incentives, and include factors such as the free-rider problem, the portfolio problem, the principal–agent problem, and the horizon problem (Olson 1971; Jensen and Meckling 1979; Vitaliano 1983; Cook 1995).

The horizon problem, which is the subject of this paper, occurs when a producer's individual time horizon is shorter than the expected payback time of the investment to the group. One reason a shorter horizon may exist is that a producer may no longer be part of the group at some point (e.g., they may have stopped farming) and thus will not collect the entire benefits. Regardless of the cause, it is expected that farmers with shorter membership horizons will have less of an incentive to make an investment (Jensen and Meckling 1979; Vitaliano 1983; Cook 1995).

Since the benefits of agricultural R&D investment occur over a long time period, the horizon problem would appear to be of particular interest in the case of producer-funded R&D. Alston et al (2010) argue that agricultural R&D can provide benefits for as long as 50 years, with the maximum benefits occurring at 25 years on average. Since the average age of Canadian farmers is 54 years (Beaulieu 2015), and their membership horizons are likely to be about 15–20 years (assuming their retirement age is 70–75), farmers' planning horizons are much shorter than the benefit horizon associated with the R&D.[3] However, while there is an intuitive appeal to the idea that the horizon problem is contributing to the underinvestment, no examination of the extent to which it is a factor has been carried out.

The purpose of this paper is to examine the degree to which the horizon problem explains the underinvestment of check-off–funded agricultural R&D. Using a model of discounted profit maximization, the paper determines an analytical expression for the optimal check-off chosen by a farmer with a specific time horizon. For a particular industry, this expression is then used to calculate (a) the levy a producer association can be expected to optimally select and (b) the discount rate and producer horizon combinations that generate, as the optimal levy, the check-off levy that is actually observed in the industry under examination. The horizon problem is deemed to be an important

[3] There is no precise estimate of farmers' retirement age. According to the age distribution of farmers presented by Beaulieu (2015), approximately 5% of farmers are age 70 or more, while just over 1% are age 75 or older, suggesting that a reasonable retirement age is in the range of 70–75 years.

contributing factor to R&D underinvestment if the levy calculated in (a) is less than or equal to the current levy or, what is equivalent, if the estimated horizon calculated in (b) is less than or equal to the horizon that is operational in the industry being examined. If these conditions are met, the horizon problem is sufficiently large that it can explain the underinvestment without considering other factors. If these conditions are not met, then, while the horizon problem may contribute to underinvestment, it is not of a large enough magnitude to explain the entire underinvestment and other additional explanations are required.

To undertake the analysis, a particular commodity—namely pulses—is used as the basis for the modeling. Pulse crops make a particularly good focus for the analysis because of the high returns that have been observed (Gray et al 2008). In addition, the SPG, one of the largest check-off associations in Canada, operates a mandatory nonrefundable levy, which means that the free-rider problems that often plague levy-funded research are attenuated to a significant degree.[4]

Since shortened horizons result in underinvestment relative to what would be optimal if the full horizon of the investment could be considered, what is of interest in this paper is the degree to which shortened horizons can explain the low levies and underinvestment that has occurred. The conclusion of the analysis in this paper is that to generate the low levies (and high IRRs) that are observed, profit-maximizing farmers would have to have time horizons that are much shorter than those that are likely to exist. This conclusion is equivalent to saying that, given the likely time horizon governing their decisions, farmers would not find it optimal to set the levy as low as it is currently set. As a result, it is concluded that while the horizon problem likely contributes to underinvestment, other factors are required to generate the low levy rates that are observed. In addition to examining the horizon problem, the paper also provides a theoretical framework for the determination of the optimal levy that can be used to examine the impact of other factors such as the free-rider problem and risk aversion that are likely to contribute to low levies.

The remainder of the paper is structured as follows. The next two sections develop the theoretical model. The key result is the derivation of an expression for the optimal levy chosen by the producer association. A comparison of the optimal levy with the levy observed in the industry indicates the horizon problem alone is not of sufficient magnitude to explain completely the observed underinvestment. The paper concludes with a discussion of other factors that might be at work in generating underinvestment in R&D.

[4] The free-rider problem emerges in producer association investments because, although everyone benefits from the investment, each person would like the others to finance the investment. Mandatory nonrefundable levies deal with the free-rider problem by requiring everyone to contribute to the collective asset and by not providing an option for producers to obtain a refund of this levy. In contrast, mandatory refundable levies require everyone to pay the levy, but provide a mechanism by which producers can obtain a refund upon request. In Canada, most producer-levy schemes are mandatory refundable (for further information, see the section later in the paper on the free-rider problem). In addition to the SPG, pulse producer organizations in Idaho and Washington, and producer organizations for most crops in Australia, operate with mandatory nonrefundable levies.

MODEL SETUP

The model developed in this paper is based on a set of assumptions that simplify the analysis and focus attention on the specific impact of the horizon problem. It is assumed farmers are risk neutral, maximize the net present value of profits from the crop being grown, and rent the land they farm. It is also assumed that farmers are members of a producer association and the association is managed in a way that allows the members' objectives to be achieved. Maintaining these assumptions isolates the horizon problem as a factor explaining levy determination and creates a set of conditions under which the horizon problem is most likely to occur. If the analysis finds the horizon problem by itself does not generate the observed underinvestment even under these conditions, then support is provided for the conclusion that other factors are responsible. As will be shown later in the paper, the model provides a robust theoretical framework for examining the impact of relaxing these assumptions.

The analysis also assumes prices are fixed for the output and for all variable inputs (captured in this model in a composite input). As shown in the online Supplementary material, introducing a downward sloping demand curve does not markedly change the results in most cases, and when the results do change, the effect is to make the horizon problem less of a contributor to low R&D investment. This observation is important because the assumption of a fixed output price does not hold for the pulse industry, where Canadian output makes up a significant percentage of total world output.

Although the farmer members of the association are assumed to be homogeneous with respect to the technology they use, it is assumed they differ in the horizons over which they calculate the net present value of profits. For farmers with time horizons less than the horizon over which the R&D benefits occur, the optimal levy—that is, the levy that maximizes profits—is less than the levy that maximizes profits if the full time horizon of the investment is considered.

The analysis assumes the levy chosen by the producer association is the optimal levy chosen by one of the producers with a shortened horizon. The member that effectively decides for the group is referred to as the pivotal member. The idea of a pivotal member applies directly to cases where decisions are made by majority or supermajority rule—in the case of majority rule, the pivotal member is the median member.[5] More generally, the notion of a pivotal member captures the idea that some members have more influence than others in an organization. Given the compulsory nature of the check-off, the levy chosen by the pivotal member applies to all members.

The model determines two optimal levies for the pivotal member—a one-shot levy that applies for one period only and a steady-state levy that applies for all periods. In determining these levies, use is made of the fact that if a producer has a sufficiently long

[5] Alston and Fulton (2012) argue that the need for supermajority support present in many check-off organizations (e.g., the support of at least 80% of the membership) can play an important role in underinvestment. Underinvestment occurs because of member heterogeneity; only a small check-off is acceptable to a supermajority of the membership, even though a larger check-off would benefit the members on average. For one of the first treatments of the median voter theorem, see Black (1948).

time horizon (i.e., at least as long as the horizon over which the benefits of the R&D occur), she has a marginal IRR equal to the values estimated empirically in the R&D literature (e.g., Gray et al 2008; Alston et al 2010). The recognition of this relationship serves as a way of parameterizing the model and of ensuring the numerical analyses that are undertaken are consistent with what has been observed in the industry under examination.[6]

Calibrating the model in this way creates a benchmark in which none of the factors that might influence the levy choice is operational (this follows because the model is built on the assumption of risk neutral producers with sufficiently long time horizons operating in an association with a mandatory levy). If shortened time horizons are then introduced while keeping the other assumptions in place, it is possible to explore the degree to which the horizon problem is a factor in explaining reduced R&D investment.

The importance of the horizon problem as a factor in R&D underinvestment can be examined in two ways. The first way is to derive the optimal one-shot and steady-state levies for the pivotal member. Since these levies depend on the pivotal member's discount rate, the analysis has to consider a range of appropriate discount rates. If the optimal levies are greater than the one currently observed in the industry, this is evidence that the current low levy (and the resulting underinvestment) is caused by something in addition to shortened horizons. The magnitude of this difference is, of course, important. The larger the deviation, the greater is the likelihood that other factors besides the horizon problem are at work. As a result, the analysis below examines the percentage of the difference between the optimal levy and the observed levy that would need to be explained by factors other than the horizon problem.

The second way is to use the expressions for the optimal one-shot and steady-state levies to find the member horizon that would generate an optimal levy equal to the one that is currently observed. If the member horizon that is calculated is less than the pivotal member's time horizon, then it can be concluded that the horizon problem alone is not the cause of the underinvestment in R&D (similar caveats to those raised above about the magnitude of the difference apply). As in the first approach, this approach also has to consider a range of discount rates.

These two procedures, of course, generate the same conclusion regarding the horizon problem for any given set of parameters (including the discount rate). However, since they provide different perspectives on the horizon issue, both are undertaken in this paper. While the first is the most direct way of looking at the impact of shortened horizons on the levy that is chosen, the second allows an explicit comparison of time horizons, which is the subject of interest. In addition, as will be shown, the second method is more general and provides for an intuitive understanding of the conditions under which the horizon problem is likely to be a factor in inducing underinvestment in R&D.

[6] The IRR was used because it is widely reported in the R&D literature. As Hurley et al (2014) point out, the IRR assumes the returns generated by R&D can be reinvested by farmers at the same rate of return as the original investment. Since this is not generally the case, the IRR overstates the actual rate of return generated by R&D. Although the IRR is used in this paper as a way of parameterizing the model, other measures of the rate of return such as the BCR could also be used. As will be shown, as long as these different measures are equivalent given the specified discount rates (e.g., the IRR makes the BCR equal to one), the use of different measures will give the same results.

THE THEORETICAL MODEL

Consider a group of producers that have organized a producer association to undertake R&D. In period zero, the association determines the levy rate for that period, which, in turn, determines production and the check-off revenues that are collected. The revenue is then used to finance R&D, which increases the knowledge stock over the next T years—that is, a one-shot increase in R&D in period zero leads to an increase in the knowledge stock for periods one to T, where T is the horizon over which the investment generates benefits.

