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Charging for the use of plant varieties†

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Private and many publicly funded plant breeding organisations charge farmers for use of varieties they develop. This article compares four alternative charging mechanisms and outlines responses to these alternatives by farmers and plant breeders. Risk-averse farmers and breeders are shown to have opposite preferences for charging mechanisms. Results suggest profit-based or *ad valorem* royalties are preferred by farmers whereas breeders prefer area or tonnage-based royalties. Risk-sharing arrangements between both parties could lead to an overall preference for profit-based or *ad valorem* royalties. However, this finding is subject to important caveats and practical limitations.

1. Introduction

Traditionally farmers pay for use of a new variety when they acquire seed of that variety. In situations where there is little use of farmer-saved seed, and consequently farmers purchase seed annually, this charging method is simple to administer. However, in situations where there is predominant use of farmer-saved seed, seed sales are a restricted opportunity for variety developers to charge for varietal use (Alston and Pardey 1998). In these situations other means of charging need to be considered by varietal developers seeking a greater return on their investment in plant breeding.

The need to charge farmers for use of new varieties is felt increasingly by publicly funded plant breeding organisations. The world-wide trend of decreased real investment by the public sector in agricultural R&D (Persley 1998; Huffman and Just 1999) is limiting public funding for plant breeding. The restriction in funding is occurring at a time when servicing new and differentiated markets often requires more not fewer new varieties.

One reaction of many publicly funded plant breeding organisations has been to seek other equity partners in varietal development (Wright 1996;

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Watson 1997). However, diversification of funding and sharing of equity is not without its own problems (Banks 1996). Another reaction of publicly funded plant breeding organisations has been to charge farmers for use of new varieties. Charging for use of new varieties raises several economic issues. Among these is the issue of what is the most appropriate mechanism for charging. This is the subject of the present article.

The article consists of three sections. The first briefly describes some possible charging mechanisms. The second describes a model used to analyse the responses to these mechanisms of, first, a risk-averse farmer and, second, a risk-averse varietal provider (e.g. a plant breeder or seed merchant). A final section explores some implications and the limitations of the findings.

2. Mechanisms for charging for use of varieties

There is a range of charging mechanisms available to a varietal provider. In this article the following charging mechanisms are examined:

(a) a fixed fee per hectare applying to the area planted to the variety. An example of this charge is Monsanto charging farmers growing INGARD® cotton a licence fee based on the area sown to INGARD® cotton (Lindner 1999). The traditional seed royalty, if paid annually and if the seeding rate is fixed, can also be expressed as a fixed fee per hectare.

(b) a flat charge applying to production from use of the variety. Examples of such charges can be found in various regions of Australia and are often associated with closed-loop marketing systems. A charge is imposed on each tonne of grain of the variety delivered. Similar production royalties are common in the mining sector (Emerson and Lloyd 1983).

(c) an *ad valorem* charge applying to the value of production. In Western Australia *ad valorem* royalties on new varieties were being considered for introduction in 1999 (McKinlay 1999; Kingwell and Watson 1998). However, the charges actually introduced in 1999 were flat charges based on tonnages delivered (Agriculture Western Australia 1999).

(d) a profit-based royalty. Such profit-based royalties (e.g. resource rental tax) apply in some energy and mining industries (Thorpe and Hogan 1992).

3. The model

3.1 Impact on a farmer's profit

Prior to facing such charge options, a farmer's profit from varietal use can be specified as:

$$\pi = pyA - CA - F \tag{1}$$

where π is profit, p is the uncertain price, y is the uncertain yield, A is the fixed area, C is the certain variable costs of production per hectare and F is the fixed production costs.

Equation (1) can be modified to represent each alternative charging mechanism and the resulting expected farm profit and profit variance, assuming product price and yield are independent, can be expressed as:

Case 1 (Flat charge per hectare)

$$E(\pi_f) = (\overline{py} - f)A - CA - F \tag{2}$$

and

$$Var(\pi_f) = A^2(\overline{p}^2 Var(y) + \overline{y}^2 Var(p) + Var(p)Var(y)) \tag{3}$$

where f is the flat charge per hectare. Note the formulation of equation (2), and in related subsequent equations, importantly infers that both the level of charge and the mechanism of charging leave A, C and F unaffected. In short, decisions about varietal portfolios, input adjustments for a new variety and adoption patterns are not addressed. Rather, a new variety, subject to a charging mechanism, is assumed to replace an old variety completely.

Case 2 (Flat charge per tonne)

$$E(\pi_t) = \overline{py}A - t\overline{y}A - CA - F \tag{4}$$

and

$$Var(\pi_t) = A^2(\overline{p}^2 Var(y) + \overline{y}^2 Var(p) + Var(p)Var(y)) - A^2 t^2 Var(y) \tag{5}$$

where t is the flat rate charge per tonne.

Case 3 (*Ad valorem* royalty on production)

$$E(\pi_r) = (1 - r)\overline{py}A - CA - F \tag{6}$$

and

$$Var(\pi_r) = (1 - r)^2 A^2(\overline{p}^2 Var(y) + \overline{y}^2 Var(p) + Var(p)Var(y)) \tag{7}$$

where r is the royalty per unit value of product.

Case 4 (Profit-based royalty)

$$E(\pi_s) = (1 - s)((\overline{py} - C)A - F) \tag{8}$$

and

$$Var(\pi_s) = (1-s)^2 A^2(\bar{p}^2 Var(y) + \bar{y}^2 Var(p) + Var(p)Var(y)) \tag{9}$$

where s is the royalty per unit of profit.

For a risk-neutral farmer to be indifferent between the charging mechanisms, $E(\pi_f) = E(\pi_t) = E(\pi_r) = E(\pi_s)$ or re-arranging equations (2), (4), (6) and (8) and simplifying:

$$f = t\bar{y} = r\overline{py} = s\left(\overline{py} - C - \frac{F}{A}\right)$$

By illustration, if f is \$10/ha then t must be \$5/t (assuming average yield is 2 t/ha), r must be 1/30$^{\text{th}}$ (assuming average price and yield is \$150/t and 2 t/ha respectively) and s must be 1/10$^{\text{th}}$ (assuming C is \$120/ha, F is \$80/ha and A is a hectare, along with the previous yield and price assumptions).

Although f, t, r and s can be set such that expected profits are identical, the variance of income associated with each charging mechanism will matter to risk-averse farmers.

The relativities of the profit variances can be seen after denoting the right-hand side of equation (3) as K. Then

$$Var(\pi_f) = K \tag{10}$$

$$Var(\pi_t) = K - A^2 t^2 Var(y) \tag{11}$$

$$Var(\pi_r) = (1-r)^2 K \tag{12}$$

$$Var(\pi_s) = (1-s)^2 K \tag{13}$$

Comparing equations (10) to (13) reveals:

$$Var(\pi_f) > Var(\pi_t),$$

$$Var(\pi_f) > Var(\pi_r) \text{ and}$$

$$Var(\pi_f) > Var(\pi_s)$$

Further, as shown in appendix A:

$$Var(\pi_r) > Var(\pi_s) \text{ and } Var(\pi_t) > Var(\pi_r).$$

The conclusion is that where f, t, r and s are set to equate expected profits a risk-averse farmer will least prefer the charging mechanism to be the flat rate charge on the area sown to the variety and most prefer the profit royalty option. A risk-averse farmer will least prefer the flat rate charge on the area sown because the farmer remains fully exposed to all profit variability attributable to yield and price risk. The charge on production, however, reduces the farmer's exposure to profit variability associated with yield risk.

In high yielding years the farmer pays more for varietal use whereas in low yielding years he pays less; hence the farmer's profit variance is reduced. The *ad valorem* charge allows the farmer's profit variance to be further reduced because it accounts for price risk. Finally, the profit-based charge covers all the factors that affect the farmer's profit variance and so is the most effective in reducing this variance. Accordingly, among the charging mechanisms with equivalent expected profit, the profit-based charge is the most preferred one by a risk-averse farmer.

In table 1 are illustrated some typical findings using the following parameters; $A = 1000\,\text{ha}$, $C = 120\,\$/\text{ha}$, $F = \$75\,000$, $\overline{p} = 160\,\$/\text{t}$ and $Var(p) = 330$. Given that most empirical studies of risk attitudes of Australian farmers suggest they are moderately risk-averse (Bond and Wonder 1980; Bardsley and Harris 1987), then an implication of this analysis is that most farmers would prefer a profit-based royalty to a flat rate royalty on tonnage or area sown to a variety, assuming the royalties paid by the farmers were the same for each charging mechanism and that compliance and transaction costs did not differ across the charging mechanisms.

A further implication is that risk-neutral variety developers could design a profit-based royalty that returns to them a greater expected royalty stream than that from a flat rate royalty on tonnage or area, yet risk-averse farmers would be indifferent between paying the profit-based royalty or the flat rate royalties. This second implication can be explored and illustrated by applying the mean-variance formulation of expected utility:[1]

$$E(U(\pi)) = U(E(\pi)) + \frac{1}{2}U''(E(\pi)) \cdot Var(\pi) \tag{14}$$

where $U(\pi)$ is the utility function of profit and $U'(\pi) > 0$ and $U''(\pi) < 0$.

Following Fraser (1991), the farmer's utility function of profit can be represented by the constant relative risk aversion form:

$$U(\pi) = \pi^{1-R}/(1-R) \tag{15}$$

where:

$$R = -U''(\pi)\pi/U'(\pi) \text{ and}$$

R is the farmer's coefficient of relative risk aversion.

A profit-based royalty that would leave a risk-averse farmer with equivalent expected utility to that generated by a flat rate charge on area can be determined by the following steps:

[1] See Hanson and Ladd (1991) for arguments supporting this approach.

Table 1 An illustration of outcomes for various charging options for varietal use

				Methods of charging for use of varieties							
				Area charge		Tonnage charge		*Ad valorem* charge		Profit charge	
Expected yield	$Var(y)$	Expected farm profit under each charge option	Farmer payments for varietal use	Flat charge per hectare (f)	$Var(\pi_f)$	Flat charge per tonne (t)	$Var(\pi_t)$	Royalty on the value of production (r)	$Var(\pi_r)$	Royalty on farm profit (s)	$Var(\pi_s)$
t/ha		\$'000	\$'000	\$/ha	$\times 10^9$	\$/t	$\times 10^9$	no.	$\times 10^9$	no.	$\times 10^9$
1.5	0.06	35	10	10	2.298	6.66	2.296	0.0416	2.111	0.2222	1.390
1.5	0.06	40	5	5	2.298	3.33	2.297	0.0208	2.203	0.1111	1.816
2	0.10	115	10	10	3.913	5	3.911	0.0312	3.672	0.0800	3.312
2	0.10	120	5	5	3.913	2.5	3.912	0.0156	3.792	0.0400	3.606
2.5	0.12	195	10	10	5.174	4	5.172	0.0250	4.919	0.0488	4.682
2.5	0.12	200	5	5	5.174	2	5.174	0.0125	5.046	0.0244	4.925

(a) for the flat rate charge on area, substitute values of A, C, F, f, $\overline{p}$, $\overline{y}$, $Var(p)$ and $Var(y)$ into equations (2) and (3) to calculate $E(\pi_f)$ and $Var(\pi_f)$.
(b) substitute $E(\pi_f)$ into equation (15) to obtain $U(E(\pi_f))$. Calculate $U'(E(\pi_f))$.
(c) substitute $E(\pi_f)$, $Var(\pi_f)$ and $U'(E(\pi_f))$ into equation (14) to obtain $E(U(\pi_f))$.
(d) repeat steps (a) to (c) using parameters for the profit-based royalty and solve for the value of s that equates $E(U(\pi_s))$ to $E(U(\pi_f))$.

It is possible to find values of s that equate $E(U(\pi_s))$ to $E(U(\pi_f))$ for any set of R values and any set of values of f. Table 2 presents values of s for three levels of R and two different values of f. Table 2 also lists values of r associated with the equating of expected utility, under a regime of *ad valorem* and profit royalties, with that when a flat rate charge on the area sown is imposed. The royalty receipts of varietal developers are also shown.

In the case where the farmer is most risk-averse ($R = 0.9$) and f is \$10 per hectare, profit-based royalties are 23.6 per cent higher than those based on the area sown to the variety (i.e. \$12 357 versus \$10 000). For the same case of risk aversion the *ad valorem* royalty is 8.2 per cent higher. Even where a farmer is mildly risk-averse ($R = 0.3$), the profit-based royalties are 8 per cent higher than those based on the area sown to the variety. Admittedly such an increase may seem small, especially in light of the greater administration costs that would accompany the introduction of a profit-based royalty. However, the scale of the grains industry would mean that even small percentage differences nation-wide could potentially translate into annual revenue flows of millions of dollars.

Table 2 An illustration of combinations of f, r and s about which risk-averse farmers would be indifferent[a]

		R					
		0.3		0.6		0.9	
		r	s	r	s	r	s
f (\$/ha)	5	0.0161	0.0431	0.0165	0.0463	0.0169	0.0493
Royalties (\$)		5148	5394	5284	5789	5400	6158
f (\$/ha)	10	0.0322	0.0864	0.0331	0.0929	0.0338	0.0989
Royalties (\$)		10307	10804	10585	11610	10819	12357

[a] Based on $A = 1000$ ha, $C = 120$ \$/ha, $F = \$75,000$, $\overline{p} = 160$ \$/t, $\overline{y} = 2$ t/ha, $Var(p) = 330$ and $Var(y) = 0.1$.
Note that with these parameters the royalty derived from an area-based fee would be \$10 000 with $f = 10$ and \$5000 with $f = 5$.

The results in table 2 also reveal that the additional royalty revenue generated by the *ad valorem* royalty is about 40 per cent of the additional revenue associated with the profit-based royalty (i.e. \$307 versus \$804 for $R = 0.3$). If the administrative costs of introducing a profit-based royalty compared to an *ad valorem* royalty are much higher, the *ad valorem* royalty may in practice be a preferred means for charging for use of varieties.

The preceding findings illustrate the general finding in the risk-sharing literature that if one agent is risk-neutral, then that agent can profit from bearing all of the risk (Leland 1978). A risk-neutral varietal provider will be willing to accept the greater variability of profit associated with a profit-based royalty, compared to one based on area, in return for an increase in expected profits. Also, a risk-averse farmer would be indifferent between supporting such a profit-based royalty and one based on area, in spite of the expected payments by the farmer being greater for the profit-based royalty.

3.2 The case of a risk-averse varietal provider

The preceding analysis assumed that the varietal developer was risk-neutral. However, where the varietal provider is risk-averse, the appropriate charging mechanism will depend on a range of factors such as their degree of risk aversion relative to that of the farmer and their relative capacities to reduce the profit variance associated with each charging mechanism. In practice, a negotiated risk-sharing arrangement is likely to eventuate.

In situations where an organisation has developed a new variety and now charges farmers for use of that variety, the organisation's profit from using the different charging mechanisms can be specified as:

Case 1 (Flat charge per hectare)

$$E(\pi_f) = f \sum_{i=1}^{n} A_i \tag{16}$$

where the ith farmer plants A_i hectares of the new variety and there are n farmers growing the new variety and f is the flat charge per hectare. Given the earlier assumption that A_i is fixed for each farmer, it follows that $Var(\pi_f) = 0$.

Case 2 (Flat charge per tonne)

$$E(\pi_t) = t \sum_{i=1}^{n} y_i A_i \tag{17}$$

In equation (15) A_i is fixed for each farmer and y_i is each farmer's uncertain yield. Denote $\sum_{i=1}^{n} y_i$ by Y and $\sum_{i=1}^{n} A_i$ by A_T. Hence:

$$Var(\pi_t) = t^2 A_T^2 Var(Y) \tag{18}$$

where t is the flat rate charge per tonne.

Case 3 (*Ad valorem* royalty on production)

$$E(\pi_r) = r\overline{p}\sum_{i=1}^{n} y_i A_i \tag{19}$$

In equation (17) it is assumed that all farmers face the same price distribution for the new variety and that price and yield are independent. Hence:

$$Var(\pi_r) = r^2 A_T^2 (\overline{p}^2 Var(Y) + \overline{Y}^2 Var(p) + Var(p)Var(Y)) \tag{20}$$

where r is the royalty per unit value of product.

Case 4 (Profit-based royalty)

$$E(\pi_r) = s\left(\left(\overline{p}\sum_{i=1}^{n} y_i A_i - \sum_{i=1}^{n} C_i A_i\right) - \sum_{i=1}^{n} F\right) \tag{21}$$

and

$$Var(\pi_s) = s^2 A_T^2 (\overline{p}^2 Var(Y) + \overline{Y}^2 Var(p) + Var(p)Var(Y)) \tag{22}$$

where s is the royalty per unit of profit and price and yield are independent.

For a risk-neutral seed seller to be indifferent between the charging mechanisms, then $E(\pi_f) = E(\pi_t) = E(\pi_r) = E(\pi_s)$ or re-arranging equations (16), (17), (19) and (21) and simplifying:

$$f = t\overline{Y} = r\overline{p}\overline{Y} = s\left(\overline{p}\overline{Y} - \overline{C}_T - \frac{\overline{F}_T}{A_T}\right)$$

where $C_T = \sum_{i=1}^{n} C_i$ and $F_T = \sum_{i=1}^{n} F_i$.

Although f, t, r and s can be set such that expected profits for the varietal provider are identical, the variance of income associated with each charging mechanism will matter to risk-averse providers.

The relativities of the profit variances for the provider are:

$$Var(\pi_t) > Var(\pi_f),$$

$Var(\pi_r) > Var(\pi_t)$ and following a similar procedure to that in appendix A,

$$Var(\pi_s) > Var(\pi_r).$$

Under such rankings of profit variance, and given identical expected profits, a risk-averse provider would most prefer the flat charge per hectare and least prefer the profit-based royalty. The preference ordering of charging mechanisms by a risk-averse provider is exactly opposite to that preferred by a risk-averse farmer.

4. Implications

Whether varietal providers in Australia are as risk-averse as farmers has not been the subject of empirical investigation, as far as this author is aware. Where the farmer and varietal provider both are risk-averse, their optimal sharing or trading of risk depends on their individual risk aversion and the profit distributions of each charging mechanism they face (Newbery and Stiglitz 1981). If one partner in the negotiated trade has less risk aversion or is equally risk-averse yet is more able to reduce the variance of their profit distribution, then their cost of bearing risk is less. In other words, the amount that one partner is willing to pay for risk reduction can exceed the amount that the other partner requires as compensation for the risk incurred.

It could be argued that varietal providers are more likely to be able to reduce their risk exposure through a greater geographical spread of their varieties and through maintaining portfolios of varieties on offer in different regions for different crops. Accordingly, in practice, this would mean a varietal provider, even if as risk-averse as the farmer, would more likely prefer a profit-based or *ad valorem* royalty provided that the expected royalty payments (net of implementation costs) were sufficiently large to compensate for the greater variability associated with those charging mechanisms compared to an area-based fee.

5. Limitations

An important limitation of the preceding analyses is the exclusion of implementation costs, including moral hazard and transactions costs. For example, it is likely that the legalities and practicalities of introducing profit-based royalties will greatly lessen their desirability. However, the other charging mechanisms are not without problems. For example, the area charge requires an effective low-cost method of measuring or imputing the area sown to a variety. All the charging mechanisms rely on being able to identify either the area planted to each variety or the amount of each variety delivered by each grower. Further, where grain is used on-farm as seed or feed, this will constitute a leakage of revenues for all charging mechanisms, apart from the area-based fee. Some of the charging methods require agreed procedures for determining the price of grain produced from a variety and measuring or verifying variable and fixed costs of grain production.

These are important practical issues. The administrative, monitoring and policing costs associated with each charging mechanism are likely to be sufficiently different to influence preferences over charging mechanisms. The importance of these costs for the introduction of genetically modified (GM) varieties has been noted by Lindner (1999, 2000). For example, he comments about practical difficulties such as the 'problems of identifying which crops are protected by the rapidly expanding number of PBR certificates, and identifying and proving which ones were grown using an illegal source of seed' (Lindner 2000, p. 19).

Another limitation, raised by a reviewer, is the exclusion of negative covariance effects, particularly regarding price and yield. However, as shown in appendix B, the finding concerning the desirability of a profit-based royalty for a risk-averse farmer would be unchanged by inclusion of such correlations. Further, because the Australian grains industry exports about 65 per cent of its production and its production is not a key determinant of international grain prices, negative correlations between yield and price are unlikely to be large for the main grain crops.

Another limitation is that no account is taken of the effect of charging for varietal use on the pattern or level of varietal adoption. In a commercial setting a varietal developer would need to account for the effect of its charges on varietal use in order to maximise the net present value of its revenue stream from charging growers. In determining its charging regime a varietal developer would have to account for the relative advantage of its variety over competing varieties, the likely duration of this advantage and the impact of its charges on varietal adoption.

6. Conclusion

The preceding analyses have compared four different methods of charging for varietal use and found that, in the absence of differential implementation costs, risk-sharing arrangements will lead to profit-based royalties being the preferred charging mechanism. In the context of resource taxation in the minerals sector, Fraser and Kingwell (1997) and Fraser (1999) also have disclosed the desirability of profit-based royalties. They observe, however, that many governments have persisted with *ad valorem* royalties despite the clear tax revenue advantages to governments of imposing profit-based royalties (e.g. resource rent taxes).

In agriculture the situation is such that not even *ad valorem* charges are common in varietal use. However, as discussed by Watson (1997) and Kingwell and Watson (1998), there is a range of policy and practical issues that prevent the simple implementation of *ad valorem* charges on varieties. Some of the implementation and policing costs could be such as to bring into question a main finding of this article that risk-sharing arrangements between a farmer and varietal developer will lead to *ad valorem* or profit-based payments being a preferred means of charging for varietal use. In short, the simple behavioural model in this article, although providing some insights about possible charging mechanisms, ideally requires further refinement to incorporate other factors that influence mechanism preference.

With the increasing commercialisation of the provision of genetic material to farmers, interest will remain in the design of mechanisms for charging farmers for varietal use. Developments in gene technology, supported by trade secrets, patent, contract law and plant variety legislation, provide opportunities for charging. Against this legal backdrop, what constitutes appropriate charging mechanisms and what are efficient and equitable mechanisms will remain a topical issue.

Appendix A

The purpose of this appendix is to show that, for the variances described earlier in equations (11) to (13), $Var(\pi_r) > Var(\pi_s)$ and $Var(\pi_t) > Var(\pi_r)$.

The relativity of $Var(\pi_t)$ and $Var(\pi_r)$ can be gauged by examining their difference:

$$Var(\pi_t) - Var(\pi_r) = K - A^2t^2 Var(y) - (1-r)^2K \tag{A1}$$

Remembering the requirement that

$$t = r\overline{p}$$

in order for expected profits to be equal under each charge option, equation (A1) can be expanded:

$$r((2-r)K - A^2r\overline{p}^2 Var(y))$$

Further expanding K gives:

$$rA^2((2-r)(\overline{p}^2 Var(y) + \overline{y}^2 Var(p) + Var(p)Var(y)) - r\overline{p}^2 Var(y)) \tag{A2}$$

In equation (A2), noting that $0 < r < 1$, only the first and last terms determine the sign of the equation. That is:

$$(2-r)(\overline{p}^2 Var(y)) - r\overline{p}^2 Var(y)$$

and simplifying gives:

$$2\overline{p}^2 Var(y)(1-r) \tag{A3}$$

In equation (A3) $(1-r) > 0$, therefore:

$$Var(\pi_t) > Var(\pi_r)$$

Further, the relativity of $Var(\pi_r)$ and $Var(\pi_s)$ can be established by first examining the condition where:

$$E(\pi_s) = E(\pi_r)$$

Expanding gives:

$$(1 - s)(\overline{py}A - CA) - f = (1 - r)\overline{py}A - CA - F$$

and simplifying gives:

$$\overline{py}A(r - s) = -sCA \tag{A4}$$

Because p, y, A, C, r and $s > 0$, then in order for equation (A4) to hold:

$$r < s$$

and thus:

$$Var(\pi_r) > Var(\pi_s).$$

Appendix B

The model of producer behaviour as outlined earlier in equation (1) assumes that product price and yield are independent. A reviewer wondered if relaxing this assumption would alter the finding that a risk-averse farmer preferred a profit-based royalty compared to a fee based on the area sown to a variety, assuming no difference in implementation costs of each charging mechanism. In particular, what is the impact of a negative covariance between price and yield?

Consider the impact of inclusion of covariance in the calculation of the level and variance of a farmer's profit.

Case 1 (Flat charge per hectare)

$$E(\pi_f) = (\overline{py} + \mathrm{cov}(p, y) - f)A - CA - F \tag{B1}$$

and

$$\begin{aligned} Var(\pi_f) = {} & A^2(\overline{p}^2\,\mathrm{var}(y) + \overline{y}^2\,\mathrm{var}(p) + 2\overline{py}\,\mathrm{cov}(p, y) - (\mathrm{cov}(p, y)^2 + E[(p - \overline{p})^2(y - \overline{y})^2] \\ & + 2\overline{y}E[(p - \overline{p})^2(y - \overline{y})] + 2\overline{p}E[(p - \overline{p})(y - \overline{y})^2] \end{aligned} \tag{B2}$$

Case 2 (Profit-based royalty)

$$E(\pi_f) = (1 - s)((\overline{py} + \mathrm{cov}(p, y) - C)A - F) \tag{B3}$$

and

$$\begin{aligned} Var(\pi_f) = {} & (1 - s)^2A^2(\overline{p}^2\,\mathrm{var}(y) + \overline{y}^2\,\mathrm{var}(p) + 2\overline{py}\,\mathrm{cov}(p, y) - (\mathrm{cov}(p, y)^2 \\ & + E[(p - \overline{p})^2(y - \overline{y})^2] + 2\overline{y}E[(p - \overline{p})^2(y - \overline{y})] + 2\overline{p}E[(p - \overline{p})(y - \overline{y})^2] \end{aligned} \tag{B4}$$

Examining equations (B1) through to (B4) reveals that a negative covariance reduces the farmer's expected profit and variance of profit for both types of payment. However, comparing these expected profits with those earned when there is no covariance shows that expected profit declines, first, by $A\,\mathrm{cov}(p, y)$ in the case of area-based payments and, second, by $(1 - s)A\,\mathrm{cov}(p, y)$ in the case of profit royalties. As $0 < s < 1$ it follows that the decline in expected profit is less for profit royalties than for area-based payments.

Further, as pointed out by Fraser (1984):

> a negative covariance between price and output will decrease both the expected level and the variance of income (compared to a zero covariance). If a producer is not very risk-averse ($R < 1$), then the utility-reducing effect on expected income of this covariance dominates overall. (p. 270)

Accordingly, for the same reasons, a risk-averse ($R < 1$) farmer in the presence of a negative correlation between yield and price will still prefer the profit royalty to the area-based payment (assuming compliance costs are similar in both cases).

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