End-Point versus Point of Sale Levying of Plant Breeding Royalties: An Economic Analysis using Optimal Control Theory

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Abstract

Intellectual property rights for commercial crops have become increasingly controversial as plant breeders have sought to protect their investment through licensing and royalties, and farmers, in particular ecologically-oriented farmers, have promoted seed-saving as a conservation measure. Plant breeders have argued that seed saving reduces sales to breeders and that the imposition of royalties is necessary to maintain sales and to compensate them for the intellectual property invested in commercial varieties. These issues are explored here. In this paper, an optimal control model of seed purchase decisions in the presence of seed saving is developed. The model is used to analyze the impact of both point of sale royalties and end-point royalties on seed puchase decisions. The two approaches to levying royalties are then compared and policy conclusions drawn.

JEL Classification: Q18,Q12,D92

1 Introduction

The issue of plant breeders' rights versus the farmer's privilege to save seed is a controversial one. The farmer's perspective is neatly summarized by Woodhouse (1933) [13, pp. 106-107]:

> The production of seed has been overlooked to a large extent. When producing the seed necessary to sow on the farm, it is also possible to produce an additional amount of seed sufficient to pay all costs in connection with the harvesting, and the seed used on the farm costs practically nothing. There are many grasses and clovers which are adapted to certain sections that will not produce seed crops under those particular conditions. It is entirely possible to use only such grasses and clovers as will produce a seed crop in the vicinity in which they are grown, thus making it unnecessary to buy from outside sources.

The statement that farm seed "costs practically nothing" and that it may be "unnecessary to buy from outside sources" is precisely what disturbs today's plant breeder's the most. The time, effort, money and resources devoted to plant breeding today are enormous and without doubt farmers have benefited from this through increased yields and profitability. Plant breeders' rights are therefore protected by law. However, legislation also protects the farmer's privilege to save seeds so neatly summarized by L.H.Woodhouse.

The regulation of breeders' rights for plant breeding is governed by the "International Convention of the Protection of New Varieties of Plants" 1991. The governing body responsible for co-ordinating implementation of the convention is the "international union for the protection of new varieties of plants" (UPOV). UPOV is an international organization based in Geneva.

Details of plant breeders' rights are subject to the legislation of individual countries. However, member countries attempt to craft legislation that is compliant with the UPOV convention.

In the United States plant breeder rights are regulated by the "Plant Variety Protection Act Amendments of 1994". Paragraph 113 of the Act states:

> Except to the extent that such action may constitute an infringement under subsections (3) and (4) of section 111, it shall not infringe any right hereunder for a person to save seed produced by the person from seed obtained, or descended from seed obtained, by authority of the owner of the variety for seeding purposes and use such saved seed in

> the production of a crop for use on the farm of the person, or for sale as provided in this section. A bona fide sale for other than reproductive purposes, made in channels usual for such other purposes, of seed produced on a farm either from seed obtained by authority of the owner for seeding purposes or from seed produced by descent on such farm from seed obtained by authority of the owner for seeding purposes shall not constitute an infringement. A purchaser who diverts seed from such channels to seeding purposes shall be deemed to have notice under section 127 that the actions of the purchaser constitute an infringement. (7 U.S.C. 2543.)

Consequently, seed-saving is protected by law. The situation rearding how to levy royalties differs however from country to country. So for example Australian plant breeders' rights are governed by the "Plant breeders rights act 1994" (PBR). Section 17 of this act states:

> Conditioning and use of farm saved seed does not infringe PBR (1) If: (a) a person engaged in farming activities legitimately obtains propagating material of a plant variety covered by PBR either by purchase or by previous operation of this section, for use in such activities; and (b) the plant variety is not included within a taxon declared under subsection (2) to be a taxon to which this subsection does not apply; and (c) the person subsequently harvests further propagating material from plants grown from that first-mentioned propagating material; the PBR is not infringed by: (d) the conditioning of so much of that further propagating material as is required for the persons use for reproductive purposes; or (e) the reproduction of that further propagating material. (2) The regulations may declare a particular taxon to be a taxon to which subsection (1) does not apply.

Current controversy in Australia should be interpreted as pressure by plant breeders to change section 17 of the act. An equivalent provision is not contained in the UPOV convention. Therefore this should be interpreted as a provision in the Australian act that was designed by legislators to protect farmers engaged in seed saving activity.

Canadian legislation includes "The Plant Breeders' Rights Act" (PVP Gazette 62 Published: April) 1991 and the "Regulations Respecting Plant Breeders' Rights" (PVP Gazette 69 Published: November) 1992. Canada's solution to the seed saving issue differs quite markedly from the Australian solution. The paragraph of the Canadian "plant breeder's rights act 1991", relating to compulsory licenses states that:

> (1) Subject to this section and the regulations, the Commissioner shall, on application by any person, where the Commissioner considers that it is appropriate to do so, confer on the person in the form of a compulsory licence rights to do any thing that the holder might authorize another person to do pursuant to paragraph 5(1)(d). (2) In disposing of an application for, and settling the terms of, a compulsory licence pursuant to this section in relation to any plant variety, the Commissioner shall endeavour to secure that (a) the plant variety is made available to the public at reasonable prices, is widely distributed and is maintained in quality; and (b) there is reasonable remuneration, which may include royalty, for the holder of the plant breeders rights respecting the plant variety.