Given this new knowledge stock, each producer determines her profit-maximizing level of variable input use for each of the H periods over which she expects to receive benefits, where $H < T$ is the horizon of the farmer.[7] This input use determines the output produced and the profits earned by the farmers. Farmers with $H < T$ will not see the entire stream of benefits from the R&D. If a farmer with a shorter horizon (i.e., an H less than T) is in a position to influence the levy the association selects in period zero (i.e., she represents the pivotal farmer), the result is an underinvestment in R&D. Determining the magnitude of this underinvestment is the goal of the analysis.

To undertake this analysis, the first step is to determine the optimal output, and thus the returns, of a producer with horizon H, for any given levy chosen by the association. The optimal levy for a pivotal producer with horizon H is then chosen so as to maximize these returns.

Determination of Producer's Optimal Output

Consider a profit-maximizing farmer in a producer association who has a time horizon of H years. The problem facing this farmer is

$$\max_{x_0,\ldots,x_H} \Pi_H = \sum_{t=0}^{H} \pi_t(x_t, K_t)\delta^t = \sum_{t=0}^{H}[P(1-l_t)y_t(x_t, K_t) - P_x x_t]\delta^t \tag{1}$$

where Π_H is the net present value of profits over time horizon H, $\pi_t(x_t, K_t)$ is profit in period t, $y_t(x_t, K_t)$ is output in period t, x_t is a composite input (e.g., labor, fertilizer, and machinery) in period t, K_t is the industry knowledge stock in period t, P and P_x are constant output and input prices, respectively, $\delta = 1/(1+r)$ is the discount factor, r is the farmer's discount rate, and l_t is the percentage of total revenue paid to the producer association as a check-off levy. The input price is normalized to unity—that is, $P_x = 1$. Since the knowledge stock is determined by R&D decisions made in earlier periods, it is thus fixed at any given time t when producers make their input decisions.

The analysis is carried out for the case of the Cobb–Douglas production function, $y_t(x_t, K_t) = AK_t^{\alpha}x_t^{\beta}$, where $A > 0$ and $0 < \alpha, \beta < 1$. There are diminishing marginal returns to increases in the knowledge stock ($\alpha < 1$) and diminishing marginal returns to the use of the input x_t ($\beta < 1$). The value of $\alpha + \beta$ is not restricted to be equal to one.

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[7] We restrict the analysis to cases where the producer's horizon H is less than T, since if the horizon were equal to or greater than T the producer would see the full stream of benefits and investment would not be affected.

Solving the problem of the representative farmer and substituting the resulting optimal input demand function into the production function gives the industry supply curve in period t[8]

$$y_t^*(P, l_t, K_t) = A^{\frac{1}{1-\beta}} \beta^{\frac{\beta}{1-\beta}} [P(1-l_t)]^{\frac{\beta}{1-\beta}} K_t^{\frac{\alpha}{1-\beta}} \tag{2}$$

If the supply elasticity is denoted as ϵ, then $\epsilon = \beta/(1-\beta)$; this implies $\beta = \epsilon/(1+\epsilon)$ and $(1-\beta) = 1/(1+\epsilon)$. Substituting the optimal input demand function into the period t profit expression gives the indirect profit function in year t

$$\pi_t^*(P, l_t, K_t) = A^{\frac{1}{1-\beta}} \beta^{\frac{\beta}{1-\beta}} (1-\beta)[P(1-l_t)]^{\frac{1}{1-\beta}} K_t^{\frac{\alpha}{1-\beta}} \tag{3}$$

It is useful to express the indirect profit function in year t as a function of output $y_t^*(P, l_t, K_t)$

$$\pi_t^*(P, l_t, K_t) = (1-\beta)(1-l_t) P y_t^*(P, l_t, K_t) \tag{4}$$

Determination of the Optimal Levy

Now consider the problem facing the producer organization in determining the optimal levy at time $t = 0$. The problem considered here is one where the levy has been set at a fixed $\bar{l}$ for the T periods prior to time $t = 0$. At time $t = 0$, the producer association selects the levy l_0 on the assumption that this levy is in effect only for period $t = 0$. For subsequent periods, the levy reverts to $\bar{l}$. This one-shot change in the levy produces a change in the industry knowledge stock for the next T periods.

The industry knowledge stock is modeled following Alston et al (2010, p. 276), who assume the knowledge stock in period t is determined by the sum of the weighted R&D expenditures in the previous T years, that is,

$$K_t = \sum_{s=1}^{T} \omega_s E_{t-s} \qquad \forall\, t \in [1, T] \tag{5}$$

where s is the number of years since the R&D investment, E_t is the R&D expenditure in period t, and ω_s is marginal impact on the knowledge stock K_t of a dollar change in R&D expenditures s periods previously. R&D expenditures E_t are given by $E_t = \mu l_t P y_t$.[9] Alston et al (2010, p. 276) assume that ω_s has a gamma distribution and can be expressed

[8] The optimal input demand function is derived in the online supplementary material.

[9] The parameter μ is typically less than one because generally some portion of the levy collected is invested in other activities such as marketing programs. As well, a portion of the levy collected will go to administration. However, the parameter μ is also affected by the presence of matching funds. For instance, if an external agency matches every dollar spent by the producer association with an additional dollar of R&D funding, then μ could be greater than one.

as follows

$$\omega_s = \frac{(s-g+1)^{\frac{\phi}{1-\phi}}\lambda^{s-g}}{\sum_{s=1}^{T}(s-g+1)^{\frac{\phi}{1-\phi}}\lambda^{s-g}} \text{ for } g < s \leqslant T; \text{ otherwise } \omega_s = 0 \tag{6}$$

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

To explore the levy decisions that emerge from a producer association where producers have different time horizons, it is assumed that the producer with an H horizon is pivotal in the sense that she decides the organization's levy so as to maximize her own profits Π_H^*. This problem can be written as

$$\max_{l_0} \ \Pi_H^* = \pi_0^* + \sum_{t=1}^{H}\pi_t^*\delta^t \tag{7}$$

The first-order condition for this problem is given by

$$\frac{\partial \Pi_H^*}{\partial l_0} = \frac{\partial \pi_0^*}{\partial l_0} + \sum_{t=1}^{H}\frac{\partial \pi_t^*}{\partial l_0}\delta^t = 0 \tag{8}$$

Rewriting Equation (8) shows that the optimal levy is determined by equating the marginal benefit with the marginal cost, that is,

$$\underbrace{\sum_{t=1}^{H}\frac{\partial \pi_t^*}{\partial l_0}\delta^t}_{\text{MB}} = \underbrace{(-\frac{\partial \pi_0^*}{\partial l_0})}_{\text{MC}} \tag{9}$$

where the marginal cost MC is the profit lost in period zero as a result of a change in the levy l_0 and the marginal benefit MB is the net present value of the increase in profit in the subsequent H periods generated by the levy change. The derivation of MC and MB are examined below.

Marginal Cost of R&D Investment

The marginal cost of R&D investment is derived from the indirect profit function in period $t = 0$, where, using the result in Equation (4), the indirect profit function at $t = 0$ is given by

$$\pi_0^* = (1-\beta)(1-l_0)Py_0^* \tag{10}$$

The marginal cost of R&D investment is thus

$$\mathrm{MC} = -\frac{\partial \pi_0^*}{\partial l_0} = P y_0^* > 0 \tag{11}$$

Marginal Benefit of R&D Investment

For a producer with a time horizon H, the marginal benefit of an increase in the levy l_0 is given by the net present value of the change in profits generated from period one to H, that is,

$$\mathrm{MB} = \sum_{t=1}^{H} \frac{\partial \pi_t^*}{\partial l_0} \delta^t = \sum_{t=1}^{H} \frac{\partial \pi_t^*}{\partial K_t} \frac{\partial K_t}{\partial l_0} \delta^t \tag{12}$$

where, given the expression for the knowledge stock in Equation (5), $\partial K_t / \partial l_0$ is

$$\frac{\partial K_t}{\partial l_0} = \omega_t \frac{\partial E_0}{\partial l_0} \tag{13}$$

This implies that

$$\mathrm{MB} = \frac{\partial E_0}{\partial l_0} \sum_{t=1}^{H} \frac{\partial \pi_t^*}{\partial K_t} \omega_t \delta^t \tag{14}$$

Since R&D investment E_0 is given by $E_0 = \mu l_0 P y_0^*$, $\partial E_0 / \partial l_0$ is given by

$$\frac{\partial E_0}{\partial l_0} = \frac{\mu(1 - (1 + \epsilon) l_0)}{(1 - l_0)} P y_0^* \tag{15}$$

To ensure MB is positive, $\partial E_0 / \partial l_0$ must be positive. Thus, the optimal levy, l_0^*, must satisfy $l_0^* < 1/(1 + \epsilon)$.

Using Equation (4) and noting that $K_t \approx E_t$ (note—this approximation holds exactly for the steady-state case examined below), $\partial \pi_t^* / \partial K_t$ is given by

$$\frac{\partial \pi_t^*}{\partial K_t} = \frac{\alpha(1 - l_t)}{\mu l_t} \tag{16}$$

Noting that $l_t = \bar{l}$ for $t = 1, \ldots, T$, the marginal benefit can be obtained from Equation (14) by making the appropriate substitutions and simplifying to give

$$\mathrm{MB} = \frac{\alpha(1 - (1 + \epsilon) l_0)(1 - \bar{l})}{(1 - l_0)\bar{l}} P y_0^* \sum_{t=1}^{H} \omega_t \delta^t \tag{17}$$

This equation can be rewritten as

$$\text{MB} = \frac{\alpha(1-(1+\epsilon)l_0)(1-\bar{l})}{(1-l_0)\bar{l}} P y_0^* \Phi(H, r) \tag{18}$$

where

$$\Phi(H, r) = \sum_{t=1}^{H} \omega_t \delta^t \tag{19}$$

Determination of the Optimal Levy

Two optimal levies—one designated for a one-shot investment and the other carried out in a steady state—can be determined using the marginal cost and marginal benefit derived above. The optimal one-shot levy is determined by assuming that the levy $\bar{l}$ has been in place for at least T years prior to the current period (i.e., period zero) and will again be in place indefinitely starting in period one. However, in the current period (i.e., $t = 0$), the levy l_0 is chosen to equate marginal cost and marginal benefit.[10] Thus, the optimal one-shot levy, l_0^*, solves the following equation

$$P y_0^* = \frac{\alpha(1-(1+\epsilon)l_0^*)(1-\bar{l})}{(1-l_0^*)\bar{l}} P y_0^* \Phi(H, r) \tag{20}$$

Solving this equation for l_0^* gives

$$l_0^* = \frac{\alpha\gamma\Phi(H, r) - 1}{\alpha\gamma(1+\epsilon)\Phi(H, r) - 1} \tag{21}$$

where $\gamma = (1-\bar{l})/\bar{l}$.

Now consider the optimal steady-state levy. Assuming constant values for price P and parameter A, the steady-state optimal value for the levy, l^*, can be found by solving Equation (20) under the assumption that $\bar{l} = l_0^* = l^*$ (note that, as a consequence of this assumption, $K_0 = K_t = K$ and $y_0 = y_t = y$). Solving for the optimal steady-state levy results in

$$l^* = \frac{\alpha\Phi(H, r)}{1 + \alpha(1+\epsilon)\Phi(H, r)} \tag{22}$$

The assumption that $\bar{l} = l_0^* = l^*$ ensures that the optimality conditions for the choice of the levy in period zero are based on a value of the levy in past and future periods that is the same as the levy that is chosen in period zero. Thus, regardless of the period that is designated as period zero, the same optimal levy is selected.

[10]To ensure that l_0^* is a maximum, the expression $(1-(1+\epsilon)l_0^*)/(1-l_0^*)$ in Equation (20) must be a decreasing function of l_0^*. This condition holds.

Focusing first on Equation (21), comparative static results indicate that l_0^* is increasing in γ. Since γ is decreasing in the levy $\bar{l}$, a larger $\bar{l}$ leads to a lower l_0^*. In addition, a direct comparison of l_0^* as given in Equation (21) to $\bar{l}$ shows that $l_0^* > \bar{l}$ if $\bar{l} < l^*$.

Standard comparative static results for the expressions in Equations (21) and (22) show that both l_0^* and l^* are increasing in α and decreasing in ϵ. Thus, the more responsive is output to the knowledge stock (i.e., the larger is α) and the more inelastic is the supply curve, the larger are the optimal levies l^* and l_0^*.[11]

Equations (21) and (22) also indicate that both l_0^* and l^* increase with an increase in $\Phi(H, r)$, where $\Phi(H, r)$ is given by Equation (19). Since $\Phi(H, r)$ is increasing in H and decreasing in r, longer time horizons lead to higher optimal levies, while higher discount rates lead to lower optimal levies.

The relative magnitude of l_0^* and l^* can be obtained from a comparison of Equations (21) and (22). Specifically

$$l_0^* - l^* = \frac{\alpha\Phi(H, r)(\gamma - \epsilon) - 1}{[\alpha\gamma(1+\epsilon)\Phi(H, r) - 1][1 + \alpha(1+\epsilon)\Phi(H, r)]} \tag{23}$$

Equation (23) indicates that the optimal one-shot levy l_0^* is equal to the optimal steady-state levy l^* when $\alpha\Phi(H, r)(\gamma - \epsilon) = 1$. This expression can be used to calculate the critical value, $\Phi(H, r)_c$, where

$$\Phi(H, r)_c = \frac{1}{\alpha(\gamma - \epsilon)} = \frac{\bar{l}}{\alpha(1 - (1+\epsilon)\bar{l})} \tag{24}$$

The optimal one-shot levy l_0^* is greater than the optimal steady-state levy l^* when $\Phi(H, r) > \Phi(H, r)_c$.

The critical value $\Phi(H, r)_c$ is important for the subsequent analysis because it indicates the conditions under which $l_0^* > l^*$. One of the approaches taken in this paper is to compare the optimal levy—either l^* or l_0^*—to the levy that is observed in the industry. Two outcomes are possible from this comparison. First, if the optimal levy is greater than the observed levy, then it follows that the horizon problem alone is not the cause of the low levy, but instead other factors are at work. Given this approach, it is sufficient to examine the smaller of the two optimal levies, since if the smaller of the two optimal levies is greater than the observed levy, the other levy must also be greater. Second, however, if

[11]The optimal levies l_0^* and l^* are not affected by μ, the ratio of R&D expenditures to the levy. The reason for this result is that μ has both a direct and indirect effect on the optimal levies. While a smaller μ has the direct effect of lowering the marginal benefit of R&D, the indirect effect is to lower the knowledge stock, which in turn raises the marginal benefit of R&D. Since the increase in the marginal benefit offsets the decrease, the optimal steady-state levies are unaffected by the value of μ. It is important to note, of course, that although the levies are unaffected, higher values of μ will be associated with greater R&D, a greater knowledge stock, higher production, and larger producer returns. Thus, there is an incentive for farmers to economize on administration costs, scrutinize carefully spending on other programs, and engage in partnerships that provide matching funding. On this last point, this result suggests that matching funding does not necessarily "crowd out" producer funding; a full examination of the determinants of μ is required, however, to answer this question.

the optimal levy is less than or equal to the observed levy, then it follows that the horizon problem could, by itself, result in the selection of the low levy. In this case it is sufficient to examine the greater of the two optimal levies, since if the larger of the two optimal levies is less than the observed levy, the other levy will also be less.

As will be shown later in the paper, l^* is greater than the current levy when $\Phi(H, r) > \Phi(T, \text{IRR})$, where, it will be recalled, IRR is the internal rate of return to R&D that has been calculated for an industry when the benefits accrue over T periods. In addition, since it can be shown that $\Phi(T, \text{IRR}) = \Phi(H, r)_c$, the condition that determines whether l^* is greater or less than the current levy is the same condition that determines whether l_0^* is greater or less than l^*.[12] As a result, it is sufficient to compare l^* to the current levy. As a result, the subsequent analysis will focus attention on l^* rather than on l_0^*.[13]

Given the discussion above, the next step in the analysis is to examine in depth the determination of l^*. Also examined is the determination of what is referred to as the critical horizon, $\hat{H}$—the time horizon that generates the currently observed check-off levy as the optimal levy. As will be seen, the determination of both l^* and $\hat{H}$ depends on an understanding of the $\Phi(H, r)$ function. With this understanding in place, a numerical analysis is then undertaken.

MODEL ANALYSIS

The Basis for Analysis—The $\Phi(H, r)$ Function

The starting point for the analysis of l^* and $\hat{H}$ is to determine the nature of the $\Phi(H, r)$ function. Figure 1 shows a graph of the knowledge stock weights ω_t for the case where $T = 50$, and for parameter values $\lambda = 0.80$ and $\phi = 0.75$, a parameter combination that generates the peak R&D benefits at roughly 12 years. Also shown in Figure 1 is the multiplication of δ^t and ω_t, for a discount rate r of 10%—that is, $\delta = 1/(1 + 0.10) = 0.91$.

The multiplication of ω_t by δ^t shifts the ω_t curve down and to the left. As outlined earlier, the parameter ω_t is the marginal impact on the knowledge stock in period t (i.e., K_t) of a dollar change in R&D expenditures in period zero. The term δ^t discounts this marginal impact back to time zero. Thus, given the case illustrated in Figure 1, while the biggest marginal impact of current R&D is felt 12 years out, the biggest marginal impact in discounted terms is at about nine years.

The $\delta^t\omega_t$ curve forms the basis for the determination of the $\Phi(H, r)$ function—specifically, $\Phi(H, r)$ is the area under the $\delta^t\omega_t$ curve and to the left of a vertical line at any given horizon H. Thus, in Figure 1, the value of the $\Phi(H, r)$ function for $H = 12$,

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[12]To see that $\Phi(T, \text{IRR}) = \Phi(H, r)_c$, assume that the current observed levy has been in effect for a long time and will remain in effect for an indefinite period; thus it can be denoted as $\bar{l}$. Suppose also that economic analysis has indicated that, over a T period horizon, the internal rate of return generated by the levy $\bar{l}$ is given by IRR. Under these assumptions, $\bar{l}$ solves Equation (22) for $\Phi(H, r) = \Phi(T, \text{IRR})$. Rearranging terms in Equation (22) shows that $\Phi(T, \text{IRR}) = \bar{l}/[\alpha(1 - (1 + \epsilon)\bar{l})]$. A comparison of the above expression with Equation (24) shows that $\Phi(T, \text{IRR}) = \Phi(H, r)_c$.

[13]Assume, as in Footnote 12, that $l_0 = \bar{l}$. If $\Phi(H, r) > \Phi(T, \text{IRR})$, then $l^* > l_0$; however, if $\Phi(H, r) < \Phi(T, \text{IRR})$, then $l^* < l_0$. Since $\Phi(T, \text{IRR}) = \Phi(H, r)_c$, it also follows that $l_0^* > l^*$ when $\Phi(H, r) > \Phi(T, \text{IRR})$ and $l_0^* < l^*$ when $\Phi(H, r) < \Phi(T, \text{IRR})$. Thus, it is either the case that $l_0^* < l^* < l_0$ or that $l_0 < l^* < l_0^*$. In both cases, knowledge of the magnitude of l^* relative to l_0 is sufficient to determine the magnitude of l_0^* to l_0, and thus it is appropriate to focus attention on l^*.

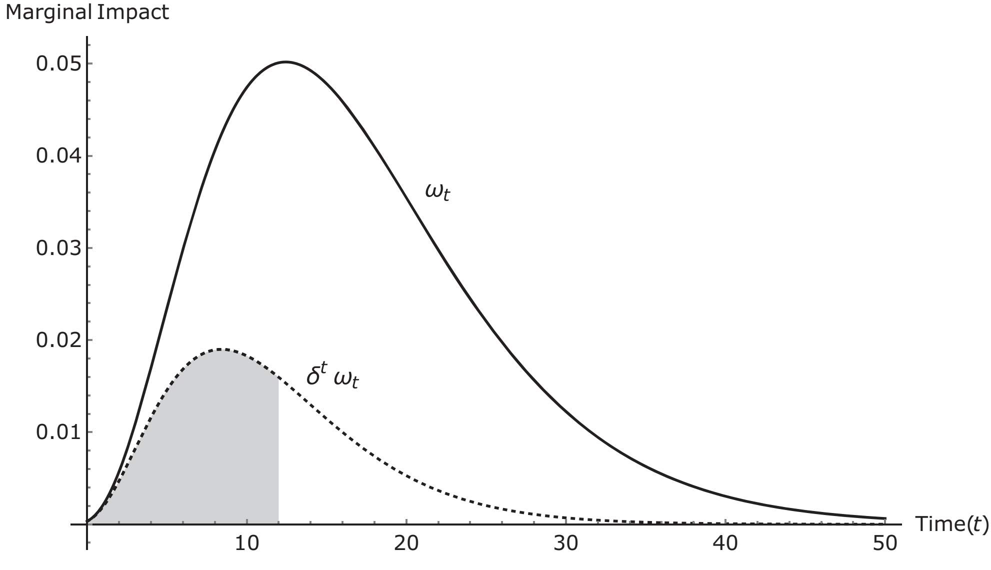

Figure 1. The ω_t and $\delta^t\omega_t$ functions ($\lambda = 0.80$, $\phi = 0.75$, $r = 10\%$)

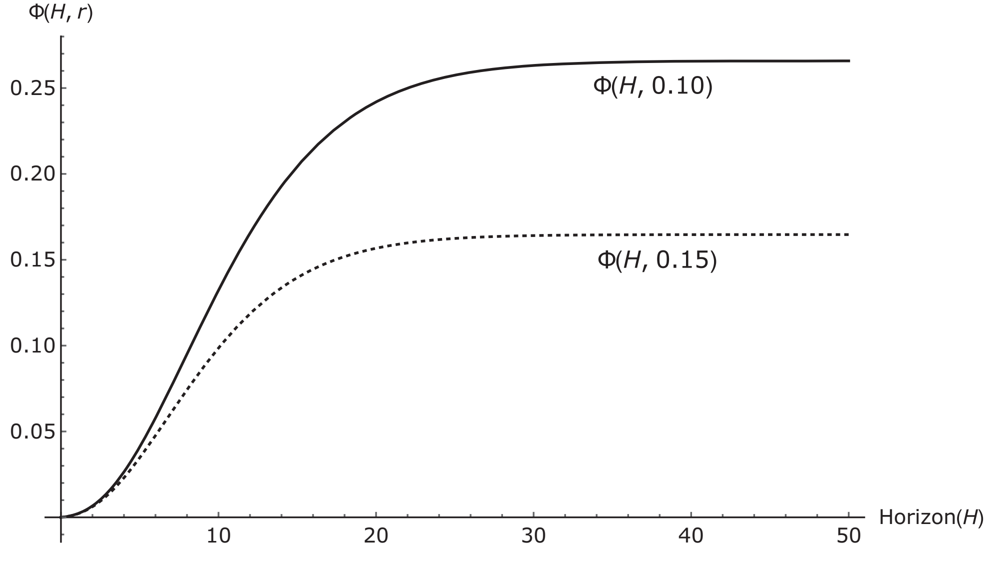

Figure 2. The $\Phi(H, r)$ function for selected discount rates ($\lambda = 0.80$, $\phi = 0.75$)

for example, is given by the shaded area. The $\Phi(H, r)$ function is thus the cumulative discounted marginal impact on the knowledge stock of a dollar change in R&D expenditures in period zero.

Figure 2 graphs the $\Phi(H, r)$ function. The $\Phi(H, r)$ function has the S-shape of most cumulative functions. Starting with $H = 0$, an increase in the horizon H results in a fairly

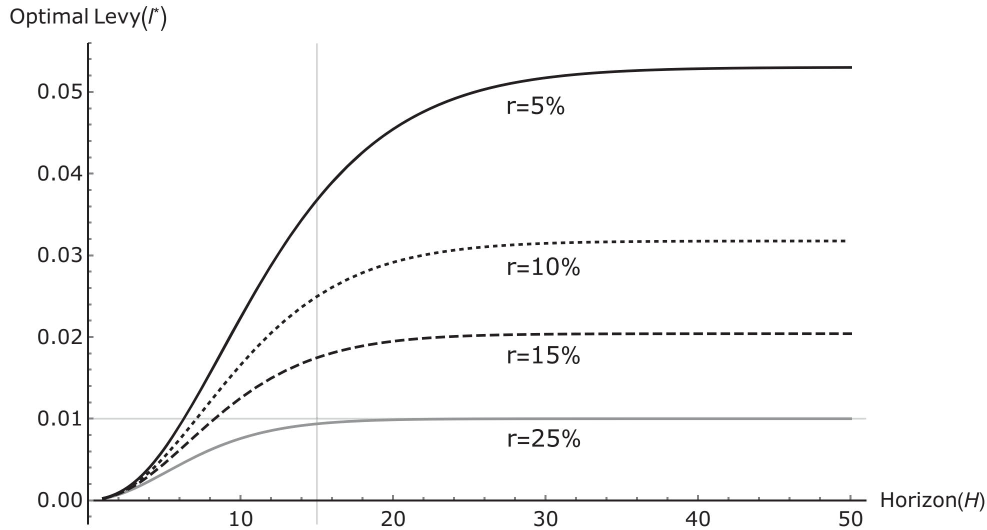

Figure 3. Optimal levy for selected discount rates ($\lambda = 0.80$, $\phi = 0.75$, $\epsilon = 2.0$, $\alpha = 0.132$)

rapid increase in the $\Phi(H, r)$ function, so that by the point where $H = 20$, the $\Phi(H, r)$ function for $r = 10\%$ has achieved most of its maximum possible value. In fact, beyond some point (roughly 25 years in the case of $r = 10\%$), further increases in H result in virtually no increase in the $\Phi(H, r)$ function. The value of H at which the $\Phi(H, r)$ function levels off depends, of course, on the shape of the ω_t function (and hence the parameters λ and ϕ) and the discount rate r (which determines the discount factor δ). Importantly, with higher discount rates (e.g., $r = 15\%$ in Figure 2), the $\Phi(H, r)$ function reaches something near its maximum value at lower H values. Similarly, the smaller is the number of years to the peak value of ω_t, the smaller is the value of H at which the $\Phi(H, r)$ function levels off.

The Determination of l^* and $\hat{H}$

The shape of the $\Phi(H, r)$ function is important for the value of the optimal levy chosen, since it indicates that once the horizon is sufficiently long, further increases in H are unlikely to have much impact on the optimal levy. This relationship is illustrated in Figure 3, which graphs the optimal levy derived from $\Phi(H, r)$ for four different discount rates. The optimal levy curve has roughly the same S-shape as the $\Phi(H, r)$ function, indicating that the choice of the optimal levy is relatively insensitive to changes in the horizon when H is large. However, changes in H can have fairly large impacts on the optimal levy when H takes on small to intermediate values, particularly if the discount rate is relatively small. In addition to making l^* more sensitive to H (and over a wider range of H), lower discount rates also shift the l^* curves up and generate larger values of l^* for any given H.

Figure 3 can be used to examine the impact of the horizon problem on a producer association's levy choice. The starting point for the analysis is the parameterization of the model. As will be discussed in detail later, the values of λ, ϕ, and ϵ are chosen to correspond to the characteristics of the industry under examination (in the case of this paper, the pulse industry). With these values given, the parameter α is chosen by noting that the marginal IRR is the discount rate at which the current observed check-off levy is optimal (i.e., equates marginal benefits with marginal costs) when the horizon is T years. Thus, using this relationship, α is calculated so that, given the current levy rate in effect, a time horizon of T generates a marginal IRR equal to the value estimated for the industry. For instance, as is illustrated in Figure 3, a levy rate of 1% is optimal if the time horizon is 50 years and the discount rate is 25% (or what is equivalent, the IRR is 25%).

If the horizon problem is an issue, it is because the farmers that are pivotal in levy determination do not have a time horizon equal to 50 years, but instead have time horizons that are shorter. At the same time, farmers can be expected to have discount rates that are less than 25%. Indeed, the belief that there is an underinvestment in R&D is based on this expectation, since the reason it is believed that underinvestment is occurring is because the IRR is much higher than the discount rates that would govern farmers' decision making.

Figure 3 provides a graphical method to examine the relationship and trade-off between time horizon and discount rate, and to determine whether the horizon problem is an issue in the determination of R&D. The first thing that is clear from Figure 3 is that if the pivotal farmer has a time horizon H that is shorter than T, then the levy chosen by the pivotal farmer will always be less than the levy chosen if the full time horizon T were considered. The magnitude of the shortfall in the levy depends on the value of H and the discount rate r. For instance, if the pivotal farmer had a horizon of 15 years, then with $r = 25\%$, the reduction in l^* from its optimal value of 1.0% is very small. However, if $r = 5\%$, then the reduction is quite large—for example, a value of $l^* = 3.68\%$ versus a maximum of over 5.0%.

Viewing the problem in this way, however, does not shed light on whether the horizon problem by itself can explain the observed underinvestment in R&D, or whether other factors are also playing a role. To examine this question, it is necessary to examine the current levy chosen in the industry. Specifically, two approaches can be used in this examination, both of which can be undertaken using Figure 3.

The first approach is to ask what might be a reasonable time horizon H for the pivotal farmer to have, and to find the optimal levy that corresponds to this time horizon. If this optimal levy is roughly equal to or less than the current levy, then this provides evidence that the time horizon is a key factor in the underinvestment in R&D. The second is to ask what time horizon $\hat{H}$ would be required to generate the current levy as an optimal levy. If this critical time horizon is roughly equal to, or greater than, the time horizon that could be reasonably assumed to govern producer decisions, then this would suggest that a shortened time horizon alone is able to explain underinvestment. Of course, since in both cases the farmer's discount rate affects the choice of the optimal levy, the analysis also has to consider this factor.

Using the first approach, suppose a reasonable time horizon for the pivotal farmer is 15 years. With this time horizon, Figure 3 indicates that the optimal levy is 1.75% in the case of a 15% discount rate, 2.5% in the case of a 10.0% discount rate, and 3.7% in the case of a 5.0% discount rate. Since all of these optimal levies are greater than the current levy rate of 1.0%, it could be concluded that the horizon problem alone is not the cause of the low levy rate, since, even with a shortened horizon (i.e., 15 years instead of 50), farmers would find it rational to select a levy rate that is larger than the one currently observed. Thus, assuming that the time horizon that was selected is reasonable, there must be other sources of the smaller levy and the resulting underinvestment.

Now consider the second approach. With a 15% discount rate, the current 1% levy is optimal if farmers have roughly an eight-year time horizon—that is, the critical time horizon is eight years. With a 10% discount rate, the critical time horizon is approximately seven years, and with a 5% discount rate, the critical time horizon is about six years. If these critical time horizons are less than what would be expected in the industry, then the horizon problem is not the only source of R&D underinvestment. Instead, other factors have to be looked at as sources of a smaller than optimal levy.

Mathematically, the starting point for both approaches is the determination of the parameter α. Recall that α is chosen so that for any given marginal IRR, for any given ϵ, and for any given ω_t function, the optimal levy at $H = T$ is equal to the current levy l_0. Given this, α can be calculated by rearranging Equation (22) to give

$$\hat{\alpha} = \frac{l_0}{\Phi(T, \mathrm{IRR})[1 - l_0(1 + \epsilon)]} \tag{25}$$

where $\Phi(T, \mathrm{IRR})$ is the value of Φ evaluated at $H = T$ and $r = \mathrm{IRR}$.[14]

The first approach involves using Equation (22) to determine the levy $\hat{l}^*$, where

$$\hat{l}^* = \frac{\hat{\alpha}\Phi(H, r)}{1 + \hat{\alpha}(1 + \epsilon)\Phi(H, r)} \tag{26}$$

and $\hat{\alpha}$ is given by Equation (25). Substituting in the expression for $\hat{\alpha}$ gives

$$\hat{l}^* = \frac{l_0\Phi(H, r)}{\Phi(T, \mathrm{IRR}) + (1 + \epsilon)l_0[\Phi(H, r) - \Phi(T, \mathrm{IRR})]} \tag{27}$$

The second approach involves finding the critical horizon $\hat{H}$ that solves Equation (27), with $\hat{l}^*$ replaced with the current levy l_0. Making the substitutions and simplifying results in

$$\Phi(\hat{H}, r) = \Phi(T, \mathrm{IRR}) \tag{28}$$

where $\Phi(\hat{H}, r)$ is the value of Φ evaluated at time horizon $\hat{H}$ and discount rate r.

The Iso-Φ Function

Equation (28) indicates that, for a given T and IRR, the critical time horizon depends only on r and the ω_t function, and is independent of the current levy rate l_0 and the supply elasticity ϵ (this conclusion follows because the Φ function depends only on r and ω_t). Conceptually, Equation (28) describes an iso-Φ curve—that is, the set of points in H and r space that generate a fixed value, $\Phi(T, \mathrm{IRR})$. The iso-Φ curve depends on the ω_t function, with different ω_t functions generating different iso-Φ curves. Given an iso-Φ

[14] Instead of calculating $\hat{\alpha}$ using the IRR, it is possible to use the BCR. From Equation (20), it follows that $\Phi(T, \mathrm{IRR}) = \Phi(T, r)/\mathrm{BCR}$. To use the BCR, substitute the term $\Phi(T, r)/\mathrm{BCR}$ for $\Phi(T, \mathrm{IRR})$ in Equation (25).

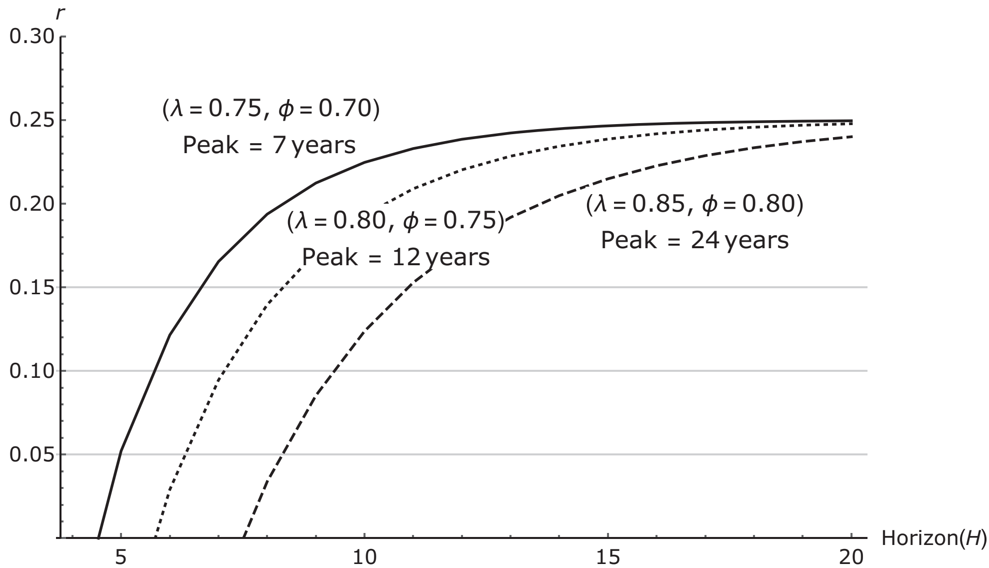

Figure 4. Iso-Φ curves for selected ω_t functions (IRR = 25%)

function, the determination of the critical time horizon $\hat{H}$ involves finding the value of H on the iso-Φ function that corresponds to a given r.

Figure 4 illustrates the iso-Φ curves for three different ω_t functions under the assumption that the marginal IRR is 25% and T is 50 years. The ω_t function associated with the uppermost curve ($\lambda = 0.75$, $\phi = 0.70$) has the marginal research benefits peaking at seven years. In the middle and lower curves—($\lambda = 0.80$, $\phi = 0.75$) and ($\lambda = 0.85$, $\phi = 0.80$)—the marginal research benefits peak at 12 years and 24 years, respectively. With a discount rate of 15%, the critical horizon is roughly 6.5 years if the marginal research benefits peak at seven years, roughly 8.25 years if the marginal research benefits peak at 12 years, and roughly 11.0 years if the marginal research benefits peak at 24 years. For any given set of parameters λ and ϕ, the area below and to the right of the iso-Φ shows the combinations of H and r for which $\hat{l}^* > l_0$—that is, the combinations of H and r for which the horizon problem by itself cannot explain the observed underinvestment.

Figure 4 provides a simple graphical way of determining the importance of the horizon problem in generating underinvestment in R&D. For any given discount rate r, the range of critical horizon values (given different ω_t functions) can be determined and compared to the time horizon expected to govern R&D decisions in the industry. For instance, if most farmers can be expected to have a time horizon of at least 15 years, then it can be concluded that the observed underinvestment in R&D cannot be explained only by the horizon problem, since even with a 15% discount rate, all the critical horizon values are less than this expected horizon value.

In the analysis that follows, the determination of $\hat{l}^*$ and $\hat{H}$ is used to examine whether the horizon problem alone is the cause of lower than optimal levies and lower than optimal R&D investment. Specifically, $\hat{l}^*$ and $\hat{H}$ are calculated numerically given different discount

Table 1. Parameter values used in the numerical analysis of l^*

Parameter	Assumed values					Source
Current levy (l_0)			**0.01**			SPG (2015)
IRR	0.20		**0.25**		0.30	Gray et al (2008)[a]
Discount rate (r)	0.05		**0.10**		0.15	Lence (2000) Bhaskar and Beghin (2007)
Time horizon (H)		10		15		Alston et al (2010) Beaulieu (2015)
λ, ϕ	(0.75, 0.70) Peak = 7 years		**(0.80, 0.75)** Peak = 12 years		(0.85, 0.80) Peak = 24 years	Alston et al (2010)
T			**50**			Alston et al (2010)
Supply elasticity (ϵ)		**2**		4		Davis et al (1987)
α			$\frac{l_0}{\Phi(50,\mathrm{IRR})[1-l_0(1+\epsilon)]}$			Equation (25)

Note. The bold values represent base values. The other values are used in the sensitivity analysis.
[a]The marginal IRR used in the analysis is based on the average IRR estimated by Gray et al (2008).

rates and different underlying parameters of the optimal levy and $\Phi(H, r)$ functions. The parameterization of the numerical analysis model is outlined in the next section, followed by the presentation of the numerical results.

NUMERICAL ANALYSIS

Model Parameterization

The parameterization of the model requires knowledge of the current levy l_0, the marginal IRR, the time horizon H, and the discount rate r. Also required are the parameters T, λ, and ϕ of the ω_t function, and the parameters α and β of the production function.

Table 1 presents the parameter values used in the numerical analyses, along with the source of the values that were chosen. The starting point for the numerical analyses is a set of base values—these are presented in bold. The other values listed are used in the sensitivity analysis.

The analysis in this paper focuses on the SPG.[15] In 1983, the pulse growers in Saskatchewan voted to establish a mandatory, nonrefundable check-off to fund R&D and market development. The check-off levy was initially set at 0.5%. The levy was increased to 0.75% in 2002, and then to the current 1.00% in 2003. The value of 1.00% is used as the current levy l_0.

[15]The Saskatchewan Pulse Crop Growers Association was formed in 1976. In 2001, Pulse Canada Research released a report demonstrating that there was an underinvestment in R&D for pulse crops and an increased check-off levy was required. This report lead to the increase in the levy rate. The major proportion of SPG's R&D investment is used to support pulse breeding programs at the Crop Development Centre at the University of Saskatchewan. The major output of the CDC is new seed varieties with higher yield and improved quality such as disease resistance, chemical tolerance, drought tolerance, and cold tolerance. Currently, more than 20,000 registered pulse producers grow pulses across Saskatchewan.

Gray et al (2008) estimate that the average IRR of the R&D funding is roughly 40%. Assuming the marginal IRR is less than the average IRR, the base value for the marginal IRR was chosen to be 25%, with alternative values of 20% and 30%.

Farmer discount rates are expected to be lower than the IRR. Using data from 1936–94, Lence (2000) estimated that the 95% confidence interval for the discount factor for U.S. farmers is (0.9512, 0.9720); these discount factors translate into discount rates in the range of 2.9–5.1%. Bhaskar and Beghin (2007) used a discount factor of 0.95 (i.e., discount rate of 5.3%) to examine the effects of price, yield, and policy uncertainty on optimal production decisions by risk-averse farmers. To be conservative (and thus more likely to show the existence of the horizon problem), the base value of the discount rate was chosen to be 10.0%, with alternative values of 5.0% and 15.0%.

The time horizon H is required for the determination of $\hat{l}^*$. Two values are chosen for the analysis—10 years and 15 years. Although some farmers may see themselves retiring in less than five years, a substantial proportion of farmers likely see themselves involved in farming for a longer period than this; thus, five years was deemed to be too low. If it is assumed that farmers leave farming at age 75 and that retirement corresponds to the end of their financial interest in farming, then any farmer 65 years of age or younger has a time horizon greater than 10 years. Roughly 85% of farmers fall into this age range. If the critical time horizon is 15 years, then any farmer 60 years of age or younger has a time horizon greater than this value; over 70% of farmers fall into this group (for the age distribution of farmers in Canada, see Beaulieu 2015). The assumption of time horizons of 10 and 15 years thus captures the argument expressed by Alston and Fulton (2012) that a supermajority of farmers would need to be in favor of the levy that is chosen in order for it to be adopted.

The base values for the parameters ϕ and λ were chosen to generate an ω_t distribution that peaked at 12 years, and that remained positive for 50 years. The values that generated this shape were $\lambda = 0.80$, $\phi = 0.75$, and $T = 50$. The choice of $T = 50$ ensures the results of the analysis are conservative; no alternative values for this parameter were chosen. The alternative values of λ and ϕ generate an ω_t function that peaks at seven years for the combination ($\lambda = 0.75$, $\phi = 0.70$) to 24 years for the combination ($\lambda = 0.85$, $\phi = 0.80$).[16]

The two remaining parameter values, α and β, determine the shape of the production function. As was shown earlier, β is a direct function of the supply elasticity, ϵ—specifically, $\beta = \epsilon/(1 + \epsilon)$. Davis et al (1987) estimate the supply elasticity of pulse crops (dry peas and lentils) in North America at 1.7; thus, the base value is assumed to be 2.0, with an alternative value of 4.0. The parameter α is determined using Equation (25).

Results

Tables 2 and 3 present the optimal levies $\hat{l}^*$ and the critical horizons $\hat{H}$, respectively, using the parameter values in Table 1. It should be noted the results in the two tables represent, in effect, different sides of the same coin. Thus, assuming r is the same, if it is found that

[16]An analysis of the impact of the parameters λ and ϕ indicated that the way in which they combined to determine the location of the peak year was the key determinant of the optimal steady-state levy l^* and critical horizon $\hat{H}$. With this knowledge, the numerical analysis focused on three different values for the peak year.

Table 2. Optimal steady-state levies ($\hat{l}^*$), in percentage terms, for selected values of the key model parameters

				$H = 10$ Discount rate			$H = 15$ Discount rate			$H = 50$ Discount rate		
IRR	λ	ϕ	Peak year	5%	10%	15%	5%	10%	15%	5%	10%	15%
								(%) $\epsilon = 2.0$				
20%	0.75	0.70	7	1.78	1.37	1.08	2.29	1.67	1.26	2.57	1.78	1.31
	0.80	0.75	12	1.62	1.19	0.90	2.69	1.81	1.26	3.94	2.31	1.47
	0.85	0.80	24	1.01	0.71	0.51	2.62	1.62	1.03	7.85	3.60	1.80
25%	0.75	0.70	7	2.23	1.73	1.37	2.86	2.09	1.58	3.20	2.24	1.65
	0.80	0.75	12	2.24	1.66	1.25	3.68	2.50	1.75	5.30	3.18	2.04
	0.85	0.80	24	1.66	1.17	0.84	4.17	2.63	1.70	11.37	5.63	2.92
30%	0.75	0.70	7	2.72	2.11	1.68	3.47	2.55	1.94	3.87	2.73	2.02
	0.80	0.75	12	2.95	2.20	1.67	4.77	3.28	2.31	6.77	4.14	2.70
	0.85	0.80	24	2.52	1.79	1.30	6.09	3.93	2.57	14.90	8.03	4.35
								$\epsilon = 4.0$				
20%	0.75	0.70	7	1.75	1.36	1.08	2.23	1.64	1.25	2.49	1.76	1.30
	0.80	0.75	12	1.60	1.19	0.90	2.60	1.78	1.25	3.71	2.25	1.46
	0.85	0.80	24	1.01	0.71	0.51	2.53	1.60	1.03	6.88	3.41	1.78
25%	0.75	0.70	7	2.18	1.70	1.36	2.75	2.05	1.56	3.06	2.18	1.63
	0.80	0.75	12	2.18	1.64	1.25	3.48	2.42	1.72	4.87	3.04	2.00
	0.85	0.80	24	1.64	1.17	0.85	3.92	2.55	1.67	9.37	5.14	2.81
30%	0.75	0.70	7	2.62	2.07	1.65	3.30	2.47	1.90	3.65	2.63	1.97
	0.80	0.75	12	2.84	2.15	1.65	4.43	3.13	2.25	6.05	3.89	2.60
	0.85	0.80	24	2.44	1.76	1.29	5.51	3.71	2.49	11.58	7.01	4.07

Note: Shaded cells denote parameter combinations that generate the horizon problem.

Table 3. Critical horizons ($\hat{H}$), in years, for the steady-state case and for selected values of the key parameters

				Discount rate		
IRR	λ	ϕ	Peak year	5%	10%	15%
					(Years)	
20%	0.75	0.70	7	5.91	6.94	8.77
	0.80	0.75	12	7.51	8.80	11.10
	0.85	0.80	24	9.98	11.67	14.68
25%	0.75	0.70	7	4.98	5.64	6.60
	0.80	0.75	12	6.29	7.11	8.30
	0.85	0.80	24	8.29	9.36	10.90
30%	0.75	0.70	7	4.32	4.79	5.41
	0.80	0.75	12	5.42	6.01	6.77
	0.85	0.80	24	7.12	7.86	8.84

Note: Shaded cells denote parameter combinations that generate the horizon problem.

$\hat{l}^*$ is greater than l_0 for a given value of H, then it will always be the case that the critical horizon $\hat{H}$ that makes l_0 optimal will be greater than the horizon H.

Table 2 also presents the optimal levy if the time horizon was the full 50 years. As was pointed out, the optimal levies for time horizons less than this—for example, 10 years and 15 years—will always be less than the optimal levies for a time horizon of 50 years. Thus, limited time horizons, if they are operational, always lower the levy chosen by farmers to some degree. As expected, the results in Table 2 indicate the extent of this reduction is greatest when the IRR and the peak year are large.

While it is important to recognize that shortened horizons reduce the optimal levy that is chosen, it is also important to understand the degree to which the levies presented in Table 2 deviate from the levy that is observed in the industry. If this deviation is substantial, then it suggests that other explanations besides reduced time horizons are required to understand why farmers have underinvested in R&D.

To explore this question, examine the optimal levies shown in Table 2 for time horizons of $H = 10$ and $H = 15$.[17] The shaded cells show the parameter combinations in

[17]Reading across any given row allows a straightforward determination of the impact of either the discount rate r or the horizon H on the optimal levy—that is, increasing r reduces the optimal levy, while increasing H increases the optimal levy. Similarly, for any given peak year, reading down a column shows the impact of the IRR or the supply elasticity on the optimal levy—higher IRRs result in larger optimal levies, while larger supply elasticities result in lower optimal levies. However, comparing different peak years by reading down a column requires some additional interpretation. The reason is that, for each different peak year, the value of $\hat{\alpha}$ is recalculated, which effectively changes the production function. As a consequence, the impact of the peak year on the optimal levy alone is not particularly insightful; instead, what is important is the size of the optimal levy relative to the current levy and to the optimal levy if $H = 50$. With respect to this latter comparison, as the peak year increases, the ratio of the optimal levy for time horizon $H = 10$ and $H = 15$ relative to the optimal levy for $H = 50$ falls—that is, the impact of the shortened time horizon is larger, the larger is the peak year.

which the horizon problem by itself can explain the observed underinvestment—in these cases, the optimal levies are less than or roughly equal to the current levy of 1%. As might be expected, the horizon problem alone can generate the current levy in cases where a low IRR (i.e., 20%) and a short time horizon (i.e., 10 years) are combined with either a high discount rate (i.e., 15%) or peak years for R&D that are relatively high. The horizon problem by itself can explain the observed underinvestment with higher IRRs (e.g., 25%), but only if the peak research results occur far in the future. Note that the magnitude of the supply elasticity has little impact on the presence of the horizon problem.

The same conclusions, of course, emerge from an examination of the values presented in Table 3. The horizon problem alone can generate a low levy in cases where a low IRR (i.e., 20%) is combined with either a high discount rate (i.e., 15%) or peak years for R&D that are relatively high. Higher IRRs can also generate situations where the horizon problem by itself can explain the observed underinvestment, but only if the peak research results occur far in the future.

To understand more fully the degree to which the horizon problem contributes to the choice of the current levy, Table 4 shows the percentage of the difference between the optimal levy when $H = 50$ (denoted $\hat{l}^*_{50}$) and the current levy that requires explanation by factors other than the horizon problem—that is, the numbers in Table 4 are determined by calculating $100(\hat{l}^*_H - l_0)/(\hat{l}^*_{50} - l_0)$, where $H \in \{10, 15\}$ and $l_0 = 0.01$. This percentage increases with an increase in H, an increase in the IRR, a decrease in the peak year, and an increase in the supply elasticity.

For short to moderate peak years (e.g., 7 years or 12 years), and for a time horizon of 15 years, the percentage of the gap between the current levy and the overall optimal levy $\hat{l}^*_{50}$ that is not explained by the horizon problem is well over 50%, and reaches a high of more than 80% when the IRR is in the range of 25–30%. Given that these parameter combinations might be expected to represent reasonable values given the age distribution of farmers, the estimated rates of return in the pulse industry, and the relatively applied nature of most of the pulse research, a significant proportion of the optimal levy gap remains to be explained by factors other than the horizon problem.

Four conclusions can be drawn from the above analysis. First, if farmers have shortened time horizons, then the optimal levy chosen is less than what would be chosen if time horizons were sufficiently long to capture all the benefits of R&D—that is, the horizon problem always has a downward impact on the levy that is chosen. Second, the horizon problem by itself cannot explain the observed underinvestment if discount rates are sufficiently low, even if the horizon is very short. Third, if the IRR is small and only somewhat larger than the discount rate that farmers use (e.g., a 20% IRR compared to a 15% discount rate), then the underinvestment is small in both absolute (i.e., the difference between l^*_{50} and l_0) and percentage terms.

Fourth, higher IRRs are associated with higher gaps between $\hat{l}^*_{50}$ and l_0 that require explanation by factors other than the horizon problem. Since the magnitude of the IRR typically serves as an indicator of the size of the underinvestment, the results in Tables 2 and 4 indicate that it is precisely when the underinvestment is the greatest (i.e., the IRRs are the largest) that the horizon problem is less likely to be the only, or even the major, cause of underinvestment.

Table 4. Percentage of the difference between the overall optimal levy ($\hat{l}^*_{50}$) and the current levy to be explained by factors other than the horizon problem for selected values of the key model parameters

				$H = 10$ Discount rate			$H = 15$ Discount rate		
IRR	λ	ϕ	Peak year	5%	10%	15%	5%	10%	15%
						(%)			
						$\epsilon = 2.0$			
20%	0.75	0.70	7	49.7	47.7	27.4	82.1	84.9	82.9
	0.80	0.75	12	21.1	14.7	−21.5	57.6	61.5	54.3
	0.85	0.80	24	0.1	−11.3	−61.2	23.6	23.8	3.9
25%	0.75	0.70	7	56.0	58.9	56.9	84.4	88.2	89.9
	0.80	0.75	12	28.8	30.3	24.4	62.2	68.8	71.7
	0.85	0.80	24	6.4	3.7	−8.1	30.6	35.3	36.2
30%	0.75	0.70	7	59.8	64.5	66.7	85.9	89.8	92.2
	0.80	0.75	12	33.8	38.1	39.5	65.4	72.5	77.5
	0.85	0.80	24	10.9	11.3	8.9	36.6	41.8	47.0
						$\epsilon = 4.0$			
20%	0.75	0.70	7	50.5	48.1	27.6	82.6	85.1	83.0
	0.80	0.75	12	22.1	15.0	−21.7	59.0	62.2	54.6
	0.85	0.80	24	0.1	−11.9	−62.8	26.1	24.8	4.0
25%	0.75	0.70	7	57.1	59.5	57.2	85.0	88.4	90.0
	0.80	0.75	12	30.6	31.2	24.8	64.2	69.7	72.1
	0.85	0.80	24	7.6	4.0	−8.5	34.9	37.4	37.1
30%	0.75	0.70	7	61.2	65.3	67.2	86.6	90.1	92.3
	0.80	0.75	12	36.4	39.6	40.3	67.9	73.8	78.1
	0.85	0.80	24	13.6	12.7	9.5	42.6	45.1	48.7

Note: Cells with negative values denote parameter combinations where the horizon problem generates an optimal levy $\hat{l}^*$ that is less than the current levy.

It is worthwhile to understand intuitively why the horizon problem is likely to be relatively less important as a source of underinvestment in R&D when IRRs are high. The key to this intuition is found in the iso-Φ curve, $\Phi(T, \text{IRR})$ (see Equation (28)). As was established earlier, if $\Phi(H, r) > \Phi(T, \text{IRR})$ for a particular combination of $H < T$ and $r < \text{IRR}$, then the horizon problem by itself cannot explain the observed underinvestment in R&D. The horizon H is lower than T because of the reduced horizon, while r is believed to be less than IRR given our knowledge of the discount rates that farmers are likely to use. Indeed, the conclusion that there is underinvestment in R&D follows from the belief that $r < \text{IRR}$. While the reduction of H compared to T has the effect of lowering $\Phi(H, r)$, making it likely that underinvestment is occurring as the result of a reduced horizon, the reduction in r relative to IRR has the effect of raising $\Phi(H, r)$, making it less likely that the shortened horizon by itself can explain the observed underinvestment. Thus, as the iso-Φ curve illustrates, the important feature is the rate at which a reduction in r can offset the reduction in H.

When the problem is understood in this way, it is clear why the horizon problem by itself cannot explain the observed underinvestment in R&D as the IRR increases. The reason is that the larger is the IRR, the larger is the difference between IRR and r, and hence the larger the reduction in H that can occur and still satisfy the iso-Φ relationship. Thus, it is precisely when the underinvestment is the largest (i.e., when IRR is very large) that it is most likely that the horizon problem by itself cannot explain the observed underinvestment in R&D.

However, if the underinvestment cannot be fully explained by a shorter time horizon, then additional causes of the underinvestment have to be examined. This is particularly the case when it is recognized that a key assumption in the model is that farmers only rent the land; they do not own it. Land ownership effectively lengthens the time horizon, since the future benefits of the R&D can be expected to be capitalized, at least in part, into land values. Land owners can realize this capitalization even if they sell their land tomorrow. Given the prevalence of land ownership among farmers (nearly 60% of the total land farmed in Canada is owned, see Statistics Canada 2016), combined with the age distribution outlined above, it is likely that a large proportion of farmers will have a horizon greater than the critical values presented in Table 3 or that are assumed for the analysis in Table 2. As a consequence of land ownership, it can be expected that the horizon problem is even less likely by itself to explain the observed underinvestment, even when IRRs are low and the peak benefits do not occur for some time. An examination of other factors that might lead to underinvestment is the subject of the next section.

OTHER CAUSES OF UNDERINVESTMENT

As was outlined in the Introduction, a number of other causes of underinvestment have been identified in the literature on collective organizations, including the free-rider problem, the portfolio problem and the principal–agent problem. In addition, there are other possible causes of underinvestment that are not linked to the nature of the incentives created in a producer association, but instead are linked to the manner in which individuals make decisions. In this section, we will consider the impact of the free-rider problem and risk aversion, as well as two concepts from behavioral economics, namely hyperbolic discounting and tax aversion. Since a full analysis of these problems is beyond the scope of this paper, the discussion in this section focuses on laying out the basic economic intuition of the impact of these factors and illustrating how they could be examined within the framework developed earlier.

Before examining these problems, it is useful to consider the magnitude of the impact these problems would have to generate to make up the gap presented in Table 4. To understand this magnitude, recall that Equation (20) presents the expression for marginal cost equals marginal benefit. Suppose a factor ρ is added to the marginal benefit side of the equation to give

$$Py_0^* = \rho \frac{\alpha(1-\beta-l_0^*)(1-\bar{l})}{(1-\beta)(1-l_0^*)\bar{l}} Py_0^* \Phi(H,r) \tag{29}$$

If $\rho < 1$, then it means that either marginal benefits are reduced from what they would otherwise be or that marginal costs are increased. Thus, ρ can be used to capture the impact of other factors besides the horizon problem. For instance, if a particular factor (e.g., risk aversion) results in a reduction of the marginal benefits by 50%, then $\rho = 0.5$.

The addition of ρ results in the following expression for $\hat{l}^*$

$$\hat{l}^* = \frac{\hat{\alpha}\rho\Phi(H, r)}{1 + \hat{\alpha}\rho(1 + \epsilon)\Phi(H, r)} \tag{30}$$

With the above expression, it is possible to determine ψ, the elasticity of $\hat{l}^*$ with respect to ρ, where

$$\psi = \frac{\partial \hat{l}^*}{\partial \rho}\frac{\rho}{\hat{l}^*} = \frac{\hat{l}^*}{\rho\alpha\Phi(H, r)} \tag{31}$$

The elasticity ψ gives the percentage reduction in the marginal benefit that would generate a given reduction in the optimal levy. Thus, ψ can be used to determine how large the impact of other factors besides the horizon would have to be to produce the current levy l_0 as the optimal levy.

Table 5 shows the percentage change that would have to occur in $\hat{l}^*$ to make $\hat{l}^* = l_0$, as well as the values of ψ, for selected values of the model parameters. The values for ψ have been calculated assuming $\rho = 1$. The percentage change required in $\hat{l}^*$ range in value from over 80% to less than zero (for those instances where $\hat{l}^* < l_0$), while the elasticities ψ are all under 1.0.

Taken together, the values in Table 5 allow a determination of the magnitude of the reduction in ρ required to reduce $\hat{l}^*$ from the values presented in Table 2 to the current observed value of l_0. For instance, consider the case where the IRR is 25%, the peak year is 12, H is 15 years, and r is 15%. To obtain the 42.7% reduction in $\hat{l}^*$ that would be required to make $\hat{l}^* = l_0$, a reduction in ρ of $42.7/0.95 = 44.9\%$ is required. Put differently, if other factors besides the horizon problem had the effect of cutting the marginal benefit by 44.9%, then the current optimal levy of 1% can be explained.

As will be discussed in the remainder of this section, the determination of ρ (or some more complex discount term) requires substantial additional modeling of the other factors besides the horizon problem that could affect the levy decision. However, taken together, it would appear reasonable to expect that, at least in some cases, these other factors could reduce the marginal benefit by the percentage necessary to explain the underinvestment that is observed. Of course, if the horizon problem is not an issue because of the high degree of land ownership, then the magnitude of the gap that requires explanation is substantially larger.

Free-Rider Problem

The free-rider problem in producer organizations manifests itself in two ways that are important for the analysis of the optimal levy choice. The first considers whether the pivotal farmer is likely to free ride, while the second considers whether the other members are likely to free ride. If payment of the levy is compulsory for farmers, as is the case in the SPG examined in this paper, then neither the pivotal farmer nor the other members are able to opt out of paying the levy. Thus, the free-rider problem is not expected to be an issue and the analysis carried out above is relevant.

Table 5. Percentage change required in $\hat{l}^*$ for $\hat{l}^* = l_0$, and elasticity ψ for selected values of the key model parameters

				$H = 10$ Discount rate			$H = 15$ Discount rate		
IRR	λ	ϕ	Peak year	5%	10%	15%	5%	10%	15%
				Percentage change required for $\hat{l}^* = l_0$					
20%	0.75	0.70	7	43.8	27.2	7.8	56.3	40.0	20.3
	0.80	0.75	12	38.2	16.2	−11.3	62.9	44.7	20.4
	0.85	0.80	24	0.8	−41.3	−97.1	61.8	38.2	3.0
25%	0.75	0.70	7	55.2	42.2	27.0	65.0	52.2	36.8
	0.80	0.75	12	55.4	39.7	20.2	72.8	59.9	42.7
	0.85	0.80	24	39.7	14.6	−18.5	76.0	62.0	41.1
30%	0.75	0.70	7	63.2	52.7	40.4	71.1	60.8	48.3
	0.80	0.75	12	66.1	54.5	40.1	79.1	69.5	56.8
	0.85	0.80	24	60.3	44.2	23.0	83.6	74.6	61.2
				Elasticity (ψ)					
20%	0.75	0.70	7	0.95	0.96	0.97	0.93	0.95	0.96
	0.80	0.75	12	0.95	0.96	0.97	0.92	0.95	0.96
	0.85	0.80	24	0.97	0.98	0.98	0.92	0.95	0.97
25%	0.75	0.70	7	0.93	0.95	0.96	0.91	0.94	0.95
	0.80	0.75	12	0.93	0.95	0.96	0.89	0.93	0.95
	0.85	0.80	24	0.95	0.96	0.97	0.87	0.92	0.95
30%	0.75	0.70	7	0.92	0.94	0.95	0.90	0.92	0.94
	0.80	0.75	12	0.91	0.93	0.95	0.86	0.90	0.93
	0.85	0.80	24	0.92	0.95	0.96	0.82	0.88	0.92

Note: Cells with negative values denote parameter combinations where $\hat{l}^* < l_0$.

However, if the levy takes a mandatory refundable form, as is the case in many producer associations in Canada, then the possibility exists that producers can ask for a refund of the levy they have paid.[18] While exact figures are not available, it is known that only a small fraction of the producers operating under mandatory refundable check-offs ask for a refund—somewhere in the range of 5.0–8.0%. Thus, although free-riding is not widespread, it is present. As a result, the possibility of free riding has to be taken into account in terms of whether the pivotal farmer will ask for a refund and whether the other members will ask for a refund.

If the pivotal farmer asks for a refund (and thus does not pay the levy), then the marginal cost to her of the levy is zero; alternatively, if she pays the levy, then the marginal cost is Py_0^* as shown in Equation (11). If the marginal cost is zero, then the pivotal farmer has an incentive to introduce a higher levy than would be the case if she pays the levy.

[18]Most producer associations in western Canada that operate levies and undertake R&D use a mandatory refundable levy. Prominent examples include the Saskatchewan Canola Development Commission, the Saskatchewan Wheat Development Commission, and Alberta Barley. Examples are also found in other crops such as mustard and flax, and in other areas, such as cattle and beekeeping.

Thus, free riding by the pivotal farmer is expected to result in a higher levy and greater investment, providing the other members do not free ride.

In choosing the levy, the pivotal farmer would, however, also look at the impact of the levy on the rest of the members in the association and in particular on the percentage that free ride. A reasonable behavioral assumption is that a higher levy would increase the proportion of the membership that free rides. As more members free ride, the marginal benefit of the levy is lowered, since a given levy now generates less R&D and a lower knowledge stock. At the same time, if the pivotal farmer is also free riding, then her output is greater, which results in a higher marginal benefit. One of the questions for future research is the determination of the relative magnitude of these effects and their impact on the levy that is chosen.

Risk Aversion

Since farmers are often assumed to be risk averse, the presence of risk has the potential to affect the optimal levy choice. There are at least two routes through which the impact of risk can be felt. The first route involves the impact of risk on production decisions and the benefits that flow from these decisions. Since risk is expected to lower profitability and utility, risk has the effect of reducing the benefits received from any given level of the industry knowledge stock. This alteration in benefits lowers the marginal benefits from changes in the knowledge stock, thus lowering the incentive for R&D.

The second route by which risk affects the choice of the levy is via the production of the knowledge stock. The analysis above assumed that the creation of the knowledge stock from R&D expenditures occurred without risk. However, since R&D is inherently risky, risk-averse farmers can be expected to limit R&D expenditures in an effort to limit the risk that is incurred.

While both the forms of risk discussed can be expected to lower the optimal levy, the presence of risk could provide greater incentives for R&D if the R&D acts to reduce production risk (e.g., by increasing drought or disease tolerance). The magnitude of these various impacts cannot be determined without formal modeling of the various behavioral impacts. This modeling would, of course, have to be quite specific about the nature of the risk that is present and the effect of R&D on this risk. The model developed in this paper provides a good framework on which to undertake this analysis, since it offers the ability to separate out the impact of the horizon problem from risk aversion, as well as to separate these two factors from the free-rider problem.

Hyperbolic Discounting and Tax Aversion

Hyperbolic discounting and tax aversion differ from the other factors considered in this paper because both involve some form of nonrational behavior on the part of producers. Hyperbolic discounting is classified as nonrational because it induces dynamically inconsistent preferences (Laibson 1997); in contrast, the exponential discounting that is traditionally assumed does not produce such behaviors. Tax aversion—or the unwillingness of people to pay taxes regardless of the benefits they generate—is viewed as nonrational because people that exhibit such behavior fail to take into account logically relevant information and thus do not maximize their economic benefits (McCaffery and Baron 2006; Chetty et al 2009; Kallbekken et al 2011). As the articles cited show, the empirical evidence for both types of behavior is strong.

While a full treatment of these two issues requires substantial additional work, the main effects can be easily traced out. As Laibson (1997, 1998) shows, hyperbolic discounting involves the heavy discounting of costs and benefits that are relatively near in time and a much lower discounting of costs and benefits that occur well into the future. If the periods of heavy discounting correspond more or less to the horizon of the pivotal member, then the impact of hyperbolic discounting is to lower the marginal benefit associated with increasing the levy. This lower marginal benefit translates into the selection of lower levies. Since hyperbolic behavior involves nonrational behavior, the chosen levies cannot be said to be rational in the normal sense of the word. However, given the way in which the producer views the world and the benefits she sees, she finds it desirable to select a lower levy.

Tax aversion has a similar effect. As McCaffery and Baron (2006) and Chetty et al (2009) have shown, taxes that are highly salient have a much bigger negative impact on behavior than taxes that are hidden in some way or the other. If check-off levies are viewed by farmers as being highly salient, then it is reasonable to expect that they could have two effects. The first would be to reduce the use of the variable input x_t, which in turn reduces the benefits that are obtained from this input use and thus the benefits obtained from the industry knowledge stock. The second effect would be to affect the choice of the levy at the time when this decision is being made. The mechanism by which this effect would occur is likely through an increase in the marginal cost of the levy, which in turn would lead to a lower levy being chosen.

An avenue for future research would be to incorporate behavioral aspects, such as tax aversion and hyperbolic discounting, into a model that could also account for the possibility of shortened time horizons, free-rider problems and risk aversion. Such work requires the clear separation of risk preferences from time preferences (for how this can be done and the benefits that it provides, see Andersen et al 2008).

CONCLUDING COMMENTS

The analysis in this paper focused on the horizon problem as the source of the underinvestment in agricultural R&D that occurs in producer associations. To examine the importance of the problem, the paper developed a theoretical model that derived the optimal levy a producer group would choose given the nature of the production technology and the pattern of R&D benefits. In addition to the exploration of the horizon problem carried out in this paper, the model provides a framework for examining other factors likely to influence levy rates and hence R&D spending.

The key conclusion of the analysis is that the horizon problem is generally not likely to be the key source of the underinvestment in R&D when this underinvestment is large (i.e., when the IRR to R&D is large). The reason for this conclusion lies in understanding the relationship between $\Phi(H, r)$ and $\Phi(T, \text{IRR})$. The expression $\Phi(T, \text{IRR})$ gives the value of the cumulative discounted marginal impact on the knowledge stock of a dollar change in R&D expenditures in period zero, where the marginal impacts are summed over all T periods that the R&D has an impact and where the discounting is done at the IRR. In contrast, the expression $\Phi(H, r)$ gives the value of the cumulative discounted marginal impact on the knowledge stock of a dollar change in R&D expenditures in period zero, where the marginal impacts are summed over the pivotal producer's H period time horizon and where the discounting is done at the producer's discount rate r. If $\Phi(H, r) > \Phi(T, \text{IRR})$, then it can be concluded that the horizon problem is not the only reason for the low levy and the underinvestment in R&D, and that other factors must also be at work.

Although it is true that H is less than T, thus decreasing the value of $\Phi(H, r)$ relative to $\Phi(T, \text{IRR})$, it is also true that the discount rate that farmers use to discount future benefits is less than the IRR, which has the effect of increasing $\Phi(H, r)$. In other words, while producers may have a time horizon that is shorter than the life of the R&D, they also can be expected to discount the future less strongly than is suggested by the IRR that have been calculated. While the first of these factors reduces the levy that is chosen, the second of these factors increases the levy. If the second factor is sufficiently strong, then the horizon problem alone cannot explain the underinvestment that has occurred.

Seen in this light, it is clear that the larger is the IRR, the less likely it is that the horizon problem by itself can explain the observed underinvestment. Thus, the results of this paper indicate that the standard intuition that large IRRs are indicative of significant horizon problems is incorrect. In fact, it is precisely when IRRs are large that it can be expected that the horizon problem is less of an issue. The reason is that the larger is IRR, the greater is the difference between IRR and the farmers' discount rate r. The greater is the difference between IRR and r, the greater is the difference that can exist between T and H while still ensuring that $\Phi(H, r) > \Phi(T, \text{IRR})$.

To reach the above conclusion, the analysis required a number of key assumptions. In particular, the analysis assumed that farmers were profit maximizing and risk neutral. It also assumed that farmers were rational, in the sense that they maximized the sum of discounted profits, where discounting was done using exponential discounting, and in the sense that they did not exhibit an aversion to taxes. It was also assumed free riding did not occur, and that the manager and employees of the producer association followed the objectives of the farmers.

The relaxation of the above assumptions can be expected to generate results that differ from those presented in this paper. Specifically, risk aversion, hyperbolic discounting, and tax aversion can all be expected to generate lower levy rates, since all three modifications have effects on marginal cost or marginal benefit that unambiguously lowers the levy rate. While the free-rider problem may be a source of underinvestment in mandatory refundable schemes, its impact depends on whether the pivotal farmer is free riding or not. To determine if together the above modifications produce predicted levies that are roughly consistent with the levies that have been observed, the model developed in this paper would need to be expanded. This work is the subject of future research.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table A1. Optimal steady-state levies ($\hat{i}^*$), in percentage terms, for selected values of the key model parameters and a downward sloping demand curve ($\eta = 2.0$).
Table A2. Difference in the steady-state levies ($\hat{i}^*$) for selected values of the key model parameters; downward sloping demand curve case minus fixed price case (positive values indicate the downward sloping demand curve generates higher levies).