The University of Adelaide

A Game-Theoretic Approach to Modelling Crop Royalties

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A thesis submitted for the degree of

Doctor of Philosophy in

The School of Economics at

The University of Adelaide

Adelaide

South Australia

January 2015

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Abstract

Plant variety rights assist crop breeders to appropriate returns from new varieties and incentivise varietal improvement. Royalties are one form of plant variety rights and this dissertation asks which combination of the available royalty instruments is best from the perspective of consumers, farmers, crop breeders, and the overall economy.

We use a game-theoretic approach to model strategic interactions between breeders and farmers. The model allows farmer privilege, whereby farmers save seed one year to plant in the future, and we show a point-of-sale royalty with either or both of the remaining royalties is optimal, whether or not we allow the possibility of farmers under-paying royalties through under-declaring output or saved seed.

We also develop a Principal–Agent model, in which risk-neutral breeders share the risk with risk-averse farmers. In this model, the optimum royalty depends on various parameters, including the costs of compliance and enforcement.

KEYWORDS: game-theory; economic model; end-point royalty; point-of-sale royalty; saved seed; farmer privilege; principal–agent model.

Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Acknowledgements

I would particularly like to thank my supervisor, Associate Professor Ralph Bayer, who is everything a good supervisor should be and gave me his time, expert advice and encouragement.

I also acknowledge Professor Phil Pardey for the original idea and for his interest in my work, and Dr Eran Binenbaum for his early supervision. My two co-supervisors, Prof Kym Anderson and Dr Jake Wong, also deserve special thanks. Professor Geoff Harcourt was a great mentor and kindly read a draft and provided valuable encouragement, and I thank him for that.

I owe a huge debt to the casual tutors in my courses who did so much extra in order to help me. Their encouragement, interest and support was immense. I particularly thank Carolyn Toh, Ian Carman, Vivian Piovesan and David Hoey. I also greatly appreciated the support and friendship of other Ph D students, especially Brita Pekarsky and Mark Dodd.

Finally, a huge thank you to my friends and family, who always reminded me that there was a life outside the thesis! I would especially like to thank Fay for her never-ending kindness and friendship. My son Michael proofread a draft and made numerous suggestions and provided excellent advice on words; my son David was an enormous help with maths and MATLAB. I thank them both. Finally, my thanks to my husband, Clive, for his support throughout the long process.

Acronyms and Abbreviations

ACCC	Australian Competition and Consumer Commission
ACIP	Advisory Council on Intellectual Property
AGT	Australian Grain Technologies
AVC	Average variable costs
AWB	Australian Wheat Board
Bt	Bacillus thuringiensis
CARA	Constant absolute risk aversion
COGGO	Council of Grain Grower Organisations Ltd
CRS	Constant returns to scale (production function)
CV	Coefficient of variation
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EPR	End-point royalty
EU	European Union; Expected utility
FAO	Food and Agriculture Organisation of the United Nations
GM	Genetically modified
GRDC	Grains Research Development Corporation
IC	Incentive compatibility constraint of the farmer
ImpC	Implementability constraint of the farmer
IP	Intellectual property
IPR	Intellectual property rights
IR	Individual rationality constraint of the farmer
MV	Mean–variance (model)
NVT	National variety trials
NZPFR	New Zealand Institute for Plant and Food Research
PBR	Plant Breeder’s Rights
POS	Point-of-sale royalty
PVP	Plant variety protection
PVPA	Plant Variety Protection Act of 1970, US
PVR	Plant variety rights
R&D	Research and development
RDC	Research development corporation
RR	Royalty revenue
SARDI	The South Australian Research and Development Institute

SSP	Saved-seed royalty
SW	Social welfare, the sum of farmer and breeder profits
TRIPS	(agreement on) Trade-Related Aspects of Intellectual Property Rights
UK	United Kingdom
UNCTAD	United Nations Conference on Trade and Development
US, USA	United States of America
UPOV	International Union for the Protection of New Varieties of Plants

Symbols

Game-theoretic models	
a	enforcement costs parameter, $a > 0$, \$
b	proportion of farm sown to bought, new, seed, $b \in [0, 1]$; may be indexed by time period t
C	farmer's costs, \$
d	output-declaration rate, $d \in [0, 1]$
f	fine factor on cheating , $f > 1$
F	production function of wheat
g	marginal breeding cost, $g > 0$, \$ per kilogram of seed produced
K	fixed cost of wheat breeding, \$
m	saved-seed declaration rate, $m \in [0, 1]$
P_b	point-of-sale royalty, $P_b \geq 0$, \$ per kilogram of bought seed
P_s	saved-seed royalty, $P_s \geq 0$, \$ per kilogram of seed saved
$\bar{q}$	quality of new, bought, seed, tonnes of output per unit area
q	quality of the seed mix, tonnes of output per unit area; may be indexed by time period t
Q	production, output of wheat, tonnes; may be indexed by time period t
r	end-point royalty rate, $r \in [0, 1]$, \$ per tonne of output
X	enforcement cost function, \$
Greek symbols	
β	discount factor, $\beta \in [0, 1]$
ϕ	probability of the farmer being investigated, $\phi \in [0, 1]$
ψ	seeding rate, tonnes of seed per unit area sown, $\psi > 0$
π_f	profit of the farmer, \$; may be indexed by time period t
π_B	profit of the breeder, \$; may be indexed by time period t
Π	discounted sum of future expected profits of farmer, \$
θ	quality of saved seed relative to new seed, $\theta \in (0, 1)$

Principal–Agent models

a	marginal enforcement costs, \$ per kilogram of seed
A	fixed enforcement costs, \$
b	quantity of seed bought by the farmer, kilograms
c, $\tilde{c}$	cost parameter of wheat growing, \$ per kilogram^2 of seed input
e	effort of the farmer in labour units
F	production function of wheat
g	marginal cost of wheat breeding, \$ per kilogram of seed
h	marginal product of farmer effort, tonnes of output per unit of labour effort
K	fixed cost of wheat breeding, \$
l	license fee, fixed up–front payment, \$
L	risk premium
N	numeraire unit of money $=$ output price
p	point-of-sale royalty, $p \geq 0$, \$ per kilogram of bought seed
q	production, output of wheat, tonnes
r	end-point royalty rate, $r \in [0, 1]$, \$ per tonne of output
v	marginal product of seed, \$ of output per kilogram of seed
Z	certainty equivalent of the farmer's wealth; Z is such that $EU(Y) = U(Z)$, if Y denotes the farmer's wealth, \$
Greek symbols	
ϵ	uncertainty of production, a random variable with mean 0 and variance σ^2, \$ of output per kilogram of input
γ	coefficient of risk aversion of the farmer
π_f	profit of the farmer, \$
π_B	profit of the breeder, \$
σ^2	variance of ϵ, (\$ per kilogram of seed)^2

Chapter 1

Introduction

There is recent interest in the role and efficacy of types of intellectual property (IP) protection in crop breeding. This interest is partly because growth in public funding of crop variety research has decreased in many countries, forcing breeders to finance their activities privately, with royalties being one method of providing finance, and also because promoting the most appropriate royalty scheme could increase global economic welfare and crop production, and boost world food security at a time when grain prices have spiked. Governments and government agencies provide IP protection to encourage R&D; such protection has long been common in many other sectors of the economy, although it is more recent in crop breeding. With crop breeding, plant breeder's rights are one method through which breeders can at least partly appropriate the returns on their investment, although they are neither necessary nor sufficient. Within plant breeder's rights, royalties are only one way of implementing plant variety protection. Breeders have used seed royalties for a very long time[1] whilst, in Australia, they have imposed an end-point royalty (EPR) after legislation was passed in 1994 that allowed this. These end-point royalties apply to several crop species including wheat, barley, canola, lupins, field peas and lentils[2] and are imposed on the output of these crops rather than the seed.

This dissertation models end-point, point-of-sale and saved-seed royalties in order to determine which combination of royalties is best from the perspective of consumers, farmers, breeders and the economy as a whole. We do this by developing qualitative micro-economic models and comparing the outcomes from different combinations of royalties in terms of farmer and breeder profit and social welfare. The conclusion is that there is no one optimal royalty or royalty scheme; instead, the best system depends on several key factors including the difficulty of enforcing royalties and the goals of policy-makers.

There is an extensive literature on IP protection in agriculture and in crop breeding, and there have been empirical models describing and estimating the impact of plant variety protection (PVP) in crop breeding. Previous theoretical models of royalties were not developed for crop breeding and cannot be directly applied there because crop breeding is different

[1] I am indebted to an anonymous examiner for highlighting this point.
[2] See VarietyCentral 2013.

from these other activities. This dissertation explores two of these differences: farmer-saved seed and the attitudes to risk of farmers and breeders. There are few previous studies involving micro-theory models of royalties in crop breeding and these are surveyed in Chapter 2. The models we develop in this thesis are not quantitative, empirical models and will not provide realistic numerical answers; instead, they are qualitative models which will allow us to identify and characterise equilibrium positions and trade-offs, based on micro-economic theory. From our models, we will be able to identify factors which are important in determining which royalties are optimal.

First, we consider farmer-saved seed. Prior to the International Union for the Protection of New Varieties of Plants (UPOV) Convention of 1991 (see UPOV (1991)), breeder's rights did not extend to farmer-saved seed so farmers could save seed legally without paying royalties. UPOV 1991 strengthened breeder's rights by covering saved seed. Some signatories to UPOV allow farmer privilege whereby farmers may save seed legally although they may be required to pay a seed royalty. Such a royalty is open to the possibility of farmers not fully declaring their saved seed and so avoid paying the saved-seed royalty. Similarly, when farmer privilege is not allowed and farmer-saved seed is illegal, it is possible that farmers may save seed illegally. In this way, farmers avoid buying new seed and so avoid paying a point-of-sale royalty. This means breeders cannot fully appropriate returns from investing in the development of new varieties.[3] An end-point royalty allows breeders to partially appropriate returns and may be easier to enforce, depending on the institutions of the country, than the saved-seed royalty.

The role of farmer-saved seed in determining the best royalty is considered by modelling the profit of breeders and farmers separately, including the different royalties, in a game-theoretic model. In Chapter 3 we develop a model in which farmers fully declare their saved seed and output.

We consider the outcome a benevolent dictator or social planner would choose; this is the outcome which maximises social welfare and is the first-best outcome—the benchmark to which other outcomes are compared. In this thesis, social welfare is measured by economic surplus: the sum of the profits of farmers and breeders. We show that the social optimum is a point-of-sale royalty with either one or both of saved-seed and end-point royalties. With these schemes, the benevolent social planner can set the level of the royalties to both maximise the social surplus and allocate it between farmer and breeder. The surplus can be allocated according to the goals of the policy-maker. As we move away from the benevolent social planner, the allocation also depends on the market power of the breeder. A monopolist breeder will be able to push the farmer down to reservation profit and extract the full surplus for themselves.

[3]We use the term variety rather than cultivar as it is in more common usage.

Chapter 4 extends the model by introducing the possibility of a profit-maximising farmer not fully declaring their saved seed or output. We show that the same schemes are optimal as when declaration was full, although the level of social welfare is reduced by the cost of enforcing royalties. Enforcement costs and the fines for farmers caught cheating affect the effort breeders devote to detecting false declaration whilst the allocation of the surplus is affected by the enforcement costs, the fines and also the actual royalties.

The second difference between crop breeding and other sectors that we consider in this thesis is risk aversion and information frictions. We analyse this in Chapter 5 using a Principal–Agent model. Farmers are assumed to be risk-averse and breeders are assumed to be risk-neutral; this leads to breeders partially insuring farmers. Whilst the first-best outcome is full insurance, whereby the breeder pays the farmer the full amount of their costs up–front and the farmer grows the crop, this outcome is not implementable due to the possibility of shirking. Of the implementable outcomes, we show the best is an end-point royalty in conjunction with a fixed up–front license fee. There is some insurance, since breeders can do better by taking some risk from farmers via the end-point royalty. The optimal end-point royalty increases with the riskiness of the crop yield or the risk aversion of farmers.

An end-point royalty is not always used in practice and Chapter 6 considers one reason for this: enforcement costs. These costs are incorporated into the Principal–Agent model and are shown to affect the choice between royalties. The analysis shows that as fixed or marginal enforcement-costs increase, a point-of-sale royalty is more likely than an end-point royalty to be optimal with the fixed up–front license fee. This is also true the less risky the crop yield, the less risk-averse the farmer, the lower the breeder's marginal costs or the marginal product of seed, and the higher the farmer's marginal cost.

Before modelling the relationship between the farmer and the breeder, we provide in Chapter 2, a background discussion. This covers protection of IP in general and in agriculture, a review of types of royalties, a discussion of PVP in practice in Australia and around the world; and finally, a review of recent developments in the Australian wheat breeding industry. This is followed by Chapters 3 and 4 which model the impact of the different royalties, first with full declaration of saved seed and output and then with less than full declaration. Chapter 5 develops a Principal–Agent model assuming no enforcement costs, and this is extended with enforcement costs in Chapter 6. The final chapter summarises the findings and draws out policy implications.

Chapter 2

Background

2.1 Introduction

This chapter provides the background required for developing an applied micro-economic model of royalties on crop varieties.

First, we discuss the protection of intellectual property in general, and then in agriculture. The major justification for government intervention in agricultural R&D is perceived market failure. With crop varieties, this failure may arise due to the lack of appropriability and excludability of new varieties, and the asymmetry of information and risk between farmers and breeders. These reasons underpin this dissertation.

In some cases, intervention may be required. Plant variety protection is one way of achieving this—but is neither necessary nor sufficient. Since royalties vary between commodities, we discuss royalties in applications other than crop breeding, although we show crop breeding is sufficiently different as to require different models. This leads to a discussion of different types of royalties.

The following section considers plant variety protection in practice—both the international and Australian experience, including institutional changes that contributed to the protection of plant varieties in Australia. Then, we outline crop-variety royalties used by some other countries.

The last thirty years has seen major changes in the Australian wheat industry; these are next reviewed, before the final section of this chapter describes other studies of plant variety protection and royalties.

2.2 The protection of IP in crop breeding

There is an extensive literature on the economic issues of intellectual property rights (IPR) and protection in general and in agriculture, although Thomson (2013, p. 2) notes that IPR over plant material are relatively recent. A full review of IPR in general is beyond the scope of this dissertation: the reader is directed to Godden (1981, pp. 17–22), Godden and Powell (1981), Léger (2005, sec.2), Dosi *et al.* (2006); Maskus (2012) and Cimoli *et al.* (2013). For a useful review of IP protection in agriculture, see Alston *et al.* (1998); Wright and Pardey (2006); Pardey *et al.* (2007); Kolady and Lesser (2009) and Alston *et al.* (2010). A review of IPR in relation to crop breeding can be found in Godden (1987a); Louwaars *et al.*

(2005); Wright and Pardey (2006); Pardey *et al.* (2007); Alston *et al.* (2012) and Campi (2013). Important issues include inter-sectoral re-allocation, the effects on growth, trade and internationalisation, the impact on and perspectives of developing countries, effects of and on industry structure, and the efficiency and efficacy of IPR in increasing innovation and welfare.

Intellectual property protection for plant material, plant variety protection (PVP), takes various forms, the most important being patents, trademarks and plant breeder's rights (PBR) whilst (Perrin, 1994) copyrights and certificates are also possible.

IPR are (Louwaars *et al.*, 2005, p. 23) "legal instruments that allow an inventor or author to exclude others from commercializing an innovation for a specified period of time " and include the institutions and legislation of a country plus international agreements and conventions.

These property rights are justified on ethical, pragmatic or economic grounds—ethical and pragmatic reasons are covered by Godden (1982, pp. 55–59), whilst Louwaars *et al.* (2005, p. 23) cite Article 27 of the Universal Declaration of Human Rights which provides "the right to the protection of the moral and material interests resulting from any scientific, literary or artistic production of which he is the author". The economic argument is that knowledge is in part a public good as it is non-excludable in price and non-rival in consumption. Left to itself, the market would provide private returns to the innovator below the social returns, resulting in sub-optimal levels of knowledge. Government intervention might correct this by increasing private returns, thus incentivising innovators so that investment, innovation and knowledge increase, resulting in higher welfare. IPR are one possible intervention. However, they restrict free access to the knowledge, which in turn may restrict future adoption or innovation, and be welfare-reducing. The dilemma for policy-makers (Perrin, 1994) is the balance between appropriation and access; between producer and consumer surplus; or in the case of plant breeding, between farmer-saved seed and breeder's rights.

This is an old and vigorous debate—on one hand is the Schumpeterian view that appropriation of returns and monopoly power will increase R&D and hence innovation, and on the other, the Arrow view that access will be restricted and innovation decrease. The debate is furthered by Dosi *et al.* (2006) building on the work of Nelson and others—they oppose the market failure theory, arguing that the concept relates a market to a standard which does not exist and may not be desirable. Instead of a theory based on appropriability, they propose a theory of innovative opportunity. This view is further argued in Cimoli *et al.* (2013) who are critical of the potential monopoly and market power generated by IPR. A branch of evolutionary economics surrounds this debate which is summarised in Castellacci (2008). The possible market failure in crop breeding is described below.

2.2.1 Market failure

The market failure in crop breeding R&D has been well discussed in the literature—see, for example, Godden and Powell (1981); Godden (1982, 1987b); Perrin (1994); Pardey *et al.* (2007); Gray and Bolek (2010, 2012); Gray (2012); Alston *et al.* (2012) and Thomson (2013). This section draws heavily on these sources.

As mentioned above, public goods are both non-excludable and non-rival. The knowledge output of crop-breeding research has these characteristics (Alston *et al.*, 2012, p. 3): it is non-rival because one agent using the knowledge does not prevent another using it, and it is partially non-excludable because agents cannot be prevented from using the knowledge without paying since wheat is self-pollinating so farmers can save seed from non-hybrid and unpatented crops to plant in the future. Thomson (2013, p. 4) states "Of all crop types, wheat epitomises non-excludability, since virtually all wheat varieties grown commercially are self-pollinating." Non-excludability may occur in many areas of agricultural R&D, causing the social rate of return to be above the opportunity cost of capital. This is described in a meta-analysis by Alston *et al.* (2000), extended by Alston *et al.* (2011), in which rates of return were estimated to be very high, varying between 7.4% and 29.1% and averaging around 20%. For plant breeding specifically, a report commissioned by Webb (2010) estimated the return on investment in the UK is 40:1.

As well as being in part due to incomplete appropriability, private returns could be below social returns because of a decrease in negative externalities such as lower requirements for pesticides, weedicides or fertilizers, or an increase in positive externalities such as greater food security or adaptability to climate change.

Not all agricultural R&D has the characteristics of public goods; Pardey *et al.* (2007) explain that if only some members of society benefit from the R&D, the resulting goods are collective, rather than public, goods and not everyone should pay: intervention may still be warranted and (pp. 38–39) "economic efficiency (along with some concepts of fairness) is likely to be promoted by funding research so that the costs are borne in proportion to the benefits to the greatest extent possible."

Intervention is not always required to overcome market failure, bearing in mind the possibility of government or bureaucratic failure whereby damage is caused by poor intervention. However, in some cases, intervention may be required and Pardey *et al.* (2007, p. 53) conclude

> ... it is difficult for individuals to fully appropriate the returns from their R&D investments, and it is widely held that some government action is warranted to ensure an adequate investment in R&D.

2.2.2 Overcoming non-excludability

There are different ways of overcoming non-excludability in crop-breeding output—see Godden (1982, pp. 59–63), Pardey *et al.* (2007, pp. 16–20) and Louwaars *et al.* (2005, pp. 41–45, 95–98). Louwaars *et al.* (2009, sec. 2.2) provide general information on plant breeding and IP, whilst PVP is discussed in Naseem *et al.* (2005); Dosi *et al.* (2006); Pardey *et al.* (2007); Léger (2007) and Campi (2013).

Some possibilities include (IP Australia, 2013):

- natural appropriation,
- government provision of public goods,
- commodity levies,
- industry 'clubs',
- research prizes, other laws and contracts,
- design registration, brands and trademarks,
- patents and
- plant breeder's rights protection.

Breeders can naturally appropriate some of the returns on some plant species. Godden (1981, pp. 24–29) explains how natural property rights differ depending on how the plant reproduces. Since wheat is a self-pollinated, seed-harvested species, F1 hybrids have some degree of natural protection because for them, the yield of farmer-saved seed is substantially less than for new seed.

A second way of overcoming non-excludability is through government provision whereby governments provide the goods and distribute them free, as if they were public goods. This is discussed in Alston *et al.* (2012, p. 6) and was the situation with wheat breeding historically, with public funding of R&D and new varieties freely available.

Commodity levies are another solution, with levies on producers providing funding for industry research. Alston *et al.* (2004) and Alston and Gray (2013) provide a detailed discussion of the principles, practice and issues surrounding levies, especially with reference to Australian wheat.

Godden (1982, p. 60) discusses the industry-club solution as exemplified in the NSW cotton industry where Cotton Seed Distributors Ltd was a "club" formed to import varieties from breeders in the US. Alternatively, breeders could set up joint ventures or integrate vertically with farmers. However, this is unlikely given that small-scale farming is optimal for most food staples (Byerlee, 2013).

Direct government intervention is another possibility: for example, tax breaks, or prizes such as professional recognition, academic tenure or extra salary for successful researchers as detailed in Pardey *et al.* (2007, pp. 42–43) or Gray (2012), as well as other legal avenues—for example, grower contracts that restrict seed usage (Louwaars *et al.*, 2005, p. 43). Such intervention involves a transfer from tax-payers to breeders which has implications on efficiency; however, discussion of these implications are beyond the scope of this thesis.