Paragraph 5(1) states:

> (1) Subject to this Act, the holder of the plant breeders rights respecting a plant variety has the exclusive right (a) to sell, and produce in Canada for the purpose of selling, propagating material, as such, of the plant variety; (b) to make repeated use of propagating material of the plant variety in order to produce commercially another plant variety if the repetition is necessary for that purpose; (c) where it is a plant variety to which ornamental plants or parts thereof normally marketed for purposes other than propagation belong, to use any such plants or parts commercially as propagating material in the production of ornamental plants or cut flowers; and (d) to authorize, conditionally or unconditionally, the doing of an act described in paragraphs (a) to (c).

The latter has a counterpart in Australian law and is derived directly from the UPOV convention. However, under Canadian law the seed saving issue is addressed somewhat less directly. The comissioner of plant breeders' rights has the following powers with respect to seed saving according to section 5(3) and 5(4) of the Canadian act:

> Implications
>
> (3) A sale of propagating material in the exercise of any exclusive right conferred by subsection (1) does not imply that the seller authorizes the purchaser to produce, for the purpose of selling, propagating material as such but, subject to any terms or conditions imposed by the seller, the sale implies that the seller authorizes the purchaser to sell anything sold, in that exercise of the exclusive right, to the purchaser.

> Royalty
>
> (4) Without limiting the generality of paragraph (1)(d) and without prejudice to any rights or privileges of the Crown, where authority is conferred subject to conditions pursuant to that paragraph, whether or not the holder of the plant breeders rights is Her Majesty in right of Canada or a province, the conditions may include a requirement to pay royalty to the holder.

Consequently, Canadian legislation according to 5(3) allows farmers to save seed and 5(4) allows the levying of royalties but does not define how the royalty is to be levied.

So while Australian law explicitly protects seed saving, in Canada the protection of seed saving is implied. The question as to whether a POS or end-point regime should be used is open as far as the legislation in both countries goes.

Consequently, in all three countries seed saving is protected by law. However, the details of the royalty scheme are not legislated. Only in Australia has an end-point royalty scheme been adopted. The details are however contractual, so for example, seeds purchased from the Australian Wheat Board (AWB Ltd.) incur an end-point royalty that may be paid in one of two ways (http://www.awb.com.au/growers/awbseeds/ endpointroyalties/paymentofendpointroyalties/):

> A grower who purchases a AWB Seeds variety has an enduring contractual obligation to pay an End Point Royalty on all production, except grower saved seed, and this can be done in either of two ways; Option 1 Deliver directly to one of the authorised Collection Marketers (listed below) - the End Point Royalty (GST inclusive) is automatically deducted by the Collection Marketer upon payment for the grain, and a Tax Invoice prepared and sent to the grower. Option 2 Growers can choose to market their commodity grain to any third party (ie non Collection Marketer), subject to payment of the End Point Royalty to AWB Seeds. In this case, the grower must make the End Point Royalty payment (GST inclusive) directly to AWB Seeds within 30 days after day of sale. AWB Seeds will return a Tax Invoice to the grower.

This scheme corresponds to our case II below in which an end-point royalty is levied on sold grain. In the UK however, royalties are also collected on farm-saved seed, which necessitates harvest monitoring. UK practice is for farmers to self-report saved seed to the the British Society of Plant Breeders

(BSPB). The model presented here does not distinguish between who monitors but simply assumes that there may be innacuracies in the reporting or monitoring of total harvest. A further difference is that in the UK a lower royalty is applied to farm-saved seed than to sold grain. Consequently, case III presented here corresponds roughly to the UK situation, but differs in some of the details.

Despite, progress in a number of countries in introducing royalty payments on seed, there has nevertheless, been considerable lobbying for changes to the current system of royalties in all countries. In Canada for example the 2004 Seed Sector Review, stated:

> There was no clear picture as to what could be done to effectively collect royalties on farm saved seed, if in the future this is the direction that the industry chooses to go. Suggestions were made that royalties could be collected through elevators or seed processors or through CWB contract programs. In order to collect royalties, the variety would need to be identified (common seed carry the variety name) or else royalties from farm saved seed could be allocated on the basis of market shares in pedigreed seed sales. Allowing variety names on common seed would have implications to the seed certification system and identity preserved programs.

This has been interpreted by some as a recommendation to introduce a royalty scheme to recover the costs of research and development of seed varieties in order to finance investment into plant breeding research. In terms of maintaining the balance between "farmer's privilege" and "breeders' rights", proper design of a royalty scheme is crucial. Previous studies have not directly, addressed this issue.

Much of the literature has been in the nature of review articles or broad policy appraisals. Lesser (1997) [12] provides an overview of issues around intellectual property and plant breeding. Kingwell and Watson [7] discuss in broad policy terms the possible impact of end-point royalties on Australian agriculture, Lindner (2004) [8] discusses the trend towards privatisation of plant breeding in Australia and around the world, but does so again in terms of broad policy. Kingwell (2005) [9] surveys institutional changes and changes in property rights in australian plant breeding, Kingwell (2001) [10] provides the first detailed analysis of plant breeding royalties in the forms of a static model of farm decision making under risk.

Kingwell considers four possible royalty scenario's: i) a flat charge, ii) a flat charge per tonne, iii) an ad valorem royalty on production and iv) a profit based royalty. The focus of Kingwell's contribution is on the moral hazard aspects of the problem. In this paper the intertemporal incentive effects of various royalty scenarios are explored with a focus on how seed-saving and royalties interact to have an impact on the demand for seed.

Seed-saving is inherently an activity that links farmer decision making over time. If sufficient seed is saved, future demand for new seed will be reduced and vice versa. The intertemporal impact of plant breeding royalties on farm seed purchase decisions can not therefore be ignored. These issues are studied in this paper using an optimal control model of seed saving. This is used to analyse the incentive effects of different royalty schemes. A point of sale royalty scheme is compared to two types of end-point royalty scheme one based on grain sales and one based on monitoring of harvested grain. The three schemes are then compared.

Section 2 presents the basic model of farm profit with seed storage costs incorporated. Section 3 derives the steady-state demand for new seed using a discrete-time optimal control model of seed-saving in the context of a point of sale royalty scheme. Section 4 proceeds similarly but examines the impact of an end-point royalty scheme based on the amount of grain sold. Section 5 examines an end-point royalty scheme in which monitoring of the harvest is used as the basis for levying the royalty. Section 6 compares the incentive effects of the different schemes and section 7 concludes.

2 The Model

An optimal control model of the intertemporal impact of levying plant breeding royalties on farms is presented. The model is presented in three parts. Firstly, the impact of point of sale levying of royalties is analysed before moving on to the impact of end-point royalties. There are two ways of implementing end-point royalties, either on sold grain or on harvested grain. A comparison of the three approaches is then made in terms of intertemporal incentives.

Consider first the case of a point of sale levy. Farm profit in each period is given by

$$\Pi_t = p(1-\theta)f(x_t+b_t) - (c_1+r)b_t - c_2\theta f(x_t+b_t)$$

or revenue from the sale of grain minus the cost of purchasing seed plus the royalty r minus the cost of storing seed from one period to the next $c_2\theta f(x_t+b_t)$.

The variables and constants used are as follows:

- p is the sale price of grain

- θ the proportion of grain retained for seed into the next period.
- x_t the amount of seed available from carryover.
- b_t the amount of seed purchased each period.
- $f(x_t + b_t)$ the production function for grain.
- c_1 the price of seed.
- r royalties.
- θ proportion of seed saved.
- c_2 the cost of storing grain from one period to the next, one can think of this as the amortization rate of a silo, alternatively, storage costs may be determined using the cost function from inventory control theory, such as holding costs in the EOQ-model.

Further to the point about the costs of grain storage, it is assumed in what follows that θ has been determined by solving an intertemporal EOQ inventory model so that the proportion of seed saved is determined by minimizing total costs to determine the optimal seed inventory policy.

Two cases are distinguished for levying royalties: i) levying at point of sale and ii) levying at the end-point, known as an end-point royalty (EPR). Point of sale royalties are considered first.

An additional assumption that will be made is that open-pollination seeds which are considered here, are perfect substitutes for hybrid varieties and vice versa in any given period. Hybrid varieties may be propagated but the resultant seed has undesirable characteristics and is generally not commerically valuable. These cannot therefore be saved and play no role in the dynamical analysis developed in this paper as long as open-pollination and hybrid seed varieties are assumed to be perfect substitutes and that the crop production technology is additively separable in open-pollination and hybrid seed, then the role of hybrid seed may be ignored. The key point is that while these two seed varieties are clearly not intertemporally perfect substitutes from an intratemporal perspective this assumption is not overly restrictive. While one could drop this assumption this complicates the analysis and does not contribute to the key question addressed in this paper, which is which royalty structure is preferable in terms of protecting breeders rights.

3 Point of sale royalties

Farmers maximize the discounted profit stream by choosing the amount of seed to purchase b_t in each period t.

$$\max_{b_t} \sum_{t=0}^{\infty} \rho^t \left\{ p(1-\theta)f(x_t + b_t) - (c_1 + r)b_t - c_2\theta f(x_t + b_t) \right\}$$

It is assumed that seed is carried over from each harvest in a fixed proportion

$$x_{t+1} = \theta f(x_t + b_t)$$

This assumption appears somewhat restrictive, but is necessary for analytical tractability. In essence, it is assumed that our time horizon is short enough that seed storage capacity does not change through investment in additional capacity, but long enough that saved seed reaches a steady-state. In terms of analysing the impact of royalties on seed purchasing decisions assuming a fixed rate of carryover of seed does not however, appear to be important. So although it may be desirable to relax this assumption it is not absolutely critical.

A current value Hamiltonian for the above problem is given by

$$\tilde{H} = p(1-\theta)f(x_t + b_t) - (c_1 + r)b_t - c_2\theta f(x_t + b_t) + \rho\lambda_{t+1}\left[\theta f(x_t + b_t) - x_t\right]$$

Pontryagin's maximum principle gives the following

$$\frac{\partial \tilde{H}}{\partial b_t} = p(1-\theta)f^{'}(x_t+b_t) - (c_1+r) - c_2\theta f^{'}(x_t+b_t) + \rho\lambda_{t+1}\theta f^{'}(x_t+b_t) = 0 \quad (1)$$

$$\rho\lambda_{t+1} - \lambda_t = -\frac{\partial \tilde{H}}{\partial x_t} = -\left[p(1-\theta)f^{'}(x_t + b_t) - c_2\theta f^{'}(x_t + b_t) + \rho\lambda_{t+1}\left[\theta f^{'}(x_t + b_t) - 1\right]\right] \quad (2)$$

From (1) and (2) one obtains

$$\rho\lambda_{t+1}\theta f^{'}(x_t + b_t) - \lambda_t = c_2\theta f^{'}(x_t + b_t) - p(1-\theta)f^{'}(x_t + b_t) \quad (3)$$

In steady-state one-obtains from (3) (with time subscripts now suppressed):

$$\left[\rho\theta f^{'}(x + b) - 1\right]\lambda = c_2\theta f^{'}(x + b) - p(1-\theta)f^{'}(x + b) \quad (4)$$

On rearranging (4) notice that:

$$\lambda = \frac{c_2\theta f^{'}(x+b) - p(1-\theta)f^{'}(x+b)}{\rho\theta f^{'}(x+b) - 1} \tag{5}$$

then substitute (5) into the first-order condition (1) to obtain:

$$\begin{gathered} p(1-\theta)f^{'}(x+b) - (c_1+r) - c_2\theta f^{'}(x+b) + \\ \rho\left[\frac{c_2\theta f^{'}(x+b) - p(1-\theta)f^{'}(x+b)}{\rho\theta f^{'}(x+b) - 1}\right]\theta f^{'}(x+b) = 0 \end{gathered} \tag{6}$$

or

$$p(\theta-1)f^{'}(x+b)+(c_1+r)+c_2\theta f^{'}(x+b) = \rho\left[\frac{c_2\theta f^{'}(x+b) - p(1-\theta)f^{'}(x+b)}{\rho\theta f^{'}(x+b) - 1}\right]\theta f^{'}(x+b)$$

The left hand side of this is just the expression for the marginal opportunity cost of saving seed $p\theta f^{'}(x+b)$ plus the marginal cost of purchasing seed and the right-hand side is the expression for the discounted marginal benefit of saving seed.

A simple expression for the level of royalty for which the farmer is indifferent between saving and purchasing seed may now be obtained:

$$r = \rho\left[\frac{c_2\theta f^{'}(x+b) - p(1-\theta)f^{'}(x+b)}{\rho\theta f^{'}(x+b) - 1}\right]\theta f^{'}(x+b) - p\theta f^{'}(x+b) - (c_1) - c_2\theta f^{'}(x+b)$$

That is the royalty on each tonne of seed purchased should be set equal to the difference between marginal benefits of saving seeds and the marginal costs of saving purchasing and storing seeds.

The seed industry has been concerned that they lose revenue from seed saving by farmers. In order to recover revenue royalties may be imposed. What impact does imposition of a point of sale royalty have on seed purchases? to address this question the crop production technology needs to be specified in more detail. In what follows a logarithmic production function $f(x+b) = log(x+b)$ is considered.

Substituting this functional form into the steady-state first order conditions (6) results in the following:

$$p(1-\theta)\frac{1}{x+b} - (c_1+r) - c_2\theta\frac{1}{x+b} + \rho\left[\frac{c_2\theta\frac{1}{x+b} - p(1-\theta)\frac{1}{x+b}}{\rho\theta\frac{1}{x+b} - 1}\right]\theta\frac{1}{x+b} = 0$$

Multiplying by $x+b$ and simplifying gives:

$$p(1-\theta) - (c_1+r)(x+b) - c_2\theta + \rho\left[\frac{c_2\theta - p(1-\theta)}{\rho\theta - (x+b)}\right]\theta = 0$$

or

$$-(c_1+r)(x+b)^2-(x+b)\left[p(1-\theta)+c_2\theta+(c_1+r)\rho\theta\right]+\rho c_2\theta^2=0$$

This is easily solved for $(x+b)$ and then for b:

$$b=\frac{-\left[(c_1+r)\rho\theta+p(1-\theta)+c_2\theta\right]\pm\sqrt{\left[p(1-\theta)+c_2\theta+(c_1+r)\rho\theta\right]^2+4(c_1+r)\rho c_2\theta^2}}{2(-(c_1+r))}-x$$

Differentiating this with respect to r gives the impact of a a point of sale royalty on farm seed purchasing decisions. The simplest way to do this is to define a new function

$$g(b,r):=-(c_1+r)(x+b)^2-(x+b)\left[p(1-\theta)+c_2\theta+(c_1+r)\rho\theta\right]+\rho c_2\theta^2=0$$

and then implictly differentiate this to obtain $\frac{db}{dr}$:

$$\frac{db}{dr}=-\frac{(x+b)^2+(x+b)\rho\theta}{2(c_1+r)(x+b)+\left[p(1-\theta)+c_2\theta+(c_1+r)\rho\theta\right]}$$

which is clearly less than zero.

Consequently the steady-state impact of introducing point of sale royalties for seed will be negatively sloped as expected, but counter to the claims of plant breeders that royalties will protect them from losing revenue. Another way of thinking of this is that a point of sale royalty simply shifts the price of seed faced by the farmer thereby shifting the demand for seed.

This last point is illustrated by comparing the ex-ante slope of the demand function for seed $\frac{db}{dc_1}$ to the ex-post slope of the demand function for seed $\frac{db}{d(c_1+r)}$.

The former is also obtained by implictly differentiating $g(b,c_1)$ to obtain:

$$\frac{db}{dc_1}=-\frac{(x+b)^2+(x+b)\rho\theta}{2(c_1+r)(x+b)+\left[p(1-\theta)+c_2\theta+(c_1+r)\rho\theta\right]}$$

The latter is obtained similarly:

$$\frac{db}{d(c_1+r)}=-\frac{(x+b)^2+(x+b)\rho\theta}{2(c_1+r)(x+b)+\left[p(1-\theta)+c_2\theta+(c_1+r)\rho\theta\right]}$$

This clearly indicates that the slope of the steady-state demand curve does not change due to imposition of the POS levy. Combining this with the result $\frac{db}{dr}<0$ it an be concluded that the steady-state demand curve shifts to the left as the result of imposition of a POS levy. This implies ceteris paribus that producer surplus must decline. Consequently, a POS levy will not benefit plant breeders. It remains to consider an end-point royalty system.

4 End-point royalties

End-point royalties have been implemented most widely in Australia. End-point royalties involve imposing a levy on the harvested amount of grain. If this is done for grain sales farm profit is as follows:

$$\Pi_t = (p - r)(1 - \theta)f(x_t + b_t) - c_1 b_t - c_2\theta f(x_t + b_t)$$

If the levy is based on the amount of grain harvested and this is monitored perfectly then farm profit is given by:

$$\Pi_t = p(1 - \theta)f(x_t + b_t) - rf(x_t + b_t) - c_1 b_t - c_2\theta f(x_t + b_t)$$

If the harvest cannot be monitored perfectly then farm profit is given by:

$$\Pi_t = p(1 - \theta)f(x_t + b_t) - r\xi f(x_t + b_t) - c_1 b_t - c_2\theta f(x_t + b_t)$$

where ξ is a uniformly distributed random variable with unit interval support, that measures the proportion of actual harvest observed by the plant breeder. This gives us three cases to evaluate, however the last two cases may be treated as one and then setting $\xi = 1$ to evaluate the perfect monitoring case.

4.1 Case I: Levying royalties on sold grain

Firstly, consider the case of levying royalties on the actual amount of grain sold. The farmers objective function is then given by:

$$\max_{b_t} \sum_{t=0}^{\infty} \rho^t \left\{(p - r)(1 - \theta)f(x_t + b_t) - c_1 b_t - c_2\theta f(x_t + b_t)\right\}$$

It is assumed that seed is carried over from each harvest in a fixed proportion

$$x_{t+1} = \theta f(x_t + b_t)$$

current value Hamiltonian for the above problem is given by

$$\tilde{H} = (p - r)(1 - \theta)f(x_t + b_t) - c_1 b_t - c_2\theta f(x_t + b_t) + \rho\lambda_{t+1}\left[\theta f(x_t + b_t) - x_t\right]$$

Pontryagin's maximum principle gives the following

$$\frac{\partial \tilde{H}}{\partial b_t} = (p - r)(1 - \theta)f^{'}(x_t + b_t) - c_1 - c_2\theta f^{'}(x_t + b_t) +$$

$$\rho\lambda_{t+1}\theta f^{'}(x_t+b_t)=0 \tag{7}$$

$$\rho\lambda_{t+1}-\lambda_t=-\frac{\partial\tilde{H}}{\partial x_t}=$$

$$-\Big[(p-r)(1-\theta)f^{'}(x_t+b_t)-c_2\theta f^{'}(x_t+b_t)+\rho\lambda_{t+1}\Big[\theta f^{'}(x_t+b_t)-1\Big]\Big] \tag{8}$$

From (7) and (8) one obtains:

$$\rho\lambda_{t+1}\theta f^{'}(x_t+b_t)-\lambda_t=c_2\theta f^{'}(x_t+b_t)-(p-r)(1-\theta)f^{'}(x_t+b_t) \tag{9}$$

In steady-state one-obtains from (9) (with time subscripts now suppressed):

$$\lambda\Big[\rho\theta f^{'}(x+b)-1\Big]=c_2\theta f^{'}(x+b)-(p-r)(1-\theta)f^{'}(x+b)$$

On rearranging notice that:

$$\lambda=\frac{c_2\theta f^{'}(x+b)-(p-r)(1-\theta)f^{'}(x+b)}{\rho\theta f'(x+b)-1} \tag{10}$$

then substitute (10) into the first-order conditions to obtain:

$$(p-r)(1-\theta)f^{'}(x+b)-c_1-c_2\theta f^{'}(x+b)+$$

$$\rho\left[\frac{c_2\theta f^{'}(x+b)-(p-r)(1-\theta)f^{'}(x+b)}{\rho\theta f'(x+b)-1}\right]\theta f^{'}(x+b)=0$$

or

$$(p-r)(\theta-1)f^{'}(x+b)+c_1+c_2\theta f^{'}(x+b)=$$

$$\rho\left[\frac{c_2\theta f^{'}(x+b)-(p-r)(1-\theta)f^{'}(x+b)}{\rho\theta f'(x+b)-1}\right]\theta f^{'}(x+b)$$

The left hand side is just the expression for the marginal opportunity cost of saving seed net of royalties $(p-r)(\theta-1)f^{'}(x+b)$ plus the marginal cost of purchasing seed and the right-hand side is the expression for the discounted marginal benefit of saving seed.

In what follows a logarithmic production function $f(x+b)=log(x+b)$ is considered.

Substituting this functional form into the steady-state first order conditions results in the following:

$$(p-r)(\theta-1)\frac{1}{x+b}+c_1+c_2\theta\frac{1}{x+b}=\rho\left[\frac{c_2\theta\frac{1}{x+b}-(p-r)(1-\theta)\frac{1}{x+b}}{\rho\theta\frac{1}{x+b}-1}\right]\theta\frac{1}{x+b}$$

$$\Rightarrow (p-r)(\theta-1)+c_1+c_2\theta = \rho\left[\frac{c_2\theta-(p-r)(1-\theta)}{\rho\theta-(x+b)}\right]\theta$$

Solving for b one obtains:

$$b = \rho\theta - \rho\left[\frac{c_2\theta-(p-r)(1-\theta)}{(p-r)(\theta-1)+c_1+c_2\theta}\right]\theta - x$$

Differentiating this with repsect to r gives the impact of an end-point royalty on farmer seed purchasing decisions:

$$\frac{db}{dr} = \frac{-\rho(1-\theta)\theta((p-r)(\theta-1)+c_1+c_2\theta)+(\theta-1)(c_2\theta-(p-r)(1-\theta))\rho\theta}{((p-r)(\theta-1)+c_1+c_2\theta)^2}$$

The denominator of this is quadratic and therefore positive, the numerator may be simplified to:

$$-\rho(1-\theta)\theta(c_1+c_2\theta-(p-r)(1-\theta))-(1-\theta)(c_2\theta-(p-r)(1-\theta))\rho\theta$$

which again noting that ρ and θ lie between zero and one is clearly negative, so that $\frac{db}{dr}<0$.

It remains to evaluate what impact harvest monitoring would have.

4.2 Case II: Harvest Monitoring

$$\max_{b_t}\sum_{t=0}^{\infty}\rho^t\left\{p(1-\theta)f(x_t+b_t)-r\xi f(x_t+b_t)-c_1b_t-c_2\theta f(x_t+b_t)\right\}$$

It is assumed that seed is carried over from each harvest in a fixed proportion

$$x_{t+1} = \theta f(x_t+b_t)$$

The current value Hamiltonian for the above problem is given by

$$\tilde{H} = p(1-\theta)f(x_t+b_t)-r\xi f(x_t+b_t)-c_1b_t-c_2\theta f(x_t+b_t)+\rho\lambda_{t+1}\left[\theta f(x_t+b_t)-x_t\right]$$

Pontryagin's maximum principle gives the following

$$\frac{\partial\tilde{H}}{\partial b_t} = p(1-\theta)f'(x+b)-r\xi f'(x+b)-c_1-c_2\theta f'(x+b)+\rho\lambda_{t+1}\theta f'(x+b) = 0 \tag{11}$$

$$\rho\lambda_{t+1} - \lambda_t = -\frac{\partial \tilde{H}}{\partial x_t} =$$

$$-\left[(p - r\xi)f^{'}(x+b) - \theta(p+c_2)f^{'}(x+b) + \rho\lambda_{t+1}\left(\theta f^{'}(x+b) - 1\right)\right] \quad (12)$$

analysing the co-state equation (12) in steady-state and suppressing time subscripts one obtains on solving for λ:

$$\lambda = \frac{-\left[(p - r\xi)f^{'}(x+b) - \theta(p+c_2)f^{'}(x+b)\right]}{\rho\theta f^{'}(x+b) - 1} \quad (13)$$

substituting (13) into the first-order conditions and rearranging, one obtains the following quadratic polynomial in $f^{'}(x+b)$:

$$Af^{'}(x+b)^2 + Bf^{'}(x+b) + c_1 = 0 \quad (14)$$

where

- $A = [p(1-\theta) - r\xi - c_2\theta + \rho\theta^2(p+c_2)]$
- $B = -\left[c_1\rho\theta + p(1-\theta) - r\xi - c_2\theta + \rho\theta(p - r\xi)\right]$

Solving (14) gives two solution:

$$f^{'}(x+b) = \frac{-B \pm \sqrt{B^2 - 4Ac_1}}{2A}$$

Assuming that $f(x+b) = log(x+b)$, then differentiating and substituting into the quadratic equation and solving for b results in:

$$b = \frac{2A}{-B \pm \sqrt{B^2 - 4Ac_1}} - x$$

Once again this is the steady-state demand curve for seed. Differentiating this with respect to the royalty r allows us to determine impact of the royalty on the demand for seed:

$$\frac{db}{dr} = \frac{-2\xi\left[-B \pm \sqrt{B^2 - 4Ac_1}\right] - 2A\left[-(1+\rho\theta)\xi \pm \frac{1}{2}\left[B^2 - 4Ac_1\right]^{-\frac{1}{2}}(-2(1+\rho\theta)\xi + 4\xi c_1)\right]}{\left[-B \pm \sqrt{B^2 - 4Ac_1}\right]^2}$$

Because by assumption the production function is positively sloped $\frac{-B \pm \sqrt{B^2 - 4Ac_1}}{2A} > 0$ and because the denominator is squared and therefore positive, the sign of the numerator can be determined by noting that

$$\frac{db}{dr} > 0, \text{ if } f^{'}(x{+}b) > -\frac{\left[-(1+\rho\theta)\xi \pm \frac{1}{2}\left[B^2 - 4Ac_1\right]^{-\frac{1}{2}}(-2(1+\rho\theta)\xi + 4\xi c_1)\right]}{2\xi}$$

If one assumes that $\left[-(1+\rho\theta)\xi \pm \frac{1}{2}\left[B^2 - 4Ac_1\right]^{-\frac{1}{2}}(-2(1+\rho\theta)\xi + 4\xi c_1)\right] < 0$, then this can be interpreted to mean that if the marginal product of seed is sufficiently high then a royalty with monitoring will have a positive impact on seed demand. If however the marginal product is not sufficiently high then introducing a royalty would have a negative impact on seed demand. The assumed inequality leads to a polynomial inequality in monitoring accuracy ξ, the solution of which gives a range of values of ξ between which the lower bound on the marginal product of seed remains valid (see appendix). If ξ were to fall outside this range but still lie within the unit interval then the marginal product of seed would be bounded below by a negative number, $\frac{db}{dr} > 0$ would then be true regardless. If however ξ lies within the range then it is possible that for sufficiently samll marginal products of seed, that $\frac{db}{dr} < 0$.

How the different seed regimes compare will be discussed in the following section.

5 Comparative analysis and policy implications

How does the impact compare between POS and an end-point royalty scheme? Denoting the impact of introducing an end-point royalty scheme on puschases of seed by $\frac{db^{EP}}{dr}$ and the impact of introducing a POS royalty scheme on seed purchases by $\frac{db^{POS}}{dr}$ taking the difference and evaluating each derivative at $r = 0$ one obtains:

$$\frac{db^{EP}}{dr}\Big|_{r=0} - \frac{db^{POS}}{dr}\Big|_{r=0} = \frac{-\rho(1-\theta)\theta(p(\theta-1)+c_1+c_2\theta)+(\theta-1)(c_2\theta-p(1-\theta))\rho\theta}{(p(\theta-1)+c_1+c_2\theta)^2}$$

$$+\frac{(x+b)^2+(x+b)\rho\theta}{2(c_1)(x+b)+[p(1-\theta)+c_2\theta+(c_1)\rho\theta]}$$

The shift to end-point royalty regime would not be justified if this difference were negative (see below), ie. if the reduction in demand under an EP system were grater than under a POS system, assuming this is so and based on the (negative) signs already obtained for the impacts under each regime one obtains:

$$\frac{db^{EP}}{dr}|_{r=0} - \frac{db^{POS}}{dr}|_{r=0} < 0$$

However beacause both derivatives are negatively signed, one obtains[1]:

$$\left|\frac{db^{EP}}{dr}|_{r=0}\right| > \left|\frac{db^{POS}}{dr}|_{r=0}\right|$$

Consequently, if royalties are levied on sold grain and if this condition is fulfilled, an end-point royalty scheme will reduce demand for seed more than a point of sale royalty scheme. Note however that $\left|\frac{db^{EP}}{dr}\right|_{r=0}$ is independent of the amount of sown seed $x + b$, so that in terms of scale

$$\left|\frac{db^{EP}}{dr}|_{r=0}\right| < \left|\frac{db^{POS}}{dr}|_{r=0}\right|$$

if the price of seed and cost of storage of grain are sufficiently small. So under these circumstances an end-point royalty scheme would be more preferable. If however seed prices are high and costs of storage are high then introducing end-point royalties rather than POS royalties may be more detrimental.

Usually, however a POS royalty scheme is already in place so that one is comparing $\frac{db^{EP}}{dr}|_{r=0}$ to $\frac{db^{POS}}{dr}$. both of these derivatives are negative however, first of these is independt of x and b the latter however is quadratic in $x + b$ implying due to the raltive size of $x+b$ that the size of the impact on demand under point of sale is much larger. What does this mean? It means that in switching from a POS system to an EP system where royalties are reduced from some positive level to zero under the POS system and then increased from zero to some positive level under the EP system, that demand for new seed will go up under POS more than it goes down under EP. Granted these changes are for all intents and purposes instantaneous, nevertheless, one can expect an increase in seed demand from moving from POS to EP, which is precisely why plant breeders are arguing for this.

How does the impact of a royalty under monitoring compare with each of these two cases? Recall that with monitoring $\frac{db^{MON}}{dr}$ can take on either sign depending on the marginal product of seed. Furthermore, recall that the validity of the inequality depends on a range of values monitoring values

[1] To see this note the seond term becomes positive because two negatives are multiplied, taking this to the other side gives two negative signs on both sides of the inequality, expressing things in terms of absolute values then reverses the sign of the inequality. Note that this is equivalent to expressing the impact in terms of elasticities if $r = 0$

ξ. If this range lies within the unit interval then there will exist some values of ξ for which the marginal product of seed is bounded by negative values. Because ξ must lie within the unit interval by definition, this possibility will be excluded in other cases. Effectively, this means there may be some values of ξ for which the impact of introducing a royalty is always positive. The solution of the polynomial inequality also depends on the level of royalty to be introduced. This has interesting policy consequences.

Because the marginal product of seed is in part determined by research and development undertaken by plant breeders and these same plant breeders through political lobbying can influence the level of royalty to be imposed. This along with the possible positive impact of a royalty on seed demand, gives them an incentive to lobby for certain royalties.

In comparing a royalty scheme with monitoring to a POS royalty scheme or an EP royalty scheme levied on sold grain, the main difference is that there are circumstances under which an EP scheme with monitoring could lead to an increase in demand rather than a fall. From the plant breeder's perspective this then is clearly the prefereed scheme.

6 Conclusion

In this paper an optimal control model of farm seed-saving under three different royalty schemes was presented: i) a POS royalty, ii) end-point royalty on sold grain, and iii) an End-Point royalty with harvest monitoring. steady-state demand curves for seed were derived under each regime and the impact of introducing a royalty in each case was evaluated. In the first two cases it was found that contrary to plant breeder expectations, the impact of introducing seed royalties was likely to be negative, i.e. a royalty scheme was likely to reduce demand for registered seed. In the case of an end-point royalty scheme with harvest monitoring, a royalty scheme could have a positive impact on farm seed, if the the marginal product of seed is sufficiently high and if both the level of royalty and and the accuracy of monitoring remains within a specific range. These factors, may be influenced by plant breeder groups through lobbying. Consequently, plant breeder groups have an incentive to lobby for an end-point royalty scheme with harvest monitoring.

A possible extension of the model is to design a royalty scheme. To do this the model would have to incoproate plant breeder behavior. This could be done by developing an intertemporal principle agent model incorporating investment in research and development of seed varieties with farmers as agents. Such an extension is beyond the scope of this paper.

A Mathematical Appendix

Mathematically the condition that $\left[-(1+\rho\theta)\xi \pm \frac{1}{2}\left[B^2-4Ac_1\right]^{-\frac{1}{2}}(-2(1+\rho\theta)\xi+4\xi c_1)\right] <$ 0 is interesting in that it leads to a polynomial inequality in monitoring accuracy ξ. The derivation is given here:

$$\frac{1}{2}\left[B^2-4Ac_1\right]^{-\frac{1}{2}}(-2(1+\rho\theta)\xi+4\xi c_1) < (1+\rho\theta)\xi$$

$$\left[B^2-4Ac_1\right]^{-\frac{1}{2}} < 2\frac{(1+\rho\theta)}{4c_1-2(1+\rho\theta)}$$

$$B^2-4Ac_1 < 2\left(\frac{4c_1-2(1+\rho\theta)}{2(1+\rho\theta)}\right)^2$$

Expanding the quadratic term on the left hand side results in

$$(r+\rho\theta r)^2\xi^2 - 2(r+\rho\theta r)(-c_1\rho\theta+p(1-\theta)-c_2\theta+\rho\theta p)+4rc_1)\xi +$$

$$(-c_1\rho\theta+p(1-\theta)-c_2\theta+\rho\theta p)^2 - 4\left[p(1-\theta)-c_2\theta+\rho\theta^2(p+c_2)\right]c_1 - 2\left(\frac{4c_1-2(1+\rho\theta)}{2(1+\rho\theta)}\right)^2 < 0$$

The solution of this gives a range of values of ξ between which the lower bound on the marginal product of seed remains valid.

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