Finally, some form of plant variety rights (PVR) could be used to increase appropriability by giving the owner the exclusive right to produce and sell the variety. Godden (1987a) reviews the impacts and issues of PVR and describes them as conferring (p. 255) "a property right in plant material by granting legal title in a new variety to the breeder or discoverer of a new variety."

Legislation may allow for brands and trademarks which are used, along with advertising, to distinguish one breeder's varieties from others. However, whilst Louwaars *et al.* (2005, p. 44) state "the development of a strong brand image and reputation can protect a company from some types of competition", in practice in crop breeding they may be of limited value, although can be long-lasting.

More importantly for this thesis, PVR can take the form of patents or plant breeder's rights (PBR). Patents and plant breeder's rights are different instruments. A patent is "the sole, legally enforceable right to sell, make, use, offer to sell or import an innovation within the country in which it is filed" (Hodge, undated, p. 1). A plant itself and parts of it such as genes, seeds, proteins, fruits and progeny may be patented, but the discovery of a plant cannot be patented; "[t]here must have been some technical intervention such as genetically modifying the plant which distinguishes it from a mere discovery" (Hodge, undated, p. 1).

Plant breeder's rights (PBR) is a system of property rights for plants giving the owner rights over the plant variety and its name. The benefits of PBR are, through appropriation, to encourage plant breeding, genetic diversity and agricultural efficiency and hence welfare—see Godden and Powell (1981, p. 58) and Pray and Knudson (1994).

However, there are drawbacks to PBR. According to Pardey *et al.* (2007, p. 21), innovation in agriculture tends to be cumulative so that lower appropriability may slow a chain of innovation, and protection on one research output could delay follow-up research. This hold-up could be more detrimental than the short-term inefficiency of monopoly power caused by higher appropriability. Scotchmer (1991) and Green and Scotchmer (1995) discuss sequential R&D and the hold-up problem. This is similar to the anti-commons problem in which it is costly to coordinate a large number of independent individuals each holding rights over components of a new technology, resulting in its under-use. This could be one, although not necessarily the major, reason why the greatly improved rice variety, *Golden Rice*, was not as commercially successful as would have been expected (Pardey *et al.* 2007, pp. 22–23, Gray and Bolek 2010, p. 4, Alston *et al.* 2012, p. 14). Increased monopoly power and reduced access may reduce collaboration, spillovers and innovation (Pardey *et al.*, 2013, p. 26).

Louwaars *et al.* (2005, p. 27) describe the opposing interests: breeders expect PVR to prevent farmer-saved seed or other unauthorised use of their seeds, name or varieties whilst society expects plant material to be freely available to enhance innovation and variety development. IPR systems must balance these competing ends.

Godden (1981, p. 6) shows IPR are neither necessary nor sufficient for the appropriability of returns for all crops. They are not necessary since, as we saw above, there are alternatives. Godden (1987a, p. 256) explains "at least some of the value of many varieties may be appropriated without PVR". IPR may not be sufficient: (Godden, 1987a, p. 256) "PVR only *enhance* the ability of breeders to appropriate the value of new varieties ... the existence of PVR may not permit the full value of a variety to be appropriated by its owner ...". Godden (1981, p. 30) describes several factors limiting the appropriability given by PBR: the extent of farmer-saved seed; the ease of breeding specific characteristics into a cultivar; the legal system surrounding detection and enforcement; and the fact that breeders themselves (not the state) are required to pursue legal enforcement actions.

Perrin (1994, p. 502) makes the point that whilst IPR provide some appropriability and exclusion, they do not change the non-rival characteristic of the innovation so the excludability implies a social loss. A non-rival but excludable good, such as crop breeding with IPR, is a toll good (Gray, 2012, p. 5). A toll good industry has low marginal costs, with a similar cost structure to a natural monopoly; if price equalled marginal cost, firms would have negative profits. Alston *et al.* (2012) and Gray (2012) discuss the so-called "entry dilemma" in a toll goods industry—as more firms enter, monopoly power is reduced and prices move towards marginal costs but at the same time, average costs increase through a multiplication of effort and fragmentation of knowledge. Hence, Gray and Alston argue there is a role for levy funding to help overcome these problems.

Despite these concerns and competing ends, Pardey *et al.* (2007, p. 16) state that weak IP protection is the major market failure in crop research. This thesis takes the market-failure theory and the consequent role for IPR but is more narrowly focussed and considers only one form of IPR: royalties on crop breeding.

Differences between the assets themselves, as well as between industry structures and legal and institutional frameworks, shape the actual IP protection used. For example, developing countries face specific challenges with IP protection; this is well reported in United Nations Conference on Trade and Development UNCTAD (undated) and Cimoli *et al.* (2013).

Next, we outline ways in which crop breeding is different from other sectors that impose IPR and royalties. After that, we discuss types of royalties and then the development of IPR protection in plants.

2.2.3 Why crop breeding is different

Although IP protection in agriculture is relatively recent compared to the manufactured goods sector, IPR are applied within agriculture not only to crop breeding but also to other technologies such as weedicides, pesticides, knowledge and information. We concentrate on crop breeding. Wright and Pardey (2006, p. 13) describe the change in IP protection in agriculture over the last 25 years of the twentieth century as "a revolution". The use of PR in food and agriculture is also contentious, especially because of the impact on developing countries (Kolady and Lesser, 2009, p. 137). Theory relevant to other sectors may not be relevant to agriculture and crop breeding because of these different characteristics, which are now described.

One difference between agriculture and manufacturing is that rates of return in agriculture in general, and crop-breeding specifically, are high and above the social discount rate, implying an increase in output will increase welfare (Thomson, 2013, p. 8). Hence, if IPR increases output, welfare is increased. This removes one link in the chain of effect of IPR from appropriability to incentives to investment to innovation to output to welfare.

IP protection varies in different applications. For example, books or software are automatically covered by copyright as soon as they are published without requiring a formal application process, whilst manufacturing has industrial patents for inventions. Louwaars *et al.* (2005, p. 26) describe the varying IP protection in different sectors and argue that plant breeding is different from other sectors for the following reasons:

- Plant breeding is biological; its output is easily reproduced and its very use often requires reproduction,
- enforcement is difficult because there are millions of farmers,
- agriculture involves food production and cultural values, and society may feel concern for the "rural poor",

- historically, new varieties were bred using public money, and
- modern biotechnology complicates the breeding process.

We now turn our attention to royalties. They are applied to assets other than crop seeds—for example, mining and forestry, music, art and literature, IT and software, and pharmaceuticals and whilst these have some similarities to crop seeds, there are also important differences, so that models applied to one of these assets may not be appropriate to others.

Resource royalties are payments to government for mining, forestry and natural resource assets which are owned by, and whose extraction is licensed by, governments.[1] These resource royalties are payments for physical assets and so quite different from crop royalties, which are payments for the IP or knowledge content of the asset.

Royalties are common in music, art, literature and pharmaceuticals. Artists and authors provide the rights to their IP to publishers in exchange for future royalty payments, often paid as a share of net return. Drug companies extract royalties and seek patents over their research output.

In these sectors, as with crop breeding, we can distinguish the knowledge (IP) component from the physical output. For example, in crop breeding, the new cultivar and its seeds; in literature or music, the words or tune and the physical volume, CD or file; and in pharmaceuticals, the "recipe" for a drug and the actual pill or potion. The physical output can

[1] I am grateful to an anonymous examiner for pointing that, depending on the legal and institutional framework, only some of these assets are owned or controlled by government—for example, some, but not all, forests are state-owned.

be copied—books and music are probably the easiest to copy in a digital age; seeds are easy but somewhat time-consuming to bulk-up, and the actual pills of the pharmaceutical industry may be the hardest to copy as they must be first analysed. There is a grading of difficulty of copying these three outputs.

Crop seeds differ from the physical outputs of the other two because seeds are also inputs to the production of a crop—this means an end-point royalty is relevant to seeds but not the other two, since there is no final output of books or music that is different from the inputs.

Plant breeding and pharmaceuticals share a similar cost structure; Godden and Powell (1981, p. 70) argue "the market characteristics of pharmaceutical and plant breeding research were similar", with high fixed costs so that average costs fall up to a high level of output. These conditions may lead to a natural monopoly.

As we saw above, the IP (knowledge) component of these assets is non-excludable and non-rivalrous, but IP protection can provide some degree of excludability. For example, by imposing copyrights on music, legal sale of CDs can be restricted to those consumers who pay. As previously, though, IP protection cannot create rivalrous consumption from non-rivalrous so instead leads to toll goods.

The degree of excludability depends on the institutions of a country. For example, a painting can be sold to a single buyer who could prevent others from viewing it or it can be put on public display and viewable for all, when it becomes more like a "club" good.[2]

Whist the IP in these sectors have similarities, there are differences between the sectors. For example, the relative sizes of the two sides may differ: in crop breeding, the owners of the asset (breeders) are generally bigger, more concentrated, fewer in number and holding more power than the users (farmers). The same is true of pharmaceutical companies. In publishing, the users tend to be the large, powerful companies, although famous authors have more bargaining power. This difference in size and power alters the bargaining process and outcomes. Standard bargaining and contract theory predicts that the outcome of bargaining and the optimal royalty rate depends on the time and cost of bargaining, the outside option, the symmetry of information and the relative impatience, bargaining strength and risk aversion of the agents, as well as the superiority and strategic importance of the new technology.

The timing of royalty payments also differs between crop breeding and publishing. In crop breeding, the uncertainty of the yield is resolved after inputs have been bought and used, and point-of-sale royalties paid, so the farmer bears the risk of paying the costs and then being faced with low production and return. In publishing, the royalty is paid after the uncertainty is resolved: apart from a possible up–front flat fee (an advance),

[2] I am grateful to an anonymous examiner for suggesting this useful point.

royalties are paid after sales have been determined. The publisher may risk the cost of publishing but not the royalty payments.

The timing of the resolution of the uncertainty is also different between crops and pharmaceuticals. In the pharmaceutical industry, payments for drugs are made at the time of purchase when the uncertainty is more or less resolved and is more similar to publishing than crop breeding.

There may be problems with the acceptance of IP regulations in all three sectors; this may be worse for crop seeds because historically, seeds of new varieties were supplied free of royalty charges as their breeding was publicly funded.

Historically, books, music and art had some degree of natural protection as it was hard to copy them by hand so that, even though it is now easy to copy digitally, consumers may be aware of the illegality of doing so. IP protection of medicines and pills is possibly the most readily accepted because firms have built up a strong corporate and brand image and may build on consumers' risk aversion with respect to health matters.

In crop breeding, the user of the asset (the farmer) tends to be risk averse (Kingwell 1994, p. 191) whereas in mining, the owner of the asset (the government) is possibly more risk averse (Otto *et al.* 2006, p. 10).

Since crop breeding differs from other research outputs through differences in the source of market failure, the time at which uncertainty is resolved, the relative risk aversions of the agents, the ease of copying the technology, and also which agent carries the risk, general theories and results may not carry over to crop breeding and new models are required.

2.2.4 Royalties

We saw above that IP protection is one way of allowing breeders to appropriate their returns; in turn, royalties are one form of IP protection and are (Pardey *et al.*, 2007, p. 40) "a specific institutional form to implement and enforce property rights over varietal innovations." Royalty payments flow to a specific variety and breeder, and incentivise the breeder to respond to farmers' needs.

Royalties can take several forms including:

- An up–front, flat license fee paid by farmers for the use of new varieties, independent of the amount of seed purchased and paid before production,
- A charge per hectare of crop sown, such as Senova's RAC (royalty area collection) which charges a rate per hectare on oats in the UK (Green, 2008) or Monsanto's technology fee on Ingard cotton, initially set as $AU245 per hectare (Lindner, 2000).
- A point-of-sale royalty, which is essentially a price that farmers pay per kilogram of seed when they purchase seed,
- A saved-seed royalty, under which farmers pay an amount per kilogram of seed saved,

- An end-point royalty, under which farmers pay an amount or a proportion of production, paid at the time of harvest or sale of the output, and
- Profit sharing, in which a royalty is paid as a proportion of profit rather than production and is paid after profit has been determined.

End-point royalties are relatively recent and have several stated advantages. The first advantage is that they allow appropriation, even when the rate of farmer-saved seed is high, as is the case with wheat in Australia. The breeder receives revenue for all production from their varieties regardless of whether the farmer bought new seed that year or used seed saved previously. A royalty based on either saved or bought seed may not provide as much revenue to breeders, and may not provide sufficient revenue for their viability. Related to this, end-point royalties may allow a more even revenue stream over time since such royalties accrue every season—the breeder receives income even if farmers are saving seed—whereas a point-of-sale royalty accrues only when farmers buy new seed which may occur infrequently if farmers only change varieties every few years.[3] As well as revenue, the breeder receives feedback as to the actual productivity of their varieties (ACCC, 2014a, p. 5) since revenue is proportional to variety performance.

A major advantage of an end-point royalty is to share risk between farmers and breeders. With a point-of-sale royalty, the farmer pays up–

[3] I am grateful to an anonymous examiner for suggesting this useful point.

front regardless of the success of the crop. With an end-point royalty, the farmer and the breeder share the risk. In the event of a crop failure, the farmer pays nothing. Typically, farmers are assumed to be relatively risk averse—see Kingwell (2001) for example—and we assume farmers are relatively more risk averse than breeders. By facing less risk, the farmer may be more willing to adopt a new variety (Alston *et al.*, 2012, p. 22).

Adoption may be faster, and seeding rates optimal, if applying end-point royalties instead of point-of-sale royalties reduces the up–front cost to the farmer so they can use newer varieties without the cash–flow implications of a point-of-sale royalty. This may be particularity important in developing countries.

Finally, an end-point royalty removes the difficulty of calculating the appropriate rate for a point-of-sale royalty. The point-of-sale royalty could be set at a level that covers the difference in the profitability of the new variety compared to the old one, due to increased yields and decreased costs. This differs between regions and seasons, and its estimation requires detailed data. The end-point royalty can allow for the effect of the season and productivity, if not prices and costs.

There are disadvantages to end-point royalties, including a possible lack of acceptance, which could be due to social, historic or cultural issues. Whilst payment for IP is commonplace in other situation such as (Pardey *et al.*, 2007, p. 40) "technical changes embodied in mechanical and chemical inputs . . . [, i]n contrast it is much less common to charge seed users ... for new crop varieties." There is also the commercial issue that farmers are now

> ...being required to pay for use of varieties that formerly were delivered via the public purse and charged to farmers at prices just above the per kilogram market value of the grain.[4]

Allied with the problem of acceptance is the difficulty and expense for the breeder in enforcing compliance. However, over time, this problem should diminish, particularly if there is institutional support for end-point royalties. This is the case in Australia, where the Grains Research Development Corporation (GRDC) supports end-point royalties (GRDC, 2011c).

There is a trade-off in setting the royalty rate. On one hand, a lower royalty reduces the return to breeders, which lowers future investments in breeding and crop improvement. On the other hand, the lower rate decreases seed cost, increases production, speeds up the adoption of new varieties and is better accepted by farmers which in turn reduces the costs of enforcing compliance. These costs vary between types of royalties and countries, which may help explain why different countries use different royalties.

A disadvantage felt by seed growers, and mentioned by Curtis and Nillson (2012, p. 10), is that by allowing farmer-saved seed, an end-point royalty "does not support a healthy trade in certified seed" in the case of non-hybrid, non-patented varieties. Whilst trade in certified seed may

[4] I am grateful to an anonymous examiner for suggesting this useful point.

reduce breeder's transactions costs (Godden, 1982, pp. 83–4), these views reflect the interests of the seed industry.[5]

Initially, three major factors limited the use of end-point royalties—see Alston *et al.* (2012, pp. 24–25) and Alston and Gray (2013, p. 32). First, new varieties that attracted an end-point royalty were competing with royalty-free varieties. Over time, this problem lessened as more and more varieties attracted an EPR.

Second, as public breeding declined, a private sector was required to replace it. It was hoped end-point royalties would facilitate this by increasing revenue to breeding programs and speeding up adoption of new varieties (Lawson, 2013, p. 36). This appears to have happened: Gray and Bolek (2012, p. 26) believes that "EPR revenues are sufficient to support ... current wheat breeding programs' whilst Walmsley (Roth, 2011) concludes the Australian end-point royalty system is important in attracting overseas investment in wheat breeding.

Third, the collection of EPRs was initially cumbersome and costly. This problem has diminished with the development of a more efficient collection system in Australia. The growth of the private sector in the Australian wheat breeding industry is discussed further in Section 2.4. Before that, however, we look at the evolution of PVP around the world.

[5] I am grateful to an anonymous examiner for pointing out the vested interests of the industry.

2.3 The practice of plant variety protection

This section describes the history of PVP legislation around the world and draws on Godden and Powell (1981); Godden (1981, 1982, 1987a, 1989, 1988b, 1998); UPOV (1991); Wright and Pardey (2006); Alston *et al.* (2010, 2012) and Pardey *et al.* (2013). The Australian experience is discussed separately in the following section.

2.3.1 The international history of PVP legislation

Prior to 1930, plants had no IP protection (Wright and Pardey, 2006, p. 14). The late development of plant IPR has been attributed to ethical, political, legal and biological reasons (Louwaars *et al.*, 2005, p. 30).

In 1930, the US passed the Plant Patents Act, which allowed for patents over asexually reproduced plants (Pardey *et al.*, 2013, p. 25); these are mainly ornamentals, berries, vines and fruit trees (Wright and Pardey, 2006, p. 14), but not cereal crops which are sexually reproduced.

In 1961, the International Union for the Protection of New Varieties of Plants (UPOV) established, via an international convention, guidelines for granting plant breeders the rights to prevent other people from using their varieties. To claim plant variety rights, Article 5 of UPOV requires breeders to show the new variety meets certain criteria: it must be new, distinct, uniform and stable, and have an approved name. This is further discussed in Godden and Powell (1981, pp. 55–6). Many European countries enacted legislation following this convention (Wright and Pardey, 2006, p. 15). This included the Plant Breeder's Rights Act in the United Kingdom in 1964, which is described further in Godden (1988b, p. 117).

In 1970, the US Plant Variety Protection Act (PVPA) allowed for certificates on sexually propagated plants, which include grains, grasses and oilseed crops. These certificates were intended to increase the incentives to breeders, thereby boosting plant breeding and encouraging improved varieties. However, whilst similar to patents, these certificates were weaker as they allowed some form of both farmer and breeder privilege (Alston and Venner (2002, p. 528), Wright and Pardey (2006); Pardey *et al.* (2013)).

In 1980, a US Supreme Court decision made it clear that the patent protection given to plants is the same as that given to other inventions (Pardey *et al.*, 2013, p. 25).

The appropriability of returns and incentives to breeders further increased with the introduction of seed patents after a 1985 US ruling (*ex parte* Hibberd 227 US Patent Quarterly 443 (1985)) as well as the release of hybrid varieties. However, as we mentioned previously, these changes may also impede development, both via research hold–ups and through the monopoly power breeders gain over varieties. On balance, the evidence from several studies, including Knudson and Pray (1991), Jaffe (1986) and Alston and Venner (2002), is that this plant variety protection did not greatly foster improvement in crop varieties.

UPOV was extended in 1991 to give the option of including farmer and breeder privilege. Farmer privilege—also called farmer's exception—allows farmers to save seed from their crops for future use, although they may be required to pay royalties on the saved seed; breeder privilege—breeder's exception—allows breeders to use PBR protected material in breeding and research.

The World Trade Organisation agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) was determined in 1994 and obliges member countries to provide intellectual property rights on plant varieties. Some governments implement this obligation through UPOV.

US plant patents were strengthened in 2001 by a ruling allowing plants covered by a plant patent or PVPA certificate to also obtain a utility patent (Pardey *et al.*, 2013). Apart from the US, plant patents are uncommon around the world, but are allowed in Australia, Japan (Curtis and Nillson (2012); (undated, p. 3)) and South Korea (Pardey *et al.*, 2013, p. 25).

Carew and Devadoss (2003, p. 372) state that US PBR legislation was effective and "the evidence suggests that plant breeder's rights have increased the ability of private companies to appropriate returns on plant breeding investments ...".

This brief description outlined the US and international experience with plant patents, and the international obligations under TRIPS and UPOV. The next section discusses the Australian developments, before we turn our attention to crop royalties used in other countries.

2.3.2 Australia

This section relies on Godden and Powell (1981); Godden (1982, 1998); Kingwell (2005), ACIP(2007), Alston *et al.* (2012); Jefferies (2012); Thomson (2013) and Lawson (2013).

As was the case in many countries, Australia had no PBR legislation for most of the twentieth century. Commonwealth legislation was first proposed in 1979 when new crop varieties were still developed by public breeding programs and provided to growers with no price premium to cover the IP embodied in them (Lindner, 2000; McGrath, 2010, p. 5).

Godden (1989, p. 3) notes that whilst many countries enacted PVR legislation up to 30 years earlier than Australia and with little controversy, Australia only enacted such legislation after "a protracted and often acrimonious debate". According to Godden (1981, p. 56), legislation was held up whilst it was determined whether eligibility for protection would be based on field trials, as in Europe and UPOV, or by breeder's description, as in the US. Australia followed this latter approach (Godden, 1998, p. 7) and a Bill was tabled in 1981. In 1987, the *Plant Variety Rights Act 1987* (Cth) was passed, with the objective of improving varieties by encouraging plant breeding within Australia and by importing varieties. This Act granted PVR to an eligible variety for 20 years and covered varieties that were "invented" but not those that were "discovered".

Farmer privilege allowed farmers to save seed with no royalty payments (Alston *et al.*, 2012, p. 24). This, plus the relative ease of producing a

’new’ but similar variety, and the high cost of legal action (Kingwell, 2005, p. 45) meant the Act had little impact for broadacre agriculture (Kingwell and Watson, 1998, p. 323; Gray and Bolek, 2012, p. 14) but did have significant effects in horticulture through importing cultivars (Godden, 1998).

Australia signed UPOV in 1989 (Godden, 1998, p. 10), altering the legislative basis of PBR. Prior to this, the States had the power to legislate over plant breeder’s rights but chose not to. The Commonwealth could only legislate through the patents provision of section 51(xviii) of the Constitution (*Commonwealth of Australia Constitution Act, 1900*, Imp). However, by signing UPOV, the Commonwealth had entered into an international treaty and under section 51(xxix) of the Constitution, had the power to introduce PVR legislation and enforce PBRs.

An amendment in 1990 extended the coverage of the Act to discoveries as well as inventions, moving away from the original intention of the Act and weakening the farmers’ position.

In 1991, UPOV was revised and Australia signed the revised UPOV (Alston *et al.*, 2012, p. 24). The 1987 act was amended, and passed in 1994, becoming the *Plant Breeder’s Rights Act 1994* (Cth) which differed from the 1987 *Plant Variety Rights Act* in many ways (Godden, 1998) including changes to the breadth and depth of coverage, monitoring and enforcement, as well as strengthening breeder’s rights. In particular, the new Act allowed (Jefferies, 2012, p. 3) “the owner of a variety to recover a return on investment at any point in the use of that variety (eg grain or other products ...)". Hence, farmer-saved seed was an optional exemption, no longer a farmer's right, and breeder's rights were extended to output. This paved the way for end-point royalties although both Jefferies (2012) and Lawson (2013) note common law would have been sufficient for PBR since (Lawson, 2013, p. 37) " [a]ny plant material may be patented if the threshold criteria are satisfied, (see *Patents Act* 1990 (Cth.) s. 18) and patents are routinely granted for . . . plants . . . ".

There were minor amendments to the Act in 1999, a failed High Court challenge in 2000, a review in 2002 which clarified legal issues surrounding royalty payments and allowed a more efficient EPR system, and a further review conducted in 2007 (ACIP, 2007, 2010) which investigated compliance and enforcement problems including variety identification and farmer-saved seed. The PBR legislation in Australia is considered to be more effective in allowing breeders to appropriate returns than the legislation in the US or Canada (Thomson, 2013, p. 2).

Australian laws on PBRs allow farmer-saved seed, whereby farmers may save seed from one year's crop to plant the next year. Lawson (2013, p. 39) points out that the rate of farmer-saved seed is higher in Australia than Europe due to climatic conditions; the Australian Seed Federation (ASF) (2007, p. 5) estimates that the rate of farmer-saved seed in Australian wheat is up to 95%. Because of this, (McGrath, 2010) end-point royalties were preferred over point-of-sale royalties.

2.3.3 Other institutional changes in Australia

PBR legislation was only one of three institutional factors important to the wheat breeding sector in Australia. The remaining two (Alston and Gray, 2013, p. 30) are the rise of a private wheat breeding industry and the role of the Grains Research Development Corporation (GRDC). Kingwell (2005) surveys these institutional changes that took place in Australia.

The formation in the early 1990s of rural Research and Development Corporations (RDCs) was central to reform across many industries in Australia. The GRDC was established in 1990 and states (GRDC, 2013) it is "responsible for planning, investing in and overseeing RD&E to deliver improvements in production, sustainability and profitability across the Australian grains industry." It does this by funding wheat breeding and pre–breeding research as well as encouraging private breeding. It also supports projects which might not otherwise be undertaken if their private returns are below social returns due to spillovers or externalities.

Lawson (2013, p. 36) describes the importance of the GRDC in providing "the impetus" for EPRs, and (p. 44) having a " ... role in advocating EPRs and implementing the institutional changes to enable EPRs ... ".

In 2007, wheat export marketing was deregulated (McGrath, 2010, p. 5) and whilst this did not change PVR, it altered the institutional structure of the wheat industry, allowing for competition and privatisation.

Next, we review the royalties used in the wheat industry in selected countries around the world.

2.3.4 Royalties on wheat in selected countries

We saw above that few countries use patents as a means of appropriating breeder's rights; many countries use royalties, so we now consider how royalties are implemented in the wheat industry in several countries, other than Australia. The situation in Australia is considered in the following section. A 2012 report from the International Seed Federation (Curtis and Nillson, undated) provides an account of IP protection and royalties on wheat for fourteen countries, including the United States, France, Germany, Canada, Australia, Argentina and the United Kingdom. That report details the instruments used, particular problems encountered in each country, the prevalence of farmer-saved seed and the efficiency of royalty collection. In addition, a background paper to a symposium held by the Canadian Seed Trade Association (2013) outlines the royalty system in ten countries, including the United States, France, Germany, Canada, Australia, Argentina and the United Kingdom.

PBR legislation was introduced in the **United Kingdom** in 1964. New seed is subject to a point-of-sale royalty, commonly paid as a rate per tonne averaging £68.77/tonne in 2010 for wheat.[6] Farmer-saved seed is allowed and accounts for about half the cereal crop in the UK (Green, 2008, p. 2); since UPOV 1991 and an associated EU Community Regulation, this attracts a saved-seed royalty. Farmers declare saved seed at the time of sowing and pay a rate which is uniform across varieties and is approximately

[6] Dr P Maplestone, Chief Executive, British Society of Plant Breeders Ltd, pers. comm.

half the royalty rate on new certified seed (Canadian Seed Trade Association, 2013). Farmers choose whether to pay at the rate per hectare or per tonne, although farmers who use seed processors usually pay the tonnage rate as this is easier and cheaper. The royalties are collected by The British Society of Plant Breeders and distributed to breeders. All wheat breeding research in the UK is now undertaken by private companies.

Canada has been through a period of intensive debate concerning PBRs (Gray, 2012; Canadian Seed Trade Association, 2013). The *Plant breeder's Rights (PBR) Act* was enacted in 1990 (Carew and Devadoss, 2003) and strengthened IPR over plants but, prior to 2014, although Canada has signed UPOV 1991, it had not implemented it (Curtis and Nillson, undated, p. 16). It is doing so during 2014 through the introduction of the *Agricultural Growth Act* which, *inter alia*, will amend the *Plant breeder's Rights Act* (Dawson, 2013b) although there is considerable media debate and opposition from some farmer groups.

Currently, there are no end-point royalties payable to breeders (Gray and Bolek, 2012, p. 26). There is a type of end-point royalty used by Grain Farmers of Ontario, a body which represents Ontario's crop farmers. This is calculated on production, at a rate of $CAN 0.79 per tonne for wheat in 2013, and is paid to the farmer organisation, not the breeder or PBR owner. The revenue is used (Grain Farmers of Ontario, 2010) "... to cover administration, research and market development activities, and other producer programs to the benefit of all producers." This end-point royalty is different from the Australian one because it is not appropriating PBR. Breeders and government in Canada appear to favour end-point royalties in order to appropriate breeder's rights and increase their revenue, thus promoting a private breeding industry. This would be possible if UPOV 1991 were signed and the new legislation enacted. On the other hand, the National Farmers Union is concerned that, if UPOV 1991 is signed, breeders may remove the farmer privilege (Dawson, 2013a). Historically, the rate of farmer-saved seed is approximately 60–80% although it varies by region, and this high rate, together with weak IP protection, may have limited royalty revenue to breeders but provides farmers with cheaper seed.

Currently, there is some incentive for farmers to buy seed in Quebec as they can only insure their crops if they use certified (bought) seed and pay the royalties that apply to bought seed (Murrell, undated).

In **France** (Alston and Gray, 2013; Gray and Bolek, 2010; Gray, 2012; Curtis and Nillson, 2012) there are royalties on bought and saved seed, as well as an end-point royalty. The royalty on bought seed is transferred to breeders from the seed sellers who record the sales of seed of each variety. The royalty on saved seed is 25% of that on certified seed (Canadian Seed Trade Association, 2013) and the farmer-saved seed rate in France is approximately 45% (Curtis and Nillson, undated, p. 18).

There is an end-point royalty of 0.5 euros per tonne, paid on bread wheat varieties and distributed to breeders in proportion to their market share ((Gray and Bolek, 2010, p. 15), (Alston *et al.*, 2012, p. 32)). The rate is determined by seed and farmer organisations and is set for a period of three years. This particular end-point royalty has relatively low enforcement costs since it is uniform across varieties and farmer declaration of varieties is not required. However, royalty returns are not related to the performance or usage of the varieties and do not provide optimal incentives or appropriation to breeders.

The **United States** is unusual in that varieties can be patented; farmer-saved seed is usually illegal on patented varieties. The rate of farmer-saved seed varies between regions but is around two-thirds (Curtis and Nillson, undated, p. 29; Canadian Seed Trade Association, 2013). There are no royalties on farmer-saved seed nor is there an an end-point royalty. Wheat breeding is financed by levies (check-offs) at the first point of sale, usually based on quantity, and uniform across varieties. Approximately 30–40% of revenue is paid out to finance research. Gray and Bolek (2010, p. 23) note that four States have royalties of between $1/2$ and 1 cent per bushel on some varieties; these vary between States.

Next, we discuss the Australian wheat breeding sector.

2.4 The Australian wheat breeding sector

For a summary of the history and developments in the Australian wheat industry, see Kingwell (2005).

Australia is approximately the sixth largest wheat producing country in the world with 27.4 million tonnes produced in 2011 (FAO, undated), produced by approximately 25,000 wheat producing farms across Australia (Productivity Commission, 2010, p. 62).

The chain of activities in the wheat industry of interest to this thesis is pre-breeding R&D, breeding and release of new varieties and wheat marketing; these are considered in turn.

2.4.0.1 Pre-breeding

As mentioned previously, PBR legislation alone would have been insufficient to drive the changes in the Australian wheat breeding industry (Alston and Gray, 2013, p. 2). The GRDC has been crucial. In an overview of crop research funding models, Gray and Bolek (2011, p. 2) conclude the GRDC plays "...a pivotal role in a better funded and better coordinated agricultural innovation system." In 2012, the GRDC's revenue of $AU177 million was made up of a compulsory levy on all grains produced in Australia ($AU98 million), Commonwealth Government funding ($AU56 million) and interest, grants and other sources (iCropAustralia, 2013, p. 10).

The GRDC supports but does not undertake wheat breeding, by investing in pre-breeding research such as "discovering and validating novel genes and traits" (GRDC, 2011a, p. 1), and maintaining the wheat classification process and the national variety trial. It also plays an important role in stimulating a private breeding industry. This is discussed next.

2.4.0.2 Private breeding and end-point royalties

In the past, Australian wheat breeding was publicly funded and mainly associated with Universities or State Departments of Agriculture. Kingwell (2005, p. 42) estimates the public share of wheat breeding was 95% in 1985. Even in 2000, there was "…essentially no private investment in wheat breeding …" (Jefferies, 2012, p. 5). Following an economy-wide trend towards deregulation and reform, breeding was increasingly privatized in the 1980s and 1990s, altering the distribution of costs and benefits between farmers, breeders and taxpayers. Gray and Bolek (2012) discuss this change in the Australian wheat breeding industry. By 2012, there were no public wheat breeding program (Jefferies, 2012, p. 5). As predicted by the toll-good theory (Gray, 2012; Alston *et al.*, 2012), wheat breeding is now concentrated in a few firms with the largest operating "…on a scale much larger than any of the previous public programs" (Jefferies, 2012, p. 5). The major wheat breeding firms, in decreasing order of size, are AGT, InterGrain, Longreach and Advantage Wheats (formerly, HRZ) (Gray, 2012). These are private companies and have links to international seed companies; three still have shareholders from the former public breeders. Australian Grain Technologies (AGT) is Australia's largest wheat breeding company and was originally formed in 2002 by the University of Adelaide, the South Australian Research and Development Institute (SARDI) and the GRDC.[7] Table 2.1 summarises the major breeding companies; more information is available from GRDC (2011c, pp. 2–4).

[7]See Jefferies (2012) for a history of AGT.

Company Name	Year Established[a]	Geographic Focus[b]	Estimated Market Share 2011/12[b]	International Shareholders[b]	Australian Shareholders[c]
AGT	2002	Australia	23%	Limagrain	GRDC, SARDI, University of Adelaide
Intergrain	2007	West, South, East Australia	14%	Monsanto	GRDC, West Australian State Government
LongReach	2002	Australia	7%	Advanta and Syngenta	Pacific Seeds
Advantage Wheats (formerly HRZ)	2003	High rainfall zones, Australia	<1%	Dow	CSIRO, Landmark, NZPFR, GRDC
Dow		North Australia	0%		
Bayer	2010	Australia	0%		
Other			<1%		
Old public varieties			53%		

[a] Source: Jefferies (2012, p. 5)
[b] Source: Kuchel (undated)
[c] Source: Grains Research & Development Corporation (GRDC) (2011c, pp. 2–3)

Table 2.1: Australia's private wheat breeding companies

The rise of a private breeding industry was a result of institutional changes in Australia that allowed firms to better appropriate returns on new varieties. Key amongst these changes was the introduction of end-point royalties. When farmers buy seed, they enter a contract to pay an end-point royalty on all grain produced, except that which is saved. When the saved seed is planted, EPRs are due on the resulting output.

The first variety to attract an end-point royalty in Australia was Goldmark in 1996. By 2014, over 180 varieties of wheat attract an end-point royalty (McGrath, 2010) and these account for the majority of Australia's wheat production—71% in 2010 and rising (Jefferies, 2012, p. 4).

End-point royalties vary from $AU 0.95 per tonne for an Intergrain variety, *Camm*, to $AU 4.25 for Pacific Seeds Longreach *Lancer*. For example, AGT collects an EPR on its varieties at rates between $1 and $3.80 per tonne of output; *Yitpi*—one of the most popular varieties grown in South Australia (pers. comm. Rob Wheeler)—attracts an EPR of $1.00 per tonne whilst *Grenade* has an EPR of $3.80 per tonne of output.[8] The industry sets the end-point royalty on the quantity rather than value of production for administrative simplicity.

The end-point-royalty rate is increasing over time, as noted by Gray (2012), Alston *et al.* (2012) and Alston and Gray (2013) who present a graph

[8]Details of the end-point royalty rates are given in `http://varietycentral.com.au/varieties-and-rates/2014-harvest/wheatforthe2013/14harvest`.

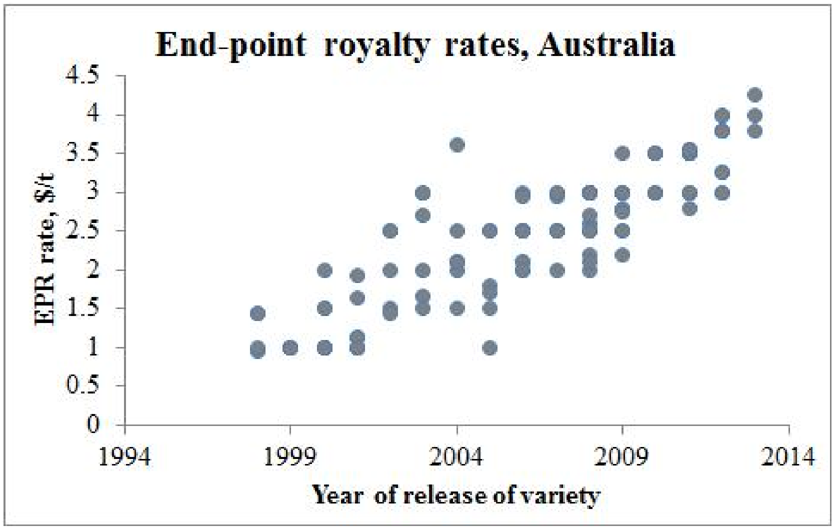

Figure 2.1: EPR rates over time
Source: See Appendix A.1 for source of data

showing the rates over time. We update the graph to the 2013/14 harvest rates and show this as Figure 2.1. This figure confirms that, at a point in time, the EPR is higher on new varieties than on old ones. Whilst in theory, this trend increase could be because either newer varieties have higher EPRs or the EPR of a given variety falls as it ages, in practice the former is more likely. An EPR only varies over the life of a variety for two reasons. First, a quality change: if the classification of a variety changes after release, the EPR will change to reflect this. Whilst this is uncommon with wheat, the barley variety *Scope* is an example: *Scope* was first released as a feed variety with an EPR of around $1.50 but this increased to $2.70 once the quality was upgraded to malting, which is more valuable. The second exception is when the EPR is dropped if the variety has been grown for so long that plant breeder's rights no longer apply.[9]

There are several explanations why the EPR is higher on newer varieties, including that there is less competition from EPR-free varieties as most varieties now attract an EPR; that farmers are more accustomed to paying an EPR and are prepared to pay higher rates; and that breeders' initial uncertainty as to what the market would bear meant they set rates relatively low initially and are increasing them sharply over time to gauge what farmers will pay. According to Mr Rob Wheeler (personal communication), farmers are now trading off marginal yield for marginal royalty, and may use varieties which yield a little below the best varieties but attract a lower royalty. He anticipates royalty rates will not increase further.

Simple linear regression based on the data used in Figure 2.1 show the end-point royalty increased by an estimated average of \$0.18 per annum, although, as mentioned above, this rise is unlikely to continue.

2.4.0.3 Wheat marketing

Once varieties are bred and released, farmers buy seed from agents authorised by the PBR owner. For example, HRZ (now Advantage Wheats) seeds are marketed through AWB seeds; Intergrain seeds are marketed through Nuseed. When a farmer buys seed, they are contracting with the

[9] I am indebted to Mr Rob Wheeler, Leader of New Variety Evaluation, SARDI, personal communication for this information.

PBR owner. The contract sets out the farmer's obligations under the PBR legislation, including the EPR.

Once the grain is harvested, it is stored or transported. Historically, storage and transport was regulated but these are now de-regulated. Major companies involved in transport and storage are Vitera in South Australia, CBH in West Australia and Graincorp in New South Wales, Victoria and Queensland. Since 2007, wheat marketing has also been deregulated and international companies have entered the local market, providing a large number of grain traders, and increased competition. Once the grain is sold or delivered, end-point royalties are due.

With many traders, the EPR collection system could be complicated and expensive but simplifications to the system and institutional arrangements have prevented this (Lawson, 2013, p. 45). One simplification is the formation of a grower registry with unique grower identification. Another is the development of a standard industry contract containing the basic terms and conditions, although the specific terms of the contract and the EPR may differ between breeders and varieties. Only one PBR owner is listed by *VarietyCentral* as not using this contract—they deal in chick peas. Some contracts allow farmers to trade varieties; 8 out of the 45 varieties listed in the 2014/5 harvest information allow this. Varieties may be subject to a "closed loop" marketing agreement whereby the farmer buys the seed from a particular agent and must deliver the grain to that agent. This agreement occurs if the variety suits a niche market, has been bred for a specific market or fills a special need, and may be a premium variety with a high EPR.[10]

Also, breeders appoint royalty managers to look after the IPR of their varieties and collect the EPRs. These managers may be the breeders (as with AGT) or the seed distributor (for example, HRZ with the variety Forrest). Further simplification is obtained by VarietyCentral providing online information on each variety including the breeder, the PBR owner, the EPR rate, the seed distributor, the royalty manager and the contract.

Rather than collecting the EPR from each individual grower, some royalty managers arranged that grain buyers will collect the royalty for them by automatically deducting EPR payments from farmers. Grain traders are not obliged to do this but are paid a collection fee if they do. If the buyer does not collect the end-point royalties, farmers declare sales on a harvest declaration form.

Several major royalty managers (Australian Agricultural Crop Technologies, AGT, InterGrain, SeedNet, Nuseed, NPZ, COGGO Seeds, Grainsearch, Pacific Seeds and Heritage Seeds) have arranged for a single company, SeedVise Pty Ltd, to act as their EPR Agent. SeedVise oversees the collection of end-point royalties and pays the collection fee, and currently acts as agent for 204 varieties that earn royalties (ACCC, 2014a, p. 1). This

[10]Closed loop marketing occurs more often in barley or crops such as lupins than in wheat, but might occur in the future with wheat. The wheat variety *Katana* was to have been subject to a "closed loop" arrangement but the quality proved not acceptable. I am indebted to Mr Rob Wheeler, Leader of New Variety Evaluation, SARDI, for this information.

agency role is explained in ACCC (2014), Alston *et al.* (2012, p. 25) and Grain Trade Australia (undated).

To standardise the royalty collection process, including the EPR collection fee, some royalty managers use SeedVise to negotiate collectively with individual grain traders (ACCC 2014b; The Weekly Times, 2014). This collective bargaining could be deemed anti-competitive under the *Competition and Consumer Act 2010* (Cth); in June 2014, the Australian Competition and Consumer Commission (ACCC) authorised Seedvise for a period of 5 years to undertake these negotiations. The ACCC anticipates (The Weekly Times, 2014) this will improve the efficiency and effectiveness of the EPR system by simplifying and reducing costs for grain traders, royalty managers and farmers, possibly leading to higher EPR collection rates.

The evolution of the end-point royalty system in Australia has fostered a private breeding sector and Alston and Gray (2013, p. 31) conclude

> EPRs are now the primary source of funding for wheat-breeding activities in Australia. . . . [B]y 2010, revenue from EPRs had grown to the point where the wheat-breeding industry made a profit.

2.5 Plant breeder's rights models

Section 2.2 outlined the literature surrounding economic issues of IP protection in general, as well as those related to agriculture and crop breeding.

However, Kolady and Lesser (2009, p. 139), Campi (2013) and Thomson (2013, pp. 2–3) argue there is relatively little formal modelling of plant variety protection. In this section, we review some contributions to modelling the effect of PVR protection. This thesis focusses on the welfare effects of different royalties in the context of Australian wheat breeding using an applied micro-economic game-theoretic approach. Hence, this section concentrates on papers that consider royalties or employ micro-theory and game-theoretic models.

The papers can be classified in several ways: the research question, the date of the study, the crops covered, the type of PVR, whether the analysis is static or dynamic and the methodology used. Appendix A.2 summarises the papers according to these classifications and we discuss them below.

2.5.1 Research question

There are several links between PVP and welfare: from PVP to appropriation, from appropriation to breeding effort, from effort to new varieties, from new varieties to quality and productivity or yield and from yield to welfare.

A series of papers by Godden (1987b, 1988a,b) and Godden and Brennan (1994) details the link between new varieties and yield, regardless of whether the new varieties are due to PVP; this link can be extended to include the effects of PVR.

Some papers investigate the impact of PVP on public R&D or wheat breeding—Knudson and Pray (1991) for example. This covers the first two links above, as do papers which concentrate on the effect on private R&D (Léger, 2005) or the effect on wheat breeding more generally (Alston and Venner, 2002; Léger, 2005; Thomson, 2013). Lesser (1994) estimates the economic value of PVP certificates and their effect on investment in breeding research.

Other papers (Babcock and Foster, 1991; Pray and Knudson, 1994; Alston and Venner, 2002; Kolady and Lesser, 2009) look at the effect of PVP on variety improvement or genetic diversity, whilst Perrin and Fulginiti (2008) narrow this to crop traits. More specifically, looking at the effect on yield or productivity is the focus of Babcock and Foster (1991); Alston and Venner (2002); Carew and Devadoss (2003); Carew and Smith (2006); Naseem *et al.* (2005); Campi (2013) and Thomson (2013).

Kennedy and Godden (1993); Moschini and Lapan (1997); Kingwell (2001); Basu and Qaim (2007) and Beard (2008) concentrate on welfare or farmer profits.

This thesis is taking a different approach: it is not estimating the effect of PVP but is building a stylised model of one specific form of PVP—royalties—in order to determine their effects at a micro-level and investigate the strategic interactions between farmers and breeders.

2.5.2 Date of study

Some of the papers—for example, Butler and Marion (1985); Babcock and Foster (1991); Knudson and Pray (1991)—are relatively old and not enough time had passed after the revised PBR legislation in the late 1980s (US) or 1990 (Australia) to accurately assess the impact of the legislation. Whilst their methods are of interest, their results may be limited.

2.5.3 Country of interest

We can see in Appendix A.2 that much of the work relates to North America, where the legislative and institutional frameworks are different from those in Australia. Some writers (Thomson, 2013, p. 2) argue that Australia's framework provides more effective appropriation than the US or the previous Canadian system, and hence different analysis may be required for Australia.

Some papers apply to countries other than the US and Canada: Godden and Brennan (1994); Brennan *et al.* (1999b); Kingwell (2000, 2001); Alston *et al.* (2004) and Thomson (2013) are centred on Australia. Further, some of the more theoretical models could be applied more generally to different countries—for example, Kennedy and Godden (1993); Basu and Qaim (2007); Beard (2008); Perrin and Fulginiti (2008) and Campi (2013).

2.5.4 Crops covered

Results that apply to one crop may not be transferable to other crops. For example, a model allowing saved seed may not be appropriate for a crop grown mainly from hybrid varieties. Of the papers reviewed in this section, wheat dominates, as Appendix A.2 shows but other crops investigated include cotton, barley and soy beans.

Some papers are not crop-specific; for example, Godden and Powell (1981); Kennedy and Godden (1993); Perrin (1994); Moschini and Lapan (1997); Alston and Venner (2002); Beard (2008) and Campi (2013).

2.5.5 Type of PVR protection

Analyses differ regarding the type of PVR protection under consideration, as shown in Appendix A.2. Some papers relate to general IPR over plants (Kennedy and Godden, 1993; Moschini and Lapan, 1997; Léger, 2005; Basu and Qaim, 2007) whilst some relate more narrowly to the effect of plant patents and the PVP Act in the US and only three relate specifically to royalties—Kingwell (2001); Beard (2008) and Jefferies (2012).

The contribution of this thesis is to construct a model specifically of royalties.

2.5.6 Static or dynamic

Whilst the majority of models are static one time-period models, three are dynamic. Kennedy and Godden (1993) simulated the seed industry over time, showing the importance of market structure. Beard (2008) considered an optimal control model of seed saving and buying in the steady state; and Perrin and Fulginiti (2008) modelled inter-temporal price discrimination. Some studies, such as Butler and Marion (1985), are simple comparative static models and compare results at different time intervals.

2.5.7 Methodologies employed

We discuss three methodologies: production and yield functions, time-series trend analysis and welfare measures. Each is discussed and an exemplar described; following that, we summarise the results and conclusions of the papers.

2.5.7.1 Time-series trend analysis

A simple way of looking at the effect of PVR is to take time-series data on yields and determine if there is a trend change when legislation is introduced or at some other time period of interest. This can be done by looking at a time-series plot, with or without descriptive statistics; by including a dummy variable in a regression model; or by testing for structural breaks. This approach is simple but of limited use as identifying a change in trend does not determine the cause—the break could be due to the variable of interest or other confounding changes (Godden, 1987b, p. 18).

One of the first studies to investigate the US PVPA followed this approach: Butler and Marion (1985) (BM) undertook a large-scale study covering many crops to "examine the economic impacts of the PVPA." This study is summarised and described by Godden (1987a); Lesser (1997); Knudson and Pray (1991); Perrin *et al.* (1983); Naseem *et al.* (2005). BM obtain their data from wide-spread questionnaire surveys of seed companies and state agriculture experiment stations (the public breeders) and certificate data. They note (p. 9) that confounding factors make it difficult to separate the effects of the PVPA legislation from biological and genetic advances, a commodities boom in the 1970s and increased interest in biological diversity.

BM's questionnaires provide a rich source of data which they tabulate and summarise to obtain their major conclusions. The results of interest to this dissertation are that the PVPA (Butler and Marion, 1985, pp. 1–3)

- stimulated the development of new varieties of soybeans and wheat but not R&D input or output for other open pollinated crops,
- did not significantly impact on public plant breeding, and
- resulted in modest private and public benefits at modest public and private costs.

BM themselves note their analysis did not give causality, covered too short a time span of data and could not measure some important variables.

2.5.7.2 Production and yield functions

Godden (1987b, 1988a) explains how a constant returns to scale (CRS) production function can be converted to a yield function in which technology can be separated from other inputs. Problems arising from this approach include the need to control for other local exogenous effects (Carew and Devadoss, 2003; Kolady and Lesser, 2009), the difficulty of picking up a significant effect if the share of PVP varieties is small, and the problem of establishing the appropriate time frame to attribute to PVP (Kolady and Lesser, 2009).

These models have yields, or yield changes, as a response variable in a regression model and include explanatory variables to allow for growing conditions, time trends, PVPA legislation and other factors. Dummy variables are often used for pre- and post-PVR legislation or to indicate if varieties are covered by PVR.

Naseem *et al.* (2005) analyse the effect of the PVPA on cotton yields in the US, using data from 1950 to 2000, and include a regression of yields on an intercept and intercept shift, trend and trend shift, area and area squared, and three variables to account for PVP. These variables are

- the area planted to PVP varieties as a percentage of total area,
- the number of PVP varieties as a percentage of all varieties and
- an interaction term between the percentage of area planted to PVP varieties and the time trend.

All three were significant; the first two variables had negative coefficients and the third one a positive coefficient. Naseem *et al.* (2005) evaluate the effects at the mean level of each variable and conclude that there is an overall positive effect of PVPA on yields. They argue the lack of significance of PVPA on yields in previous models was due to these other models ignoring the negative trend shift that appeared in their results.

This model did not include weather, disease and other inputs and factors; it did not include formal modelling but rather included an *ad hoc* set of variables with a pragmatic specification.

Kolady and Lesser (2009) apply a yield function to wheat in Washington State, US. They follow Babcock and Foster (1991) and use the difference in yield between a given variety and a reference variety as the dependent variable, and include the level of fertiliser and moisture, time trends, and a dummy variable for PVP as explanatory variables. The model is fitted separately for different classes of wheat, and with different specifications. These models suffer from problems of identification, specification and bias. The results show

> "...[i]mplementation of PVP attracted private investment in open pollinated crops such as wheat in the US and provided greater numbers of higher yielding varieties of these crops from both public and private sectors."

Thomson (2013) focusses on how PVP in Australia affects the output of wheat breeders. This study covers PVP in general, and applies regression analysis using data from wheat variety trials, 1976 to 2011. The response variable is a measure of variety performance incorporating yield, quality and cost of disease control, by variety and region, estimated as the value added of a given variety above the existing frontier. The explanatory variables are PVP and control variables for year of release, whether or not the variety is a hybrid and whether or not the variety is marketed as Clearfield™ (and so carries a specific herbicide tolerance gene). PVP is measured in two alternative ways: dummy variables to measure structural shifts with the overall time period split into 4 sub-periods, or a 3-year moving average of the share of varieties that attract end-point royalties.

The conclusion is "that the shift to royalty-funded breeding is associated with a negative impact on breeder output" (Thomson, 2013, p. 4). However, Thomson (2013, p. 23) qualifies this conclusion as the result may be due to institutional teething problems, lower investment (rather than lower efficiency) in breeding or the response variable, yields, may not fully capture the variety improvement. An increase in yield is sufficient but not necessary for technological change (Godden and Brennan, 1994, p. 248) because varieties can be better in terms of (Godden 1998 p. 2) other factors, such as pest or disease resistance, product or storage quality, processing characteristics or appearance.

Finally, in these models, the counter-factual—what would have happened in the absence of PVP—is unknown. The slowdown in agricultural productivity growth (Alston *et al.*, 2012, p. i) may have been more pronounced in the absence of PVP.

These empirical models are useful in providing an understanding of the history and impact of PVR, highlighting correlations and connections, and providing empirical regularities, that can be explained by a theoretical model. However, this dissertation is following a different route. It seeks to develop a stylised model, of limited scope, in order to trace through possible channels of impact of royalties on crop breeding. To see these connections and learn more about how royalties will impact farmers and breeders, as well as to produce a tractable model, we must necessarily make assumptions and the model will not be totally realistic. However, it will allow an understanding of the complicated workings of royalties.

2.5.7.3 Welfare measures

Godden and Powell (1981) discuss the use of economic surplus from aggregate demand and supply curve models as a measure of the welfare benefits from technical change; and Kennedy and Godden (1993) use this approach. In these models, technical change shifts or pivots the supply curve and the resulting changes in consumer and producer surplus are derived. Perrin (1994) reviews this approach, adapted to measure the effects of IPR on R&D.

An example of this approach is Moschini and Lapan (1997). In their model, IPR allow appropriation so the innovator can attempt to extract monopoly profits, which incentivises them and leads to higher R&D. In turn, this shifts the supply curve downwards, increasing welfare. This model highlights the importance of market structure and innovation type: a drastic innovation lets the innovator set an unconstrained monopoly price whereas a non-drastic innovation has the monopoly price constrained by the threat of competition. These have different welfare effects.

This model is applied with illustrative values, but is not estimated empirically and the type of IPR is not explicitly modelled. Moschini and Lapan (1997, p. 1241) conclude that since IPR confer monopoly power, the usual welfare surplus measures will overstate aggregate benefits and there will be a re-allocation to the monopolist, with the outcome depending on institutions and industry structures.

2.5.7.4 Applied micro-theory models

Micro-economic and applied game-theoretic models emphasise strategic interactions between different agents. In this section, we discuss four such models which, although not related specifically to royalties, provide insights into modelling crop breeding.

Kennedy and Godden (1993) set up a game-theoretic model for the seed industry, and investigate scenarios with and without PVRs in two different industry structures (monopoly and perfect competition) in order to understand the incentives for new varieties and the resulting welfare gains.

They consider both a single-sector model in which new varieties are developed inside the sector, and a two-sector model in which varieties are developed outside the sector. The objective is to maximise the discounted sum of welfare (if the sector is competitive) or profit (if a monopolist). If PVRs are present, the innovator retains exclusive rights to the new variety.

In the two-sector model, a non-cooperative Nash game is played. Both sectors choose how much to buy or sell, store and grow, taking into account the other's response and maximising the discounted sum of net returns. The game can end in either a monopoly with a competitive fringe or a duopoly.

Analytic solutions are not possible so illustrative parameter values are used for numerical solutions, simulated over a 5-year time horizon, and social and private returns are measured. The conclusion depends on market structure: if perfect competition results, government intervention is optimal but if monopoly prevails, the best is PVRs with private innovators.

Alston and Venner (2002) (AV) model the effect of the *Plant Variety Protection Act* on wheat in the USA in a two-stage game-theoretic model including royalties. In the first stage, breeders choose the effort to put into breeding given the expected response of the market for new seed. This determines research output and seed quality. In the second stage, seed producing companies take seed quality as given from the first stage and compete to determine the optimal outcome including the number of firms, seed production and royalty rate. Amongst other things, the solution depends on a measure of excludability (entry cost), a measure of appropriability and the royalty rate but the model shows (Alston *et al.*, 2012, p. 13) "stronger IPRs unambiguously increase the price of the invention and increases [sic] research output. However, the higher price of the invention retards adoption, creating an ambiguous effect on the rate of innovation."

AV's empirical work consists of regression models for each of commercial and experimental yields. As with other non-wheat studies, they find the PVPA had no significant effect on the growth rate of yields for experimental or commercial varieties. However, they concede the growth rate of wheat yields might have been lower in the absence of the Act (Alston and Venner, 2002, p. 541). In addition, they conclude (*ibid.*, p. 534) the Act resulted in increased public expenditure on wheat variety research—the opposite to what was expected. They conclude (*ibid.*, p. 541) "the intellectual property protection has not been strong ... the PVPA has not contributed to increases in commercial or experimental yields of wheat."

The AV paper highlights strategic interactions by using a two-stage game-theoretic model, but does not model royalties explicitly. The model presented in this dissertation uses the two-stage game-theoretic approach, but focusses on royalties.

Basu and Qaim (2007) (BQ) apply a game-theoretic model with Bertrand competition, farmer-saved seed and the possibility of illegal use of varieties. The model is applied to Bt cotton in developing countries. The BQ paper highlights the increased appropriability of stronger IPR which increases incentives, innovation and welfare on the one hand, but is offset by higher prices, decreased access and lower welfare on the other.

The agents in the game are a foreign supplier of new GM seed with limited monopoly power, domestic sellers of conventional non-GM seed, and farmers. Farmers choose between three technologies: legal purchase of new seed from the foreign monopolist; illegal purchase or use of the new variety (including illegal farmer-saved seed); and legal use of conventional seed from a domestic supplier. The game is as follows: first, government announces enforcement and fines; next, prices are announced simultaneously by the foreign and domestic suppliers; this gives the price of illegal seed; and finally farmers select the technology. Farmers maximise expected profit under each technology and government maximises welfare. This determines when the marginal farmer chooses legal GM seed rather than illegal GM seed or conventional seed.

The results indicate strengthening IPR will decrease illegal use, but it may be welfare maximising for the developing country to have zero IPR.

In their 2008 paper, Perrin and Fulginiti model the price of crop traits embedded in a variety and include strategic interaction between buyers and a monopolist breeder. The breeder attempts to price discriminate over time, setting a high price initially and subsequently reducing the price. Welfare is measured by the discounted sum of net profits. The paper considers three IPR regimes (none, patents and PBRs), two types of breeder (able or unable to commit to prices) and two types of buyers (myopic or far-sighted). The model is not estimated empirically but illustrative parameter values are simulated.

The trait owner is better off if buyers are myopic. If not, the owner can earn no more than normal monopoly profits. If the owner cannot commit and PBRs are in place, the Coase conjecture holds: buyers know the seller will reduce the price over time and wait for the lower price, making the trait owner worse off.

2.5.7.5 Royalty models

To our knowledge, the first study of the effects of royalty regimes was undertaken by Kingwell (2001). He develops separate static models for farmers and breeders, each with four variants—one for each type of royalty. For each model, Kingwell compares functions for the mean and the variance of the farmer's profit. He shows that, for the same expected profit, the risk (variance) is least for the profit-based royalty, which should therefore be the farmer's preferred option. There is an error in his formulation of the variance of the end-point royalty model, however, which may explain why some of his results appear strange, although it does not affect the overall results.[11] These models are static and relatively simple. They are not tested empirically, but illustrative examples are given using values of the parameters that are considered reasonable.

[11] This was acknowledged by Kingwell in a personal communication.

Kingwell concludes that farmers, being risk averse, will prefer a profit-based royalty over a flat-rate royalty, assuming transactions costs are the same for both. Risk neutral breeders can design a profit-based royalty that gives them a higher profit than the flat rate royalty which leaves the farmer indifferent between the two royalties. Transactions costs are not explicitly included in this model, although Kingwell makes the point that if the administrative costs of the profit-based royalty are much greater than those of the flat royalty, the preference between the royalties may be reversed. Finally, these results will be reversed if the relative risk aversion of the farmer and the breeder change so that breeders are more risk averse than farmers, which is unlikely in practice.

This dissertation also explicitly models royalties and risk, but uses the two-stage interaction of the Alston-Venner model. As with Kingwell, our model is not taken to the data, but uses illustrative parameter values.

Beard (2008) introduces a dynamic model of royalties using optimal control theory. In Beard's model, farmers are given the price of seed, the level of royalties, the cost of saving seed and the sale price of grain, and they choose how much seed to save and how much to sell by maximizing a discounted expected profit stream. At the start of each season, farmers sow newly purchased and previously saved seed. Grain is produced, and at the end of the season, farmers choose the proportion of output to save, and sell the remainder. Beard analyses and compares each royalty type, and concludes either a point-of-sale royalty or an end-point royalty on sold grain is likely to reduce the demand for seed. However, the effect of an end-point royalty on harvested grain is indeterminate and depends on the size of the royalty payment and the proportion of wheat on which the royalty is paid (Beard, 2008, p. 19).

Beard's paper is only preliminary; the paper uses a particular production function, and, due to data limitations, does not take the model to the data. However, the paper is important because it develops a dynamic model which specifically incorporates farmer-saved seed. Farmer-saved seed leads to market failure in crop research and differentiates royalties on crops from other royalties. The first set of models to be presented in this dissertation incorporates farmer-saved seed, but focuses on two-stage strategic interaction rather than an infinite-horizon optimal-control problem. The second set of models concentrates on the risk motive for an end-point royalty.

The models described in this chapter covered many aspects of crop breeding and PBRs. In the next section, we summarise their results.

2.5.8 Results and conclusions

In this section, we briefly review the results and conclusions of the papers. Further summaries are given by Lesser (1997), where results are reviewed on the basis of welfare, static and dynamic efficiency, antitrust and trade theory, and also Campi (2013) and Louwaars *et al.* (2005).

Results from some papers are ambiguous (Kolady and Lesser, 2009) or inconclusive (Louwaars *et al.*, 2005). For the PVPA in the US, some papers concluded there was no increase in private plant breeding: for wheat, see Alston and Venner (2002); for tobacco, Babcock and Foster (1991), for soy beans, Perrin *et al.* (1983) and Lesser (1994), for maize, see Léger (2005) and for canola, see Carew and Devadoss (2003).

Positive links with private plant breeding were found by Kolady and Lesser (2009) in wheat, Naseem *et al.* (2005) in cotton, Butler and Marion (1985) for various crops and Perrin (1999) for agriculture in general.

Lesser (1994) found PVPCs had limited economic value with low returns, less than the costs; whilst Pray and Knudson (1994) found the PVP was not significant.

Some studies found positive results—Naseem *et al.* (2005) concluded PBR led to higher-yielding varieties of cotton in the US, and Kolady and Lesser (2009) reached the same conclusion for wheat in Washington state. In general, Perrin (1999) concluded developing countries will require IPR to catch up to the productivity levels of other countries.

In some papers, conclusions depended on the particular model. For example, Moschini and Lapan (1997) found the results varied with market structure and whether or not the innovation was drastic; whilst in Perrin and Fulginiti (2008), the results depended on the level of seller commitment and buyer myopia.

As for the effects on public investment, both Butler and Marion (1985) and Knudson and Pray (1991) were inconclusive; whilst Perrin *et al.* (1983) and Babcock and Foster (1991) found no significant effect on variety development. Thomson (2013, p. 23) found no evidence the PVPA shifted the production possibility function outwards and Léger (2005, pp. 1876–1877) found no support for the hypotheses that IPR provided incentives for private R&D and innovation.

With prices, Lesser (1994) found the price premium for soy beans due to PVPA was statistically, but not practically, significant although he argued this may be due to the use of trial data and particular weather effects, or the uniform pricing that was in place. Alston and Venner (2002) also found no evidence of a price premium for wheat seed with the PVPA.

Naseem *et al.* (2005, p. 100) comment that the PVPA provides incentives to breeders so it is strange this does not translate into yields. There are reasons for this lack of significance of results—Campi (2013) notes results may vary by location, development status of the country, technologies and sectors, so general models may fail to pick up results. Kolady and Lesser (2009) note early models may not pick up any effect of PVPA because the share of PVR varieties may have been too small to show up. They also add it is difficult to separate exogenous effects, such as, for example, an increase in GM crops, from the effects of the PVPA. Louwaars *et al.* (2005, pp. 39–40) attribute the inconclusive results to a lack of a counter-factual situation for comparison, as well as the long term nature of variety development, although the time required to breed a new crop is falling significantly with new breeding techniques (Zheng *et al.*, 2013).

Some models may be constrained by data availability, and some empirical analyses suffer from econometric problems such as specification, identification and bias. Léger (2007, p. 24) runs a causation test and determines causation runs in the reverse direction to that hypothesised—increased R&D leads to, or causes, IPR protection.

Finally, the inconclusive nature of the results could be due to a lack of impact or effect of PBR legislation. This was thought to be the case early on in the US when legislation was thought to be weak and ineffective. Alston and Venner (2002) conclude the PVPA allowed only relatively weak appropriation.

2.6 Outlook

The models described in this Chapter covered many aspects of plant variety protection and crop breeding, although few were specific to royalties. The contribution of this dissertation is to construct an applied microtheory model in order to compare different royalties. A simplistic model would suggest the type of royalty makes no difference if the price of seed included expected royalties. However, such a model ignores the relative risk-aversion of the agents and the possibility of farmer-saved seed; these are our focus.

In Chapter 3, we develop a two-stage model of royalties: in the first stage, given the institutional and legal set-up of the country, breeders determine the optimal royalty rates to maximize their expected profits, anticipating the farmer's best response to these rates. In the second stage, the farmer uses the royalty rates to determine the levels of bought and saved seed which will maximise their expected profit. Initially, Chapter 3 assumes the farmer fully declares output and saved seed, and pays all royalties due. In Chapter 4, this assumption is relaxed and the farmer may mis-declare output or saved seed.

To investigate the role of risk attitudes, Chapter 5 uses a Principal–Agent model and derives the optimal royalty, on the assumption of no enforcement costs. Chapter 6 shows how the results change when we include enforcement costs in the Principal–Agent model.

Chapter 3

A game-theoretic model with full declaration

3.1 Introduction

The previous chapter identified farmer-saved seed as a key issue in the debate surrounding IPR in the breeding industry (Louwaars *et al.*, 2005, p. 34). It is the major market failure in crop breeding and is important because, in the absence of PBR over varieties, seed saving limits the breeder's ability to appropriate returns from a new variety, reducing their revenue and limiting new investment and innovation.

The farmer will wish to save some of the seed required for next season's production. However, farmers will not save all they require; Pardey *et al.* (2013, p. 29) state "substantial amounts of seed are now purchased annually rather than saved and reused". The purchase of new seed occurs because of the availability of new, improved varieties and because (Godden, 1981, p. 24) "there is a certain amount of variability within distinct varieties of cross-pollinated species ... [which] will, in general, become more marked with successive generations."

Royalties are one mechanism, although not the only one, for enabling breeders to appropriate some of their returns. This chapter investigates which royalty or combination of royalties is optimal in a model of farmer and breeder profits which incorporates farmer-saved seed. A point-of-sale royalty provides some appropriation by imposing a royalty on the new seed farmers buy but it encourages farmer-saved seed, thus limiting the royalty revenue. A saved-seed royalty will prevent this over-use of saved seed but relies on farmers' declarations, and may be open to error or evasion. An end-point royalty overcomes both of these problems: since this royalty affects bought and saved seed in the same way, it does not encourage inefficient use of saved seed; and since the royalty is paid on output, evasion or error in declarations is less likely than for a saved-seed royalty. All three royalties will affect production through changing farmers' cost structures.

The model developed in this chapter is a qualitative model; it is neither an econometric model, nor a forecasting model; nor is it quantitative. As such, it is not a description of reality; we wish to trace out the effects of royalties and need to make stark assumptions so that we can understand what characterises the qualitative trade-offs and equilibrium positions of the model.

In the model, output depends on seed quality, and we assume the farmer combines new and used seed to maximise a discounted sum of future profits, net of royalties. The breeders set the royalty rates to maximise their profits. This model is investigated, and simplified to a steady-state model. Whilst this leads to a loss of generality, it does allow insights and analysis.

Since the institutions and legislation of a country might not allow all royalty instruments, we consider different combinations of royalties; these combinations are called royalty schemes. Within each scheme, breeders choose which royalties they will use. This chapter assumes farmers comply with all royalties by fully declaring output and saved seed, and pay all royalties due; the following chapter introduces the possibility of under-declaration.[1]

First, we determine the first-best allocation of seed by letting a benevolent social planner determine royalties in order to maximise social welfare, which we measure by economic surplus—the sum of breeder and farmer profit. We discuss how the social planner can implement this maximum social welfare and whether they can allocate it between the farmer and

[1] A model where farmers fully comply could correspond to a situation where a third party (such as the government) credibly enforces compliance. Whilst such compliance is costly to enforce, these costs are not modelled at this stage as they do not add to the understanding of the model.

breeders. The outcome actually chosen will depend on the goals of the policy-maker.

Next, we analyse the extreme case of a monopoly breeder and compare this outcome with that of the social planner. We consider whether the monopolist breeder can achieve the maximum level of social welfare as their profit. This has two facets: whether they can implement the maximum level of social welfare and whether they can extract all of it for their profit.

It turns out that in many cases, both the social planner and the monopolist breeder can implement the maximum level of social welfare and allocate it—either according to policy goals in the case of the social planner or for their own profit in the case of the breeders. To achieve this requires at least two policy instruments, including a point-of-sale royalty—one instrument to maximise and one to allocate.

A second insight from our model is that, if used, a saved-seed royalty must be set below the level of the point-of-sale royalty for it to have any effect. Otherwise, saved seed is too expensive and none will be used. When no saved seed is used, seed quality is at its highest and output is maximised but social welfare is below maximum as bought seed is more expensive than saved seed. Maximising social welfare requires balancing the marginal costs and returns of the two seed types.

Finally, the model does not point to one scheme as being the best. The choice of which one is actually in place in a country also depends on factors outside this model. These could be legal and institutional arrangements, risk, or the cost and difficulty of enforcement and compliance. Legal and institutional arrangements were mentioned in the previous chapter; risk and the cost and difficulty of enforcement and compliance are covered in later chapters.

3.2 The full-declaration model

This section introduces a baseline model which includes the three royalties, assumes farmer privilege and so allows for farmer-saved seed, but assumes the farmer fully declares all farmer-saved seed and output. As discussed in Chapter 2, farmer-saved seed was permitted under the 1978 convention of the International Union for the Protection of New Varieties of Plants (UPOV). Under the 1991 UPOV convention, farmer-saved seed is an option and breeders are not obliged to allow it. Farmers *may* be legally allowed to save seed, and *may* be required to pay a royalty on it. Hence, farmers' rights have been decreased but breeder's rights increased under the 1991 convention.

This chapter develops a game-theoretic model to describe the impact of royalties. The timing of the model is that the institutions of the country determine which royalties are allowed under the legislation of the country. Next, breeders maximise expected profits by setting the royalty rates, bearing in mind the anticipated best-response of the farmer. Given these royalties, the farmer chooses the level of seed to buy in order to maximise their expected profit. Finally, profits, production and social welfare are realised. The model is solved by backwards induction to find a subgame perfect Nash equilibrium; this is repeated for different royalty schemes, taking royalties singly, in pairs or all three together.

First, we model the farmer's revenue, costs, output and profit, for an arbitrary year, t.

We assume a single, representative, risk-neutral farmer who sows a constant, unit-sized area to wheat. For ease of exposition, we call this area 1 hectare. The assumption of devoting the entire area to wheat growing removes the choice between wheat and non-wheat activities; whilst this is a simplification, it allows us to focus on the impact of royalties and farmer-saved seed. The farmer's choice is between using bought (new) seed and saved seed.

In practice, the farmer has many varieties to choose between, and may plant more than one variety. This choice depends on the characteristics of each variety—their expected yield, price, quality and classification of grain, time to maturity, drought tolerance and disease resistance—as well as the farmer's attitude to risk. The farmer needs to weigh up these criteria under various weather conditions that could occur, and (SARDI, 2013, p. 10)

> …consider their individual …situation and make their selection based on all available information. . …[T]he growing of a single variety only should be avoided. Climatic, disease and

price risks should be spread by growing at least two or more varieties with varying maturity, disease resistance and/or quality classification.

Our model is not concerned with this variety choice; for ease of exposition, the combination of varieties the farmer uses is called "the variety".

The model assumes the farmer sows seed of known quality at the start of the season, grows the wheat, incurs costs (including royalties) and at the end of the season retains some wheat as seed and sells the remainder. Profits are determined. At the start of the next season, the farmer buys some new seed and combines it with the previously saved seed, creating seed input, the quality of which is a weighted average of the quality of the bought and saved seed. This seed is sown and the process repeated. We model the farmer maximising the sum of discounted profits.

The timing is as follows:

- At the start of the season, the farmer has seed of given quality which they plant and grow.
- At the end of the season, wheat is harvested—production depends on the quality of wheat at the start of the season.
- The farmer pays end-point royalties on the value of production.
- For the next season, the farmer requires an amount of seed depending on the seeding rate, and chooses the proportion of the required seed which will be bought. The remainder will be sourced as farmer-saved seed.

- The combination of bought and saved seed determines the quality of the seed to be sown at the start of the next season.
- The farmer pays point-of-sale royalties on the bought seed.[2]
- The farmer pays saved-seed royalties on the saved seed.
- All wheat produced but not kept as saved seed is sold.
- This cycle is repeated yearly.

Given this setup, the farmer's expected profit for year t is given by:

$$\pi_{ft} = (1 - r)Q_t - P_b\psi b_t - P_s\psi(1 - b_t) - C \tag{3.1}$$

and this equation is now explained.[3]

With a unit sized area, the amount of seed required to sow the entire area is given by the seeding rate, denoted $\psi > 0$ and denominated in kilograms of seed required per hectare sown. The farmer sows a proportion $b_t \in [0, 1]$ of the farm to bought seed; the remainder, $1 - b_t \in [0, 1]$, is the proportion sown to saved seed, so the farmer uses ψb_t kilograms of bought seed and $\psi(1 - b_t)$ kilograms of saved seed. Output in year t is Q_t tonnes. Hence, the farmer sells $Q_t - \psi(1 - b_t)$ tonnes of wheat.[4] The output price of

[2]As a simplification, we ignore any price on bought seed other than the point-of-sale royalty. Including a non-royalty price on bought seed complicates the model without providing further insight.

[3]The dynamic behaviour of farmers in bulking-up seed is complex and outside the focus of this thesis so is not represented in this equation.

[4]For simplicity, other uses of seed, such as stock feed, are ignored. They are not the focus of this investigation and including them would add extra complexity without extra insight. EPRs are payable on the total amount of wheat harvested including grain fed to the farmer's livestock. See GRDC(2011a, p. 4).

wheat is normalised to \$1 per tonne and does not depend on the quantity produced[5] so the farmer's revenue is $\$Q_t - \psi(1-b_t)$.

After production, an end-point royalty is paid at a rate of $r \in [0,1]$, denominated in \$ per tonne of output or, equivalently, \$ per \$ value of production. In Australia, under current legislation, breeders *may* charge an end-point royalty on seed saved by the farmer; some do and some do not. AGT, for example, does not charge an EPR on saved seed (AGT, 2013) and Jefferies (2012, p. 4) notes most variety owners do not charge end-point royalties on saved seed. The model in this chapter assumes farmer-saved seed is subject to an end-point royalty, so the EPR is due on the total value of production. This is a simplifying assumption that makes the model tractable but does not significantly alter the findings of the model. The model was also analysed under the alternative assumption that end-point royalties are due on production net of saved seed; this analysis is included in Appendix C and the two models are briefly compared at the end of this Chapter.

With an output price of \$1 per tonne and valuing saved seed by its opportunity cost, the value of all production is \$1 per tonne. Assuming end-point royalties are due on all production, the total EPR payment is $\$rQ_t$ and the farmer's net revenue after paying EPRs is $(1-r)Q_t$.

[5]Implicitly, we assume farmers are price takers. This could be due to perfect competition or the farmer residing in a small open economy.

A point-of-sale royalty of $P_b \geq 0$, denominated in \$ per kilogram, is paid on all bought seed at the time of purchase with a total cost of $\$P_b \psi b_t$. Similarly, a saved-seed royalty of $P_s \geq 0$, denominated in \$ per kilogram, is paid on all saved seed with a total cost of $\$P_s \psi(1 - b_t)$. No other costs of buying or saving seed are included. In reality, there could be transport, certification, storage and other costs but these costs are not important to the model.[6]

All other costs of growing wheat are summarised as a cost C denominated in \$, which depends on the total area of wheat, but not on the split between seed types, and so, for our unit-sized farm, is a fixed cost.

It now remains to model production. Production of grain depends on many inputs. For example, the farmer could reduce the seeding rate and increase fertiliser use, and end up with the same level of production. However, in this model, a simple production function is used in order to obtain tractable results and keep the model simple but still retain the essential features we wish to model. We assume the farmer uses the required kilograms of seed ψ, and production depends on the quality of the seed used, with production in year t Q_t depending on the quality of the seed input at the start of the season q_{t-1}. That is, the production function is F with $Q_t = F(q_{t-1})$.

[6]Alternatively, the cost of bought seed P_b could be defined to include all the costs of bought seed, including the point-of-sale royalty; and the cost of saved seed P_s could be defined to include all the costs of saved seed, including the saved-seed royalty.

The quality of seed may vary between bought and saved seed. Whilst, in the past, saved seed lost vigour and may have been contaminated with weeds or diseases, this difference in quality is now less than previously.[7] However, the quality of saved seed may deteriorate due to genetic drift, adverse weather during harvesting, poor storage facilities, contamination and other reasons (Edwards (undated), GRDC (2011b), Rowehl (2013), Savage (2013)). Van Gastel *et al.* (2002) discuss the issue and comment (p. 5):

> New varieties, after they enter commercial production, may lose their genetic potential or become susceptible to pests over time, which requires their replacement. Moreover, the varieties may also be exposed to genetic, mechanical and pathological contamination during the seed multiplication process. There is a practical need to limit the number of generations that the seed is multiplied after breeder seed.

Edwards (undated, p. 1) observes that the literature is inconclusive, but that "a yield penalty . . . depends almost exclusively on the seed production and storage practices of the individual producer." Finally, Edwards (undated, pp. 1–2) presents the results of a trial comparing farmer-saved seed to the certified seed of the same variety; this showed

[7] Again, I thank an anonymous examiner for this point.

> the majority of farmer-saved seed samples performed comparably to their certified counterparts in terms of yield ... yield disadvantages of 15 percent ... were observed for some of the poorest quality samples.

Farmers will use saved seed even if its productivity is lower than new seed if its relative price is below that of the new seed by enough to compensate for the productivity loss.

Seed quality is modelled as a weighted average of the quality of bought and saved seed and is given by

$$q_t = b_t \bar{q} + \theta(1 - b_t) q_{t-1}. \tag{3.2}$$

In this equation, the quality of the seed sown in time period t, denoted q_t, is an average of the amount of bought seed used in period t b_t and the amount of saved seed used in period t $1 - b_t$. The weights are the respective qualities—the quality of the bought seed is denoted $\bar{q}$ and the quality of the saved seed is given by θq_{t-1} where q_{t-1} is the average quality of the crop from which the seed is saved, and the parameter $\theta \in (0, 1)$ indicates how close the quality of the saved seed is to the average quality of that crop. If $\theta = 1$, saved seed is as good as the average quality last period: there is no deterioration. As θ falls, saved seed becomes inferior. Implicit in this is the assumption that saved seed is never better than the quality in the previous time period and nor does it ever drop to zero or below. Whilst $\theta > 1$ is possible, if the farmer selects a natural "sport" with superior quality characteristics, this is not covered by, and is beyond the scope of, this model. Also, $\theta = 1$ is possible, but is not the focus of this model—we assume saved seed is not *exactly* as good as the crop from which it was saved, although it could be extremely close. The assumptions of this model imply that seed prices and royalties are independent of the quantities of seed, and so if saved seed was exactly as good as new seed, the decision as to which type to use would be an all-or-nothing one: use whichever of bought and saved seed is cheaper per kilogram.

The production function is assumed to have the usual characteristics, $F(0) = 0, F' \geq 0, F'' \leq 0$, and Inada conditions,

$$\lim_{x \to 0} F'(x) = \infty \text{ and } \lim_{x \to \bar{q}} F'(x) = 0. \tag{3.3}$$

The farmer will choose the proportion of seed to buy each year $b_i, i = 1, 2, \ldots$, to maximise the discounted sum of future expected profits

$$\Pi = \sum_{t=0}^{\infty} \pi_{ft} = \sum_{t=0}^{\infty} \beta^t \left[(1-r)F(q_{t-1}) - P_b\psi b_t - P_s\psi(1-b_t) - C\right] \tag{3.4}$$

where $\beta \in [0, 1]$ is the appropriate discount factor, seed quality q_t is given in Equation 3.2 and q_0, $\bar{q}$, θ, ψ, r, P_b, P_s and C are parameters.

This optimisation will provide an equation for the optimal proportion of bought seed each year $b_t^*, t = 1, 2, \ldots$, which could be simplified by repeated substitution of the terms $b_{t-1}, b_{t-2}, \ldots$. Similarly, the quality equation (Equation 3.2) can be re-expressed by repeated substitution of the terms $q_{t-1}, q_{t-2}, \ldots$. In this way, it would be convenient to re-write the optimal seed quality and proportion of bought seed for each year in terms of the original quality q_0. Unfortunately, these expressions are not simple, and this problem appears to not have a tractable analytic solution. Any solution would be complex and lead to little insight. This difficulty is due to the formulation of the quality equation, whereby terms involving the different time periods are not separable.

Instead, we turn our attention to the first-order condition, $\frac{\partial \Pi}{\partial b_t} = 0$, which can be re-arranged to give

$$\beta^t \left\{\beta(1-r)F'(q_t)(\bar{q} - \theta q_{t-1}) - (P_b - P_s)\psi\right\} = 0. \tag{3.5}$$

This equation implicitly defines the optimum proportion of bought seed b_t^* as a function of the seed quality q_t.[8] An explicit solution is not forthcoming but we can consider the intuition behind this condition as well as comparative static results.

The intuition behind the first-order condition is that the value of the choice variable at the optimum balances marginal costs and marginal returns. Consider an arbitrary year. At the start of the year, suppose the farmer buys extra seed to sow a unit area instead of saving seed to do this. This means the farmer will buy ψ units more seed and retain ψ units less

[8] The second order condition gives $\beta^{t+1}(1-r)F''(q_t)(\bar{q}-\theta q_{t-1})^2$ which is non-positive, since the production function is assumed to have non-positive second derivative.

seed. The marginal cost of buying seed increases by $P_b\psi$ but the marginal cost of saving seed decreases by $P_s\psi$. Hence, at the start of the year, profits increase by $-P_b\psi + P_s\psi$. At the end of the year, there is an increase in production (and revenue, given the output price is normalised to 1) of

$$\frac{\partial F(q_t)}{\partial q_t} * \frac{\partial q_t}{\partial b_t} = F'(q_t)(\bar{q} - \theta q_{t-1}).$$

This is made up of the extra production from increasing the quality of seed as well as the marginal change in quality due to buying more seed. However, an end-point royalty is payable on this production so the net return is $(1-r)F'(q_t)(\bar{q} - \theta q_{t-1})$ and, finally, this is discounted by 1 period as the revenue occurs at the end of the time period.

Adding the two effects, we get the marginal change in profit as

$$-P_b\psi + P_s\psi + \beta(1-r)F'(q_t)(\bar{q} - \theta q_{t-1})$$

which is analogous to the first-order condition in Equation 3.5 above.

Two assumptions of the model are critical in leading to interior solutions in both seed quality and the proportion of bought seed.[9] The first is the Inada conditions of the production function; the second is that the price of bought seed exceeds the price of saved seed, $P_b > P_s$.

First, we discuss the importance of the Inada conditions. Suppose when quality is close to zero, the marginal product (and hence marginal

[9]Interior conditions are derived in Appendix B.1.

revenue) of increasing quality are very low. It is possible this marginal revenue would be below the marginal cost of increasing quality so the farmer will not increase seed quality. Since marginal product falls as quality increases, it is never above marginal cost in this scenario and the farmer will never increase quality and will buy no new seed. Alternatively, suppose when quality is near its maximum $\bar{q}$, the marginal product (and hence marginal revenue) of increasing quality are very high. It is possible this marginal revenue would still be above the marginal cost of increasing quality and the farmer will increase quality further by buying more seed up to its limit when quality is $\bar{q}$ and the entire area is sown to new seed. The Inada conditions prevent these scenarios from occurring.

Now consider the condition on the prices of new and saved seed. If saved seed was always more expensive than new seed, the farmer would always use new seed since saved seed is never more productive than new seed. Similarly, if new seed was always more expensive than saved seed by a margin greater than the possible marginal increase in the quality of new seed, the farmer would never use new seed.

Comparative static results are derived, for an interior solution, from the first-order condition[10] and are shown in Table 3.1. Notice that seed quality moves in the same direction as the proportion of new seed. This result is because the new seed is assumed to be of the same or better quality than saved seed. These comparative statics results are largely as ex-

[10]Appendix B.2 presents the derivations.

Parameter	Impact on proportion of bought seed in year t, b_t	quality of seed in year t, q_t
End-point royalty r	-	-
Point-of-sale royalty P_b	-	-
Saved-seed royalty P_s	+	+
Quality of new seed $\bar{q}$	+	+
Seeding rate ψ	-	-
Discount factor β	+	+
Saved-seed quality factor θ	-	-

The symbol "+" indicates a positive result:
an increase in the parameter is associated with an increase in the respective variable.
The symbol "-" indicates a negative result:
an increase in the parameter is associated with a decrease in the respective variable.

Table 3.1: Comparative statics for the baseline model

pected. For example, an increase in the point-of-sale royalty or a decrease in the saved-seed royalty reduce the relative return on new seed and so decrease the proportion of new seed and increase the proportion of saved seed. An increase in the end-point royalty will also cause the farmer to use more saved seed and less new seed. This is because the marginal return is lower on seed of both types with higher end-point royalties and the farmer responds by reducing the proportion of new seed, in order to reduce marginal costs to restore the marginal product–marginal cost balance. If the quality of new seed improves, new seed is relatively more productive and the farmer uses more of it.

If the farmer is more patient and prepared to wait for the future, they trade-off current profit in favour of future profit and buy more new seed, increasing future quality and production. That is, as β increases and the time preference of the farmer decreases, the farmer buys more new seed, increasing seed quality.

Finally, consider an increase in the seeding rate. This means more seed is needed for the unit sized area, increasing the marginal costs to the farmer. To restore the marginal cost-marginal revenue balance, the farmer will reduce the amount of new seed, reducing the overall marginal cost.

The envelope theorem shows that, even when maximizing their profit, the farmer is worse off after an increase in any of the three royalties, regardless of what happens to production.

Further analysis with this model is difficult; instead, the next section simplifies the model, retaining the important characteristics but allowing analysis, by considering a steady-state model.

3.2.1 Simplifying the model to a steady-state

Simplifying the model to a steady-state will sacrifice some generality but the essential characteristics of the model will remain, and this allows qualitative solutions to be obtained and interpreted. The focus of this thesis is to provide insight and understanding into the trade-offs between, and effects of, different royalties. We wish to characterise the underlying relationships and equilibrium positions qualitatively and we do not wish to consider the effects of any random shocks and disturbances; we are not considering the farmer's choice over time. Although important, this is a different question, requiring a different model from the one in this chapter.

Concentrating on the steady-state means we need only consider two time periods. To illustrate and review the model, we run through it in the context of two time periods.

At time 0, suppose the farmer "inherits" an amount of seed which is sufficient to sow the entire area and is of quality q_0. The farmer sows this, and at time 1, harvests an amount $F(q_0)$. The farmer plans the next season's activities and chooses to buy enough seed to cover a proportion b_1 of the area. This determines the seed to be saved $1 - b_1$ and thus seed quality q_1. We assume all production not retained for sowing next season is sold.

The new and saved seed is planted, and then harvested at time 2. The proportion of new seed is chosen and this determines the proportion of saved seed and the seed quality. With a steady-state, the seed quality is the same at times 0, 1 and 2, as is the proportion of area sown to new seed. That is, $q_2 = q_1 = q_0$ and this is denoted q, and similarly, $b_2 = b_1 = b_0$ is denoted b.

Hence, over the 2 time periods of interest, we have the expected profit of the farmer:

$$\begin{aligned} \pi_f =& (1-r)F(q) - (P_b - P_s)\psi b - P_s\psi - C \\ &+ \beta\left\{(1-r)F(q) - (P_b - P_s)\psi b - P_s\psi - C\right\}. \end{aligned} \tag{3.6}$$

The problem for the farmer is to maximise this steady-state profit by choosing the level of seed quality q which then determines the proportion of new seed b; or equivalently, choosing the proportion of new seed b which then determines the level of seed quality q. This optimisation is subject to the seed quality constraint; the steady-state version of Equation 3.2 is

$$q = b\bar{q} + \theta(1-b)q \tag{3.7}$$

which can be re-arranged to

$$b = \frac{(1-\theta)q}{\bar{q} - \theta q}. \tag{3.8}$$

This steady-state assumption has altered the farmer's decision as to the proportion of each type of seed to use. The level of new seed and seed quality are no longer varying from year to year but are chosen and fixed from the first year so as to maximise lifetime profit.

To proceed further, we require a functional form for the production function; for simplicity, a linear production function $F(q) = q$ is chosen. Hence, the farmer's problem is to choose seed quality q^* in order to maximise

$$\pi_f = (1+\beta)\left\{(1-r)q - (P_b - P_s)\psi b - P_s\psi - C\right\}. \tag{3.9}$$

Since the discount rate has no effect on the maximisation, but only on the level of profit, it is dropped for all future analysis, giving

$$\pi_f = (1-r)q - (P_b - P_s)\psi b - P_s\psi - C. \tag{3.10}$$

This optimisation and the conditions required for an interior solution in seed quality are derived in Appendix B.3 giving

$$q^* = \begin{cases} 0, & \bar{q} < \frac{(P_b-P_s)\psi(1-\theta)}{1-r} \\ \frac{\bar{q}}{\theta} - \frac{1}{\theta}\sqrt{\frac{(P_b-P_s)\psi(1-\theta)\bar{q}}{1-r}}, & \frac{(P_b-P_s)\psi(1-\theta)}{1-r} \leq \bar{q} \leq \frac{(P_b-P_s)\psi}{(1-\theta)(1-r)} \\ \bar{q}, & \bar{q} > \frac{(P_b-P_s)\psi}{(1-\theta)(1-r)} \end{cases} \tag{3.11}$$

The last row of the expression for q^* covers the case where saved-seed royalties equal or exceed point-of-sale royalties, $P_s - P_b \geq 0$. In that case, the farmer will not use any saved seed because it is more expensive than new seed but under the assumptions of the model, saved seed is never quite as productive as new seed.

Since the seed quality and the proportion of seed that is bought are positively related, they have the same interior conditions and comparative static results, so we discuss these after we derive the expression for the optimum proportion of new seed b^*.

Recalling from Equation 3.8 that

$$b = \frac{(1-\theta)q}{\bar{q} - \theta q}$$

and substituting for the optimum seed quality q^*, we have the interior solution for b^* as

$$b^* = 1 - \frac{1}{\theta} + \frac{1}{\theta}\sqrt{\frac{(1-r)(1-\theta)\bar{q}}{(P_b - P_s)\psi}}. \tag{3.12}$$

The interior conditions for b^* are the same as for q^* and are also shown in Appendix B.3.

Heuristically, the interior conditions show the farmer will use *only* new seed if the quality of new seed $\bar{q}$ is above some threshold, because the loss in quality of saved seed is large. Similarly, the farmer will use *only* saved seed if the quality of new seed $\bar{q}$ is below some threshold, because the loss in quality of saved seed is small relative to the costs of new seed. The exact form of these interior conditions relate to the difference in price and

Parameter	Impact on proportion of bought seed b	Impact on quality of seed q
End-point royalty r	-	-
Point-of-sale royalty P_b	-	-
Saved-seed royalty P_s	+	+
Quality of new seed $\bar{q}$	+	+
Seeding rate ψ	-	-
Saved-seed quality factor θ	indett	indett

The symbol "+" indicates a positive result:
an increase in the parameter is associated with an increase in the respective variable.
The symbol "-" indicates a negative result:
an increase in the parameter is associated with a decrease in the respective variable.
The symbol "indett" indicates a result which can be positive or negative:
an increase in the parameter can be associated with
an increase or a decrease in the respective variable.

Table 3.2: Comparative statics for the steady-state model

quality between new and saved seed, as well as other costs which depend on the end-point royalty and the seeding rate.

The comparative static results for interior solutions to this steady-state model are derived in Appendix B.4 and shown in Table 3.2. These results are as expected, given the analogous results in the baseline model, with the exception of those for the saved-seed quality factor θ. In the baseline model, farmers responded to an increase in the quality of saved seed by using more saved, and less new, seed. This reduced the quality of future seed stocks, since saved seed, although better than before the quality increase, is still not quite as good as new seed. In the steady-state model, however, the farmer will adjust seed quality and the proportion of new seed to the optimum steady-state value in every time period. An increase in the value of saved seed would initially increase its use as it is relatively better than before; however, the quality of the seed mix would then decline. This will tend to decrease production and marginal revenue to the farmer. In turn, this will lead to an increase in use of new seed so as to restore marginal revenue. The extent to which this secondary effect offsets the initial impact depends on the seed quality the farmer is facing. The expression that determines whether the partial derivative $\frac{\partial b^*}{\partial \theta}$ is positive or negative is derived in Appendix B.4. If seed quality is low, overall the farmer will use more new seed and less saved seed in response to a marginal change in the saved-seed quality factor. The intuition is that because the seed quality is low, even after the marginal increase, the secondary change on the seed mix is relatively large and more than offsets the first change, resulting in an overall increase in new seed. If, however, seed quality is large, overall the farmer will use less new seed and more saved seed in response to a marginal change in the saved-seed quality factor. The intuition is that because the seed quality is already high, a marginal increase in quality is relatively small and does not completely offset the first change, resulting in an overall increase in saved seed.

The profit of the farmer is not the only outcome that matters, so the next section derives the optimum social welfare outcome, the first-best benchmark solution.

3.2.2 Maximising social welfare

We measure social welfare by economic surplus: the sum of the profits of farmers and breeders. Farmer profit was discussed in the preceding section. Breeder profit is royalty revenue less the breeder's costs. Royalty revenue has already been discussed in Section 3.2. Breeder costs include a fixed component K and a variable component which is assumed linear in the amount of seed sold $b\psi$ and given by $g\psi b, g > 0$. This section continues the steady-state model with the linear production function.

With this setup, breeder profit is given for an arbitrary year by

$$\pi_B = rq + P_b\psi b + P_s\psi(1-b) - g\psi b - K \tag{3.13}$$

and social welfare, the sum of farmer and breeder profits, is simplified to

$$SW = \pi_f + \pi_B = q - g\psi b - C - K = q - \frac{g\psi(1-\theta)q}{\bar{q} - \theta q} - C - K \tag{3.14}$$

which is the value of production less breeding and production costs. The social planner maximises this by ensuring an optimum level of seed quality, which then determines the proportion of new seed and of saved seed.

The first-order condition[11] with respect to q gives

$$1 - \frac{g\psi(1-\theta)\bar{q}}{(\bar{q} - \theta q^{SW})^2} = 0 \tag{3.15}$$

[11]The second derivative is $\frac{-2\theta g\psi(1-\theta)\bar{q}}{(\bar{q}-\theta q)^3}$ which is negative as required.

where q^{SW} is the welfare maximising seed quality. The superscript ^{SW} is used to indicate the maximum level that could be obtained by the benevolent social planner in this full model; this is the benchmark to which values from other models will be compared.

Re-arranging this expression gives

$$q^{SW} = \frac{\bar{q}}{\theta} - \frac{\sqrt{g\psi(1-\theta)\bar{q}}}{\theta} \tag{3.16}$$

$$\text{and then } b^{SW} = 1 - \frac{1}{\theta} + \frac{1}{\theta}\sqrt{\frac{(1-\theta)\bar{q}}{g\psi}}. \tag{3.17}$$

In this optimum, neither the seed quality nor the proportion of new seed depend on the royalties; the intuition is that royalty revenue does not impact on social welfare, since it is a transfer from farmers to breeders. The superscript ^{SW} again denotes the welfare-maximising solution.

Any consumer surplus from consuming wheat has been ignored because it will not change since changes in this model do not change the prices faced by Australian consumers. With an open economy, any extra output will enter the export market, and in a small economy such as Australia, the extra output will not alter prices or exchange rates, and there will be no effect on Australian consumer surplus.

The conditions required to provide an interior solution in both b^{SW} and q^{SW} are analogous to those for b^* and q^* and are

$$g\psi(1-\theta) \leq \bar{q} \leq \frac{g\psi}{(1-\theta)}.$$

These follow the same intuition as those for b^* and q^*.

Now consider how a social planner could implement the optimum welfare outcome. Comparing the optimum level of seed quality a benevolent social planner would choose, q^{SW} from Equation 3.16, with the optimum level the farmer would choose, q^* from Equation 3.11, we see the planner could achieve this desired seed quality if royalties are set so

$$g = \frac{P_b - P_s}{1 - r.} \tag{3.18}$$

Whilst this condition was derived from equating the optimal seed quality the farmer would choose with that of the welfare optimum, it could have been derived instead by equating the breeder's marginal costs and revenue. This alternative derivation is shown in Appendix B.5. In this way, both farmer and breeders are optimising and their optima coincide with the social planner welfare optimum, with social welfare defined as breeder plus farmer profits.

At this social planner optimum,

$$\pi_f^{SW} = \frac{1-r}{\theta}\left\{\sqrt{\bar{q}} - \sqrt{g\psi(1-\theta)}\right\}^2 - P_s\psi - C, \tag{3.19}$$

$$\pi_B^{SW} = \frac{r}{\theta}\left\{\sqrt{\bar{q}} - \sqrt{g\psi(1-\theta)}\right\}^2 + P_s\psi - K \text{ and} \tag{3.20}$$

$$SW^{SW} = \frac{1}{\theta}\left\{\sqrt{\bar{q}} - \sqrt{g\psi(1-\theta)}\right\}^2 - C - K. \tag{3.21}$$

These expressions are derived in Appendix B.6 and show, by inspection, that social welfare is higher if seed quality $\bar{q}$ is higher, the seeding rate ψ and amount of seed required is lower, or the costs are lower. As before, though, an increase in the value of saved seed θ has two opposing effects—it encourages the use of saved seed so increasing production and welfare at the same time as reducing the use of new seed, decreasing production and welfare. Previously, we noted $\frac{\partial b^*}{\partial \theta}$ and $\frac{\partial q^*}{\partial \theta}$ are indeterminate in sign; for the same reason, so is $\frac{\partial SW^{SW}}{\partial \theta}$.

Even when optimised, social welfare is not guaranteed to be positive. The expression above for SW^{SW} shows that it is non-negative if

$$\frac{1}{\theta}\left\{\sqrt{\bar{q}} - \sqrt{g\psi(1-\theta)}\right\}^2 \geq C + K.$$

This is more likely with the parameter values discussed above.

Equation 3.18 gives the condition the benevolent social planner uses to implement the maximum level of social welfare but this does not pin down the values of the royalties. Any combination of the three that satisfies this condition will maximise social welfare and the social planner can then choose the actual royalty rates to split the surplus between farmer and breeders. For example, if the social planner used only a point-of-sale royalty and set $P_s = r = 0$ and $P_b = g$, the breeder's profit is $-K$ and farmers receive $SW^{SW} + K$.

However, negative breeder profit is not sustainable without some intervention additional to the point-of-sale royalty. The social planner could apportion the surplus in any way so that both parties receive non-negative profits and meet their participation constraints. Provided the condition in Equation 3.18 holds, the total surplus is maximised. The actual outcome for farmers and breeders depends on the political goals of policy-makers and the transactions costs involved.

Royalties are not the only intervention that can provide non-negative profits to breeders. Another form of intervention is a quantity independent levy—a lump sum tax or licence fee—to transfer from farmers to breeders, an amount between the fixed breeding costs and the current level of farmer expected profit. Another possible solution is for the government to fund the breeding program and breeders to provide new varieties with no breeding charge. This is a transfer from taxpayers to breeders, rather than farmers to breeders. Historically in Australia, until the 1980s, general taxation revenue was used to finance the breeding effort, with the Federal Government funding Universities, State Departments of Agriculture and other bodies to undertake breeding programs. Gray and Bolek (2012, pp. 7–9) discusses this funding arrangement more fully. This historical funding arrangement also explains

> partly why farmers were against the "privatisation" of breeding which meant farmers would now directly contribute to the

cost of varietal provision rather than benefiting from tax-payer funding.[12]

3.2.3 A monopolist breeder

The previous section showed social welfare (the sum of farmer and breeder profits) is maximised by setting royalties so the condition

$$g = \frac{P_b - P_s}{1 - r}$$

holds; in addition, the social planner can use the royalty rates to determine the actual split of the surplus between farmer and breeders.

This section now considers the polar scenario and supposes there is a monopolist breeder instead of a public breeding program. The breeder has market power and is able to choose the level of royalties in order to maximise expected profit, subject to the anticipated response of farmers. That is, the breeder chooses r, P_b and P_s to maximise their expected profit. The introduction of market power to the breeder may, although not necessarily will, decrease social welfare in total; even so, breeders may be able to use their market power to extract a greater share of a reduced level of welfare, in which case their expected profits could increase.

This analysis continues the steady-state model with the linear productions function that was used previously. In that model, farmer profit was

[12] I am grateful to an anonymous examiner for this useful point.

given in Equation 3.10, breeder profit in Equation 3.13 and social welfare, the sum of farmer and breeder profits, is simplified in Equation 3.14. Previously, we evaluated the benchmark social optimum outcome; this is the outcome against which we will compare all models. In that outcome, the SW surplus is maximised if

$$g = \frac{P_b - P_s}{1 - r}$$

and the split between farmer and breeders depends on the particular values of the three royalties. These results are shown in Table 3.3, along with the results of other schemes, which are now discussed.

For legislative, institutional or pragmatic reasons, the breeder might not use all three royalties, so a variety of schemes involving one, two or three royalties is modelled for the monopolist breeder. For example, in Australia, end-point royalties were only used following the Plant Breeder's Rights legislation. In some situations, the institutional framework may favour one type of royalty; for example, a single marketing desk such as the one that existed historically in Australia in the 1980s would make collection of an end-point royalty easier than if there were multiple, fragmented agents. The difficulty and expense of detecting mis-declaration on saved seed in a geographically large country such as Australia may render a saved-seed royalty ineffective. In addition, it is administratively more efficient to use a single royalty, rather than two or three, if the end result is the same. Within a scheme, the breeder may, of course, choose to set available royalties to zero.

First, consider a scheme consisting of all three royalties. Recall, from the earlier discussion, that the breeder chooses royalties non-cooperatively and moves first. In the last stage, the farmer takes the three royalties as given and then maximises profit, which is given in Equation 3.10. We showed above the farmer will choose the optimum level of seed quality and the required proportion of new seed according to Equations 3.11 and 3.12. Next, breeders choose the profit-maximising royalties given the expected reaction of the farmer.

Appendix B.7 lists the necessary first-order conditions; however, they are not tractable, and optimisation cannot proceed in that way. Instead, we show the monopolist breeder can both ensure the maximum surplus is achieved *and* extract all of it.

Breeders can certainly ensure the maximum surplus is achieved—by setting royalties so the social welfare condition is met,

$$\frac{P_b - P_s}{1 - r} = g.$$

Starting from some combination of royalties that satisfies this condition, we show in Appendix B.7 that breeders will increase their profit if they increase the saved-seed and point-of-sale royalties by the same amount. By doing this, the condition still holds, but breeder profit increases, so the breeder will continue doing this until they push farmer profit down to 0 and breeders receive the full amount of the social welfare surplus.

Thus, the breeder's strategy would be to set royalties subject to the conditions

$$\frac{P_b - P_s}{1-r} = g \quad \text{and} \quad \pi_f = 0.$$

Social welfare is the same as, but breeder profit higher and farmer profit lower than, the social planner optimum; this is a result of the assumption that breeders have market power. These results are shown in Table 3.3; the social planner results are in the top half of the Table and the monopolist breeder results in the bottom half.

In practice, the royalties might not all be available. We adapt the base model for different royalty schemes, still assuming a regime of farmer privilege and full declaration, and consider royalties on their own or two at a time. Appendix B.8 derives the results of these models which are included in Table 3.3.

3.2.4 Discussion

First, we discuss the royalty schemes, the results of which are shown in Table 3.3; after this, we discuss the royalty schemes used in Australia and the UK, and then policy implications, including which scheme is best if there is no opportunity for the farmer to cheat.

	Royalty scheme			
	All three royalties, EPR & POS, POS & SSP	POS only	EPR & SSP, EPR only	No royalties, SSP only
Social planner outcome				
Condition	$\frac{P_b - P_s}{1-r} = g$ (***)	$P_b = g$	-	-
Social welfare	SW^{SW}	SW^{SW}	SW^0	SW^0
Bought seed	b^{SW}	b^{SW}	1	1
Seed quality	q^{SW}	q^{SW}	$\bar{q}$	$\bar{q}$
Allocation	determined by planner	negative breeder profit	determined by planner	negative breeder profit
Monopolist breeder outcome				
Condition	$\frac{P_b - P_s}{1-r} = g$ (***) and $\pi_f = 0$	$g < P_b < \frac{\bar{q}}{\psi(1-\theta)}$	$r = 1 - \frac{C}{\bar{q}}$	-
Social welfare	SW^{SW}	$< SW^{SW}$	SW^0	SW^0
Bought seed	b^{SW}	$\neq b^{SW}$	1	1
Seed quality	q^{SW}	$\neq q^{SW}$	$\bar{q}$	$\bar{q}$
Allocation	$\pi_f = 0$ and breeder can allocate	breeder can allocate	$\pi_f = 0$ and breeder can allocate	$\pi_B < 0$ and breeder cannot allocate

(***): Where a royalty is not allowed, the respective parameter takes the value 0.

$$SW^{SW} = q^{SW} - g\psi b^{SW} - C - K.$$

$$SW^0 = \bar{q} - g\psi - C - K < SW^{SW}.$$

Table 3.3: Results of the full-declaration model

There are three aspects to the comparison of royalty schemes—the level of social welfare achievable, whether the benevolent social planner or monopolist breeder can influence its distribution, as well as the difference in outcomes between the extremes of the planner and monopolist breeder. Table 3.4 summarises the scenarios according to these three aspects.

We have already discussed the three-royalty scenario (column 1 of Table 3.3) and shown a benevolent social planner can maximise welfare by choosing royalty rates so that

$$P_b - P_s = g(1 - r).$$

By changing both end-point and saved-seed royalties by the same amount, the social planner can determine the allocation of this maximum surplus between the farmer and breeders. At the extreme of a monopolist breeder, the same is true—the monopolist will set royalties so social welfare is at its maximum and then use royalties to force farmer profit to zero and extract the full amount of the maximum social welfare surplus. In the social planner case, the allocation can be set according to policy goals.

This same result ensues if only point-of-sale and end-point royalties are available: then, the maximum social welfare is achieved with the condition

$$P_b = g(1 - r)$$

		Level of social welfare achieved			
		SW^{SW}	$SW^0 < SW^{SW}$		
social planner	can determine allocation	All 3 royalties EPR & POS SSP & POS	EPR & SSP EPR only		
	cannot determine allocation	POS only	No royalties SSP only		
		Level of breeder profit achieved			
		$\pi_B = SW^{SW}$	$\pi_B = SW^0 < SW^{SW}$	$\pi_B < SW^{SW}$	$\pi_B < 0$
monopolist breeder	can determine allocation	All 3 royalties EPR & POS SSP & POS	EPR & SSP EPR only	POS only	
	cannot determine allocation				No royalties SSP only

Table 3.4: Summary of the full-declaration model

and the monopolist extracts this by choosing the royalties together to force farmer profit to zero.

Similarly, with saved-seed and point-of-sale royalties, both the benevolent social planner and the monopolist breeder can achieve maximum social welfare by setting $P_b - P_s = g$ and then increasing both royalties together to allocate or extract the surplus.

The maximum level of social welfare is obtained when there is some saved seed and hence the quality of the seed mix is less than the quality of the new seed. This is because saved seed is cheaper since new seed has a positive marginal cost.

The social planner and the monopolist breeder can also affect the distribution of the surplus with end-point royalties only or end-point royalties with saved-seed royalties. However, the value of social welfare is then below the maximum value obtained in the previous scenario. In these cases, since there is no point-of-sale royalty, new seed is as cheap or cheaper than saved seed and more productive so the farmer buys all new seed and $b^* = 1$ and $q^* = \bar{q}$. The social planner or the monopolist breeder can then use end-point royalties to allocate or extract the surplus. The saved-seed royalty is irrelevant because the farmer will not save seed.

The case of a saved-seed royalty only is identical to no royalties at all, because with only a saved-seed royalty, the farmer will not save seed for the reason given above. Social welfare is the same as when there are no royalties and there are no instruments available for the social planner or monopolist breeder to allocate or extract the surplus.

Finally, consider the case of point-of-sale royalties only. By setting the point-of-sale royalty equal to the breeder's marginal costs, the benevolent social planner can achieve the maximum level of social welfare. They are unable to alter the allocation as they have no extra instruments. The result is negative breeder profits. This is not sustainable in the long run without some additional intervention—as discussed previously, this could take the form of industry levies, licenses or tax-payer funded finance to breeders.

However, the monopolist breeder is able to use the point-of-sale royalty to achieve a better outcome for them, at the expense of the farmer and society. By increasing the point-of-sale royalty above marginal cost, they can increase their profit, although decreasing the farmer's profit and social welfare in total. As shown in Appendix B.8, we cannot obtain an analytic solution for the optimum level of the point-of-sale royalty the monopolist breeder chooses but we have its bounds,

$$g < P_b^* \leq \frac{\bar{q}}{\psi(1-\theta)}.$$

If $P_b^* \leq g$, we have the social planner case of negative breeder profits; if P_b^* is too high, farmer profits would be below 0 and the farmer will shut down, leaving the breeders with zero profits. The upper threshold depends on farmer profit and so is positively related to seed quality (both new seed $\bar{q}$ and saved seed θ) and negatively related to the seed requirements (seeding rate, ψ).

The model described here, with privilege and full declaration, shows that both a social planner and a monopolist breeder can achieve the highest level of social welfare (SW^{SW}) and both can allocate or extract it to further their desired ends under the legislative framework of Australia, where point-of-sale and end-point royalties are allowed, and also the UK where point-of-sale and saved-seed royalties are allowed.

It is also clear from Table 3.4 that in order to both maximise the surplus and allocate it, at least two royalties are required—one to maximise and one to allocate; and that the benevolent social planner can achieve these ends with the same regimes as the monopolist breeder.

Some of our results may be driven by specific simplifying assumptions and the functional forms chosen. The main insight from our model is that a monopolist breeder with only an end-point royalty will damage social welfare, and our model predicts lower yields in countries under these conditions (everything else equal). Further, more instruments allow for social welfare to be maximised and the surplus to be extracted. In cases where there is only one instrument, our model leads us to expect to observe further government intervention to ensure the viability of breeders. Testing this requires empirical tests which are beyond the scope of the model and this thesis. Our results and our model are theoretical; further investigation could determine if these insights hold true.

3.3 Policy implications

Social welfare is maximised under a range of different royalty schemes, as shown in Table 3.4. These schemes do not lead to maximum output because maximum output occurs with maximum seed quality and zero saved seed, whilst maximum social welfare occurs with some saved seed with the marginal productivity loss of saved seed balanced by its cheaper marginal cost.

If the benevolent social planner wishes to implement a particular allocation of the surplus, three schemes are suitable—end-point and point-of-sale royalties, saved-seed and point-of-sale royalties or all three royalties. Exactly which of these options will be used in any country depends on many factors including administration and enforcement costs, legal and institutional factors and the culture of the country. For example, it might be considered simpler and cheaper to administer two royalties, not three; then the choice is between end-point and point-of-sale royalties or saved-seed and point-of-sale royalties. Australia has chosen the former; the UK has chosen the latter. This difference could be due to the perceived difficulty of enforcing different royalties given different institutions and geographies, as discussed earlier in this chapter.

Enforcement costs depend on the potential for cheating, which is modelled in the next chapter. In a later chapter, we consider enforcement costs by incorporating them into a Principal–Agent model.

3.4 An alternative specification

So far in this chapter, we modelled end-point royalties as a proportion of all production. Whilst this is possible under Australian legislation, we mentioned previously that it is generally the case in Australia that end-point royalties are payable on production net of saved seed. We investigate the model under this alternative specification in Appendix C and we compare the two models in this section.

There are two main differences between the two models. First, algebraically, the revenue from end-point royalties is now $r\{q-\psi(1-b)\}$ instead of rq and the analogues to Equations 3.10, 3.13 and 3.14 are

$$\begin{aligned}\pi_f =&(1-r)q-(P_b+r-P_s)\psi b+(r-P_s)\psi-C\\ \pi_B =&rq+(P_b+r-P_s-g)\psi b+(P_s-r)\psi-K \text{ and}\\ SW =&\pi_f+\pi_B=q-g\psi b-C-K.\end{aligned}$$

These are different from those of the previous model because (P_b+r-P_s) has replaced (P_b-P_s), and $(r-P_s)$ has replaced $-P_s$. The intuition behind these differences is that in the previous model, end-point royalties applied equally to grain sold or saved but now we need to distinguish between seed types. Compared to the model used in this chapter, it is as if end-point royalties are paid on (subtracted from) all grain and then we refund (add back) the component on saved seed.

These changes carry through many of the calculations. For example, in the model used in this chapter, the benevolent social planner implements the maximum level of social welfare with the condition,

$$g = \frac{P_b - P_s}{1 - r}.$$

In the alternative model, this becomes

$$g = \frac{P_b + r - P_s}{1 - r}.$$

Algebra aside, the important issue is how the results compare. All but two of the schemes show the same principle and results in both models. The exceptions are an end-point royalty on its own or with a saved-seed royalty. With an end-point royalty only, in the original model, the social planner uses the end-point royalty to allocate the surplus but could not implement the maximum level of social welfare. In the new model, the social planner uses the end-point royalty to implement the maximum level of social welfare but cannot allocate the surplus. The difference is because in the old model, the farmer would never save seed because it was less productive but no cheaper than new seed and there is no difference in the impact of the end-point royalty on the two seed types. In the new model, though, saved seed is not subject to an end-point royalty and so becomes relatively cheaper than new seed and the farmer will use some of it.

With an end-point royalty only, the outcome for the monopolist breeder is not tractable in this alternative model and we cannot obtain an analytic solution. We conjecture, based on limited analysis and backed by extensive simulation, that the monopolist breeder will set an end-point royalty above the welfare maximising value. With this conjecture, we conclude the monopolist breeder outcome is essentially the same for both models; the breeder sets the end-point royalty to maximise their own profit and the level of social welfare achieved is below the maximum in both cases.

If an end-point royalty is combined with a saved-seed royalty, the results for the alternative model are the same as the original model if the saved-seed royalty exceeds the end-point royalty since then no seed will be saved. If the saved-seed royalty is below the end-point royalty, the results differ. In the original model, farmers do not save seed if there is a saved-seed as well as end-point royalty, but in the alternative model if the saved-seed royalty is below the end-point royalty, farmers may save seed, and the social planner can use royalties to vary the amount of saved seed in order to achieve the optimum allocation.

An end-point royalty only or with a saved-seed royalty (less than the end-point royalty) are the only schemes that differ between the two formulations of the model. This different formulation has made the algebra slightly harder, and the model more complicated and harder to interpret. Since the results are very similar, the simpler model was chosen for this chapter and will be extended in the next chapter.

3.5 Conclusion

This chapter modelled social welfare, farmer and breeder profits assuming various combinations of the three royalties under consideration, assuming the farmer fully and correctly declares all output and saved seed, and with social welfare defined as the sum of farmer and breeder profits.

Social welfare is maximised for several alternative royalty schemes and this maximum surplus can be both attained and allocated under three schemes. The distribution of social welfare between breeder and farmer depends on the choice of royalties and the degree of market power of the breeders. A monopolist breeder could extract all the surplus whilst a benevolent social planner could allocate according to policy goals.

Since three alternative schemes allow a maximum surplus to be realised and allocated, we require an explanation beyond the model in this chapter for the observed differences between countries. Previously, we have highlighted institutional factors, the difficulty of enforcing specific royalties, and the role of risk.

The possibility of the farmer making false declarations and not paying correct royalties is introduced to this model in the next chapter. A later chapter considers the differing risk-aversion of the agents through applying a Principal–Agent model, and then enforcement costs are added to this Principal–Agent model.

Chapter 4

A game-theoretic model with less than full-declaration

4.1 Introduction

The previous chapter modelled the market failure in crop breeding which was caused by breeders' lack of appropriability of returns due to farmer-saved seed. The model assumed the farmer paid all royalties due and did not have the opportunity to declare less than the full amount of saved-seed or output. However, in practice, the farmer may not declare all output on which end-point royalties are due, or may not declare all saved seed on which saved-seed royalties are due. Giannakas and Fulton (2000, p. 347) state that "the possibility of misrepresentation and cheating arises because it is costly to determine farmers' actions."

In its report, ACIP (2007, pp. 26–27) discuss possible reasons why mis-declaration may occur; these include unintentional errors due to the farmer having grown and saved many varieties, the difficulty of correctly identifying varieties, the complexity of the paper-work, and the large number of grain deliveries. They also note there may be deliberate errors due to the differing rates of end-point royalties. Mis-declaration of output can also occur if the farmer uses the grain for purposes other than sales—stock feed for example.[1] All these make enforcement difficult and potentially costly. We consider deliberate under-declaration only.

Louwaars *et al.* (2005) describe the problems of enforcing IPR from the perspective of the breeder and the institutions and legal framework of the country, and note (p. 137) "the challenges of adequate enforcement for IPRs in plant breeding should not be under-estimated."

This chapter extends the model developed in the previous chapter by allowing the possibility that the farmer under-declares saved seed or output and so does not pay all royalties. This is not to suggest farmers *will* do this, but we consider the incentives for a profit-maximising farmer to do so. If incomplete declaration is profitable, (Giannakas, 2001, p. 1) "rational economic agents' compliance. . . is by no means assured". This behaviour has been termed (Kingwell, 2000, p. 2)

> amoral calculation. . . . The farmer's chief interest is profit. The farmer will abide by or break agreements whenever it is pos-

[1] I am grateful to an anonymous examiner for suggesting this useful point.

sible. This assumption allows this behavioural extreme to be a benchmark case.

The literature on tax evasion considers this issue and discusses reasons why agents will act honestly even given profit incentives to cheat. Such reasons would include moral and ethical constraints. The same is true for farmers and not all will cheat on royalty payments even if they have the opportunity and incentive.

The farmer could also not pay royalties by choosing varieties that are royalty-free. This action is avoidance rather than evasion and could be modelled as rational, intentional and entirely legal if the expected profits from growing these royalty-free varieties exceeds the expected profits of varieties that incur a royalty. We do not consider avoidance; we are considering illegal evasion by less than full-declaration of saved seed or output.

In this thesis, we consider royalties and the problem of enforcement. A separate, wider, issue of whether the problems and costs of enforcement imply IPR should be discontinued, is beyond our scope.[2]

There is a body of literature on crime and enforcement, starting with Becker (1968). In Becker's model, agents compare the expected gain from an offence with the expected loss from being caught, which is determined by both the probability of being caught and the severity of punishment. Risk preferences play an important role in this analysis: a risk-averse indi-

[2] I am grateful to an anonymous examiner for suggesting this useful point.

vidual is more affected by the severity of punishment, whereas a risk lover is more affected by the probability of being caught.

In a seminal paper, Allingham and Sandmo (1972) (AS) extend this work to tax evasion with a model in which a rational agent maximises the expected utility of income. The agent does not declare all income and, if caught cheating, pays a fine on the amount of evaded income. AS conclude cheating increases as either the probability of being caught, or the fine, decreases. An increase in the tax rate has an uncertain overall effect: on one hand, it increases the expected fine which could reduce cheating, but on the other hand, it increases the marginal benefit of cheating which could increase cheating. The models of this chapter obtain similar results.

Yitzhaki (1974) shows this indeterminacy results from assuming that fines are imposed on undeclared income, rather than on the amount of unpaid tax. With fines on the amount of unpaid tax, the tax rate appears in both the marginal gain and the marginal cost of cheating, and these cancel each other out. This leads to the somewhat counter-intuitive result that higher tax rates reduce cheating if fines are levied on unpaid taxes.

A body of literature followed these papers, including discussions of administrative costs, avoidance, evasion, the role of social and psychological factors, behavioural economics and empirical and experimental results. For a review, see Chander and Wilde (1998); Andreoni *et al.* (1998); Bayer (2006a); Bayer and Cowell (2009); Slemrod and Yitzhaki (2002).

We could find no studies specifically studying cheating on crop royalties using a game-theoretic approach. Amacher, Koskela and Ollikainen (2003a,b) (AKO) model forestry and logging. In their model, the government collects royalty revenue on harvested timber, and cheating consists of under-reporting the amount harvested. The focus of AKO's papers is to choose an optimal royalty, subject to a revenue constraint, whereas this dissertation chooses an optimal royalty for the situation in which the revenue goes to the breeder rather than the government.

Kingwell (2000) considers the case of piracy of a new GM crop. The theoretical model focusses on the farmer maximising profit, or expected profit or expected utility of profit, by choosing between four options:

- legal use of the new GM crop,
- not using the new GM crop,
- illegal use of the GM crop through signing the contract but not keeping to it, and
- illegal use of the GM crop by not signing the contract.

The theoretical model is applied to GM cotton in Australia and concludes that risk aversion is important: the less risk averse the farmer, the more likely are illegal activities. Furthermore, only small changes to penalties or probabilities of detection are sufficient to incentivise the farmer to reduce illegal activity.

This model is similar to our model in that piracy ("cheating") is included via penalties and probabilities, and farmers are maximising profits. However, Kingwell's model does not include the breeder side nor the strategic interaction that our game-theoretic model uses; nor is it specific to crops or royalties. It does, however, highlight the importance of risk: we investigate this in Chapter 5.

Basu and Qaim (2007) (BQ) set up a game-theoretic model with a foreign monopolist supplying a GM crop alongside domestic suppliers of conventional seed. This model was described in Chapter 2. In this model, the farmer chooses between options which are the same as in Kingwell's model except the options for illegal use of the GM seed are combined into one in BQ's model. The game starts with the government announcing enforcement and fines; then the prices of the GM and conventional seed are announced simultaneously (this also gives the price of illegal seed); and finally the farmers choose the optimal option.

The model is not taken to the data but is developed in the context of GM cotton. The results show that strengthening IPR will decrease illegal use but that welfare may be maximised with no IPR.

This model is similar to ours in that it is a game-theoretic model with Bertrand competition, there are the same agents (farmers and breeders), and social welfare is used to compare outcomes. In addition, enforcement and fines are modelled in a similar way to our model. However, BQ's model does not focus on royalties specifically and is formulated for GM crops in general. Our model is concerned with royalties on crops such as wheat for which farmer-saved seed is important.

Fraser (2001, 2002) incorporates cheating in a model of farmers choosing the area of land under the EU's set-aside policy and (Fraser, 2013) in a general agri-environment policy. Whilst this has some similarities to our model, as it includes cheating in agricultural setting, it uses a Principal–Agent model which we introduce in the following chapter.

A different set of models are those by Giannakas and Fulton (2000, 2003a,b) (GF). These papers consider output quotas and subsidies, with the possibility of cheating by mis-declaring output. Enforcement is introduced by modelling the probability of, and penalty for, cheating. The models are theoretical ones, not taken to the data.

Giannakas and Fulton (2000, 2003b) investigate the transfer efficiency of the policy instruments with costly enforcement, and therefore cheating. Farmers maximise expected profit, and welfare is measured by economic surpluses. The main conclusions drawn by GF are

- cheating alters the welfare effects of policy instruments and makes quotas less efficient as a way of transferring income to farmers,
- failure to account for cheating may mean quotas are set up incorrectly, becoming ineffective, and
- there may be other effects—such as a distribution from honest to dishonest people.

These models do not use a game-theoretic approach and do not allow for strategic interaction between agents, nor do they model IPR or royalties. Our model does both of these.

Both Giannakas (2001) and Giannakas and Fulton (2003a) use game-theoretic models. The latter paper focusses on quotas and seeks to find the optimal level of enforcement. The game starts with the enforcement agency setting enforcement; then farmers choose output. Farmers choose the above-quota (illegal) output to maximise expected profit, with enforcement modelled by probability and penalty. The optimum outcome balances marginal returns and marginal costs including the marginal penalty. GF conclude that higher enforcement will increase welfare in aggregate, even though individually farmers would be better off if enforcement was low so they could cheat. Once many farmers cheat, the price falls and farmers lose out to consumers. GF also conclude cheating can be deterred if fines are large and enforcement not costly.

Although game theoretic, their model is not directed at IPR or royalties. As with our model, they use expected profit and measure welfare by economic surplus, and include cheating and enforcement in a way similar to our model.

Giannakas (2001) looks specifically at IPR and examines the causes of infringement and its effects on welfare. They use a game-theoretic approach; the game is

- the government sets enforcement, penalties and probabilities,
- the price of the new seed (in this case, GM seed) is set by the innovator (in this case, a foreign supplier) and
- farmers choose whether to use the new GM seed or not.

Then, cheating is introduced so the farmer has a third option of using illegal seed of the GM crop (this covers both farmer-saved seed and illegal purchase of new seed). Farmers maximise expected profits and the game is solved by backwards induction.

Conclusions are drawn from the viewpoint of farmers, innovator and government (or social planner). The innovator will earn more profits the higher is enforcement and the lower is cheating, whilst domestic welfare is maximised if farmers are allowed illegal use. Illegal use increases the welfare of both the cheating farmers and those who buy seed legally as well as increasing adoption of the new seed.

Like our model, this is a game-theoretic approach with government setting penalties and enforcement; welfare is measured by economic surplus; and a small open economy is assumed. However, the context is different. GF consider a foreign supplier of GM seed, and IPR are implicit as a means of enforcement whereas this dissertation explicitly models royalties.

This chapter extends the model from the previous chapter in which end-point royalties are payable on all production. We investigate the possibility of less than full-declaration and the different incentives to farmers to cheat under the different royalty schemes.

We find cheating on output occurs if there is an end-point royalty on its own or with one or both of the other royalties; and cheating on saved seed occurs if there is a saved-seed and point-of-sale royalty with or without an end-point royalty.

The maximum level of social welfare that could be achieved is as high as in the full-declaration model but this is achieved under a royalty scheme consisting of a point-of-sale royalty only, so the social planner will be unable to re-distribute the social surplus without other interventions. In the full-declaration model, the social planner could use more than one royalty instrument and so could extract and allocate the surplus.

The monopolist breeder is best off with the same set of royalty schemes as in the full-declaration model; however, they do not reach the level of profits achieved when declaration is full.

Finally, we show the level of fines and enforcement costs are important in both ranking the various royalty schemes and in determining the distribution of the surplus between farmers and breeder. Under the assumptions of our model, breeders are worse off if there is the possibility of under-declaration of output or saved seed.

The next section takes the model from the previous chapter, when the farmer correctly declared all saved seed and all output, and incorporates the rate of declaration for each of saved seed and output. After that, we compare the outcomes with those of the previous chapter, and finally we draw out conclusions and policy implications.

4.2 The model with less than full-declaration

In this section, we set up the model with the possibility of less than full-declaration in a regime of farmer privilege. Privilege implies the farmer is allowed to save seed but *not* that saved seed is royalty-free; farmer-saved seed may incur a saved-seed royalty.

We take the steady-state model from the previous chapter so we can consider a single time period, simplifying the analysis. As in that chapter, we consider the use of one "variety" which may in fact be a combination of varieties. In this way, we model the effects of royalties and mis-declaration, rather than variety choice.

The model in its general form is again intractable and we introduce functional forms to simplify the analysis and provide insight whilst sacrificing some generality. We use the same functional forms as in the previous chapter for the production function and farmer costs.

The farmer is unable to infringe on a point-of-sale royalty as this is paid on the purchase of seed. However, they can pay less than the royalties due on a saved-seed royalty by not declaring all saved seed, or on an end-point royalty by not declaring all output. Suppose a saved-seed royalty is imposed at P_s on saved seed $1-b$ but the farmer only declares a proportion $m \in [0,1]$ of the saved seed. Then the farmer pays $mP_s(1-b)$ and underpays $(1-m)P_s(1-b)$. Similarly, suppose an end-point royalty is imposed at a rate of r on output q but the farmer only declares a proportion $d \in [0, 1]$. Then the farmer pays rdq and underpays $r(1 - d)q$.

The breeder anticipates the possibility of under-declaration, so devotes effort to enforcing compliance. In practice, the farmer would devote effort to conceal cheating but for simplicity these concealment costs are ignored, as are the consequent losses to society. The costs of cheating are instead included in the breeder side.

A complete model of compliance would contain investigation, detection, conviction and fines. For simplicity, the model used in this chapter combines the first three into a single probability. This is as if, having been investigated, a farmer who has infringed is always convicted and fined, whilst a farmer who has not infringed is never convicted nor fined.

In practice, there are deterrents other than fines. For example, (Lindner, 2000; Kingwell, 2000) name-and-shame campaigns, tip-off rewards, use of statutory declarations and moral suasion.[3] We consider only fines.

Government can set the level of fines and influence the deterrents available and the enforcement costs incurred by breeders for given enforcement effort. However, this choice by government is a wider issue than we cover. We mentioned in the introduction to this chapter that the problems and costs involved in enforcing PBR are beyond the scope of this thesis; they depend on the political and cultural approach to the legislative framework in general, as well as the costs of promoting compliance in this instance.

[3] I am grateful to an anonymous examiner for suggesting this useful point.

If the social planner increases fines or reduces compliance costs, the social surplus is transferred towards the monopolist breeder but this has implications for government spending and is a transfer from tax-payers to breeders. This is a political decision.

We introduce a probability of investigating the farmer denoted $\phi \in [0, 1]$, and a fine which is proportional to the value of under-declaration with factor $f > 1$. If the farmer cheats by an amount x, the expected fine is $\phi f x$. Neither farmer nor breeder can influence the fine as it is determined exogenously by the legal and political institutions of the country. However, the breeder *can* influence the probability of investigating the farmer by choosing the enforcement effort, which is chosen after observing the farmer's decisions.

The enforcement cost covers the costs of investigating, detecting and taking action against mis-declaration, including legal and administrative costs. These costs will vary with the effort the breeder devotes to detecting and acting on mis-declaration,[4] and are modelled by $X(\phi)$, denominated in \$, with $X(0) = 0, X' > 0, X'' > 0$ and Inada conditions,

$$\lim_{y \to 0} X'(y) = \infty \text{ and } \lim_{y \to \infty} X'(y) = 0.$$

The breeder chooses the enforcement effort exerted ϕ but the enforcement cost *function* X is beyond their control since this depends on external fac-

[4]For simplicity, we assume enforcement costs are the same whether the breeder is investigating compliance on saved seed or output or both.

tors such as the institutional and legal framework of the country, geography, culture and social values.

The time-line is important in this model, and is as follows:

- Given the fines and enforcement cost function, the breeder determines the royalty rates.
- The farmer observes royalties, fines and the enforcement cost function, and then chooses the level of bought seed, which determines the amount of saved seed as well as seed quality.
- The farmer chooses the rate of declaration—and thus the level of under-declaration on both saved seed and output.
- The breeder knows the fines and enforcement cost function, observes the levels of bought and saved seed and declarations, and chooses the level of effort to exert to enforce royalties.
- Profits and hence social welfare are realised.

This timing means the farmer's decision is a two-stage process: choosing first bought and saved seed and hence output, and second the declaration rate. Also, the breeder does not pre-commit to the enforcement effort. The early literature on enforcement and cheating assumed that principals could pre-commit to an enforcement strategy. By doing so, though, the threat of investigation would prevent cheating and the principal would have no incentive to carry out the investigation—apart from maintaining credibility. Khalil (1997) modelled the case where the principal cannot pre-commit to an enforcement strategy and showed that without pre-commitment, the principal will increase the probability of detection. Here, it is assumed the breeder does not pre-commit but determines the enforcement effort after observing the farmer's decisions.

As solution concept, we use a subgame perfect Nash equilibrium which can be obtained by backwards induction because information is complete. The breeder chooses the optimal detection effort for given royalties and farmers' seed purchases and declarations. The farmer foresees this optimal choice and takes it into account when deciding on declaration and seed purchases. Finally, the breeder chooses royalties P_b^*, r^* and P_s^* to maximise profit, taking into account the anticipated reactions of farmers and their own optimal reaction to the farmers' choices. For simplicity, we assume both farmers and breeder are risk neutral.

The expected profit of the farmer is given by

$$(1-rd)q-P_b\psi b-P_s\psi m(1-b)-\phi fr(1-d)q-\phi fP_s\psi(1-m)(1-b)-C. \quad (4.1)$$

In this expression, q is seed quality and, since we use a linear production function, it is also output; with the output price normalised to 1, it also represents revenue. The expressions $P_b\psi b$, $P_s\psi m(1-b)$ and rdq are the amounts of point-of-sale, saved-seed and end-point royalties actually paid. Hence, $P_s\psi(1-m)(1-b)$ and $r(1-d)q$ are the amounts of underpayment on saved-seed and point-of-sale royalties respectively and these are multiplied by the expected per-unit fines (ϕf) to give the expected fines. Finally, C represents the farmer's costs. This equation is analogous to Equation 3.10 in Chapter 3.

The expected profit of the breeder is given by

$$rdq+P_b\psi b+P_s\psi m(1-b)+\phi fr(1-d)q+\phi fP_s\psi(1-m)(1-b)-g\psi b-X(\phi)-K.$$

The first three terms represent the actual royalty payments; the next two are the expected fines received by breeders, and the remaining three terms represent costs: $g\psi b$ is the variable breeding cost, $X(\phi)$ represents enforcement costs and K represents the fixed breeding costs.

A suitable functional form for enforcement costs is $a\phi^2$, in which the parameter $a > 0$ represents the difficulty of investigating the farmer and is determined by institutional factors. This is a simple functional form but captures the desired characteristics of the costs. If $a = 0$, enforcement is costless, and the breeder exerts sufficient effort to be certain of investigating the farmer; the farmer knows this and will not cheat. As a increases, the equilibrium probability of investigating the farmer falls, and cheating may result.

With these functional forms, the expected profits of the breeder are analogous to Equation 3.13 in Chapter 3 and are given by

$$\pi_B = rdq+P_b\psi b+P_s\psi m(1-b)+\phi fr(1-d)q+\phi fP_s\psi(1-m)(1-b)-g\psi b-a\phi^2-K. \quad (4.2)$$

4.2.1 Social welfare

Following the definition of social welfare we are using (the sum of farmer and breeder profits), we have

$$SW = q - g\psi b - a\phi^2 - C - K. \tag{4.3}$$

This equation is analogous to Equation 3.14 in Chapter 3. The only difference is that social welfare has fallen due to the cost of enforcement: we assume the social planner cannot influence the enforcement game and its costs are a loss to society, given our definition of social welfare. Less than full declaration could occur, necessitating enforcement, if the planner implements a saved-seed or an end-point royalty.

The first-best scenario from the perspective of the benevolent social planner is to achieve the optimum level of output with zero enforcement costs. We saw in Chapter 3 they could achieve this in the absence of cheating by various schemes: a point-of-sale royalty on its own or with either or both of the other two royalties.

In this Chapter, we allow the possibility of cheating. A point-of-sale royalty only will optimises social welfare without leading to cheating but under this scheme with the point-of-sale royalty set to its optimum value, breeder profit is negative and the participation constraint of the breeder fails. Some other intervention, such as taxes and subsidies, would be required for the social planner to be able to re-allocate the social surplus towards the breeder, confirming the breeder's participation constraint and ensuring their viability.

Alternatively, if one or both of the other royalties is used along with the point-of-sale royalty, cheating may occur and enforcement is required to confirm the farmers' incentive compatibility constraint and ensure their declarations are above zero. If enforcement was costless, the optimum level of social welfare could be reached. However, in reality, third-party enforcement is costly and these costs reduce social welfare.

In the ensuing analysis, we assume the social planner is not using other interventions—this means the point-of-sale royalty only scheme will lead to negative breeder profit and the other schemes have the potential for less than full-declaration and consequent enforcement costs. We consider the maximisation of social welfare under this assumption and therefore subject to these participation and incentive-compatibility constraints.

Following the results from Chapter 3, maximising social welfare gives Equations 3.16, 3.17 and the analogy to 3.21.

$$\begin{aligned} q^{SW} &= \frac{\bar{q}}{\theta} - \frac{\sqrt{g\psi(1-\theta)\bar{q}}}{\theta}, \\ b^{SW} &= 1 - \frac{1}{\theta} + \frac{1}{\theta}\sqrt{\frac{(1-\theta)\bar{q}}{g\psi}} \\ \text{and} \quad SW^{SW} &= \frac{1}{\theta}\left\{\sqrt{\bar{q}} - \sqrt{g\psi(1-\theta)}\right\}^2 - a\phi^2 - C - K. \end{aligned}$$

In the next section, we solve the game and then show how a benevolent social planner could implement maximum social welfare.

4.3 Solving the game

In this section, we use backwards induction to solve the game for the case where all three royalties are allowed.

4.3.1 Enforcement effort

In the final step of the game, the breeder observes the amount of seed the farmer buys and requires (b and ψ), the declaration rates (m and d) and the institutional factors (a and f), and chooses the effort to exert to enforce compliance; this determines ϕ, the probability of investigating the farmer. If there is no production, the breeder will exert no enforcement effort; otherwise, by inspection from Equation 4.2, the breeder's profit is maximised with respect to ϕ for known b, ψ, m, d, a and f with

$$\phi^* = \frac{fP_s\psi(1-m)(1-b) + fr(1-d)q}{2a}. \tag{4.4}$$

The intuition is that the breeder increases enforcement and the probability of investigating the farmer if the benefit from so doing increases. This increase could occur if fines increase, enforcement costs decrease or the farmer increases infringement by declaring less saved seed or output.

The first term in this expression for ϕ^* represents enforcement of the saved-seed royalty and disappears if there is no saved-seed royalty ($P_s = 0$), no saved seed ($b = 1$) or full declaration of saved seed ($m = 1$). The second term represents enforcement of the end-point royalty and this disappears if there is no end-point royalty ($r = 0$), no output ($q = 0$) or full declaration of output ($d = 1$). If there is no output, the breeder exerts no enforcement effort and $\phi = 0$. The breeder's response in terms of setting ϕ is not symmetric in the saved-seed and end-point royalties because with zero saved seed, the breeder may still devote effort to enforcing the end-point royalty but with zero output, there is zero seed, zero saved seed, nothing to enforce, and the breeder will not devote effort to enforcement.

4.3.2 Declaration rates

We now move back one stage. For ease of exposition, we model the farmer choosing the declaration rates m and d in this stage and then in a subsequent stage, choosing the level of new seed they purchase b. Given the game-theoretic set-up of our model, this is equivalent to the farmer choosing the declaration rates and the amount of seed to buy together in this stage but is more simple.

In this stage, the farmer chooses the level of saved seed to declare m and the level of output to declare d given the royalties P_b, P_s and r, the institutional factors f and a, their seed requirements ψ and level of new seed and b and anticipating the breeder will respond to the farmer's decision by choosing the detection probability ϕ^* as in Equation 4.4. Appendix D.1 shows the optimum levels of declaration m^* and d^* are such that

$$r(1-d^*)q + P_s\psi(1-m^*)(1-b) = \frac{a}{f^2} \tag{4.5}$$

for $0 < b < 1$ and given the values of b and hence q the farmer has already chosen. For $b = 1$, there is no saved seed and any m^* is optimal. Equation 4.5 shows evading the two types of royalties are substitutes. For example, suppose the grain market has strong enforcement tools so the farmer fully declares all output, but saved-seed is hard to detect so the farmer declares only some part of saved-seed; in this case, we have $d = 1$ and from Equation 4.5

$$m^* = 1 - \frac{a}{f^2 P_s\psi(1-b)}.$$

The intuition is that saved-seed declaration will increase, and cheating decrease, if the expected fine increases—either by an increase in the royalty or the fine factor or a decrease in the cost of enforcement. This expression for m^* shows that whilst there is some cost involved in enforcing royalties $a > 0$, the declaration rate is less than 1 and there is under-declaration of saved seed.

Alternatively, suppose that the grain market is fragmented and cultural or institutional factors make end-point royalties hard to enforce so the farmer may not declare all output but, at the same time, saved seed is easy to monitor, maybe because farms are geographically close to each other, so the farmer declares all saved seed and $m = 1$. Then the optimum rate of declaration on output is

$$d^* = 1 - \frac{a}{f^2 rq}.$$

For zero output, that is $q = 0$, the declaration rate is irrelevant. For positive levels of output, the expression for d^* makes intuitive sense—declaration increases and cheating decreases if the amount of the royalty increases, or if the expected fine increases, which can occur because the cost of enforcement decreases or fines increase.

This expression for the optimal declaration rate shows the declaration rate on output is less than 1 if $a > 0$. This implies there will be some under-declaration of output if there is some cost to enforcing royalties. If royalties were costless to enforce, they would be fully enforced, and declaration would be full.

4.3.3 Seed quality and purchases

Next, we go one step backwards and solve the farmer's problem. Recall from Chapter 3 that choosing the amount of seed to buy b determines the seed quality q and vice versa; we consider the farmer choosing the seed quality. The farmer does this after having observed the royalties (P_b, r and P_s), institutional factors (a and f), and anticipating the best responses of the breeder in terms of the detection probability (ϕ^*) as well as their best response in terms of the declaration rates (d^* and m^*). Given these, Appendix D.2 shows farmer profit reduces to

$$\pi_f = (1-r)q - P_b\psi b - P_s\psi(1-b) + \frac{a}{2f^2} - C. \tag{4.6}$$

This expression is the same as the corresponding equation in Chapter 3, Equation 3.10, with an extra term which includes fines f and enforcement costs a, and is exogenous and determined by government or institutions. Hence this model is optimised for the same values of b and q, and has the same comparative statics results, as the full-declaration model of Chapter 3. The interior solutions for optimum seed quality and optimum new seed are Equations 3.11 and 3.12 which are reproduced here for convenience.

$$q^* = \frac{\bar{q}}{\theta} - \frac{1}{\theta}\sqrt{\frac{(P_b - P_s)\psi(1-\theta)\bar{q}}{1-r}} \tag{4.7}$$

$$b^* = 1 - \frac{1}{\theta} + \frac{1}{\theta}\sqrt{\frac{(1-r)(1-\theta)\bar{q}}{(P_b - P_s)\psi}}. \tag{4.8}$$

Whilst these optimum values are the same, realised farmer profit has increased with the possibility of less than full-declaration of saved seed or output.

With these optimal values of d and m, Equation 4.4 reduces to

$$\phi^* = \frac{1}{2f} \tag{4.9}$$

showing that the probability of being investigated increases as the fine falls. In equilibrium, fines and detection effort become substitutes.

We now discuss the response of the declaration rates to changes in those parameters of the model that the farmer does not choose, using the condition for optimum declaration rates (Equation 4.5) and the optimum seed quality and purchase (Equations 4.7 and 4.8). The results are derived in Appendix D.3 and discussed next.

First, an increase in enforcement costs will increase cheating because the farmer knows that if enforcement is more costly, the breeder devotes less effort to it and the expected fine falls.

Next, the level of fines. In Allingham and Sandmo's model, as the fine increases, declaration rates increase and cheating decreases. The same is true in our model. This is also the case in the model developed by Giannakas and Fulton (2003a, p. 14): large fines can deter cheating provided enforcement is cheap enough, although in the extreme this becomes neither credible, just, nor costless.

It is worth further discussing the effect of the fine parameter f. If this increases, declaration rates increase and cheating falls, but there is no change to production, bought seed or saved seed. This neutrality is most likely a coincidence due to the particular functional forms used, and deserves mention. There is a parallel to the literature on the evasion of profit taxes. Early models on tax evasion showed that evasion of a profit tax, under monopoly, was neutral with respect to profit maximising levels of output. However, Lee (1998) showed this neutrality was a result of assuming the probability of detection and the fine rate were fixed or depended on either reported profit or the amount by which firms overstate costs or understate revenue. Further, Lee showed that evasion is not neutral if either (or both) of the probability of detection or the fine rate depend on the reported value of some variable other than profit. Bayer and Cowell (2009) extend this debate to an oligopoly model in which the probability of detection varies by firm depending on their declared profit relative to that of other firms. The interdependence between firms causes externalities which affects the firms' output decisions. Hence, if the analogy caries over to our case, then changing the fine rate might impact production in a richer model.

In addition, AS concluded that declarations increase and cheating decreases when the probability of being investigated increases. In our model, at equilibrium, the probability of detection is a substitute for, so inversely related to, the level of fines. A decrease in fines will lead to an increase in the probability of detection but also a decrease in declaration rates and an increase in cheating. In our model, the breeder sets the enforcement effort endogenously so as to keep the per-unit expected fine constant.

AS find an increase in the tax rate has offsetting income and substitution effects so the overall effect is uncertain. The counterparts in our model to AS's tax rate are the royalties and the Appendix shows that our results are also indeterminate. On one hand, an increase in royalties decreases the incentive to declare, which in turn decrease declaration rates and increase cheating. On the other hand, the higher royalties increase expected fines, the breeder steps up the detection effort, declaration rates increase and cheating falls.

4.3.4 Maximising social welfare

Before we consider the strategy of the monopolist breeder, we consider a benevolent social planner whose aim is to maximise social welfare, which we discussed in Section 4.2.1.

We substitute for ϕ from Equation 4.9 into Equation 4.3 giving

$$SW = q - \psi g b - \frac{a}{4f^2} - C - K.$$

This equation is the same as the comparable one in Chapter 3 except for the term involving a and f; this term reflects the loss to society from enforcement and compliance. The parameter a measures the difficulty of enforcement and is to some extent under the control of the social planner who can set up institutions to make enforcement easier. It is realistic to assume enforcement is not costless and $a > 0$. The parameter f represents fines, and this may be partly under the planner's control. However, we are treating these parameters as constants. Hence, the social planner chooses the same royalty rates as in the full-declaration model, although welfare is lower unless enforcement is costless. The condition the social planner puts on royalties is

$$g = \frac{P_b - P_s}{1 - r}.$$

4.3.5 Royalty rates

In the first stage of the game, the last to be solved by backwards induction, the monopolist breeder sets the royalty rates. We consider the profit of the monopolist breeder from Equation 4.2. We re-arrange this expression and simplify by substituting the sub-game perfect continuations ϕ from Equation 4.9 and m and d from Equation 4.5, giving

$$\begin{aligned}
\pi_B =& rq - r(1-d)q + P_b\psi b - P_s\psi(1-m)(1-b) + P_s\psi(1-b) \\
& + \phi f\left\{r(1-d)q + P_s\psi(1-m)(1-b)\right\} - g\psi b - a\phi^2 - K \\
=& rq + Pb\psi b + P_s\psi(1-b) - g\psi b - \frac{a}{f^2} + \frac{a}{2f^2} - \frac{a}{4f^2} - K \\
=& rq + Pb\psi b + P_s\psi(1-b) - g\psi b - \frac{3a}{4f^2} - K.
\end{aligned} \tag{4.10}$$

This expression is identical to the expression obtained for the breeder's profit in the full-declaration model, Equation 3.13 with the addition of the term involving the institutional factors a and f. The institutional factors are constants from the perspective of the breeder and so affect realised profits but not the optimum royalty rates. Hence, the breeder's profit is maximised for the same royalty rates as in the full-declaration model; this involved setting royalties to maximise the social surplus and then increasing both the saved-seed and point-of-sale royalties to extracts the surplus. This leads to the overall condition:

$$\frac{P_b - P_s}{1 - r} = g \quad \text{and} \quad \pi_f = 0.$$

As in the previous model with full declaration, the monopolist breeder can maximise the social surplus and extract the full amount of the surplus. The difference now is that the institutional factors have reduced the size of the maximum possible surplus.

4.3.6 The outcome of the scheme with three royalties

The optimum levels of bought and saved seed are the same as in the full-declaration case of the previous chapter since the farmer chooses them in the first stage of their decision, once the royalty rates are known. However, in this new model, the farmer has a second decision stage—the declaration rates—which makes the farmer better off and the breeder and society (the sum of farmer and breeder profits) worse off. Overall, social welfare falls because of enforcement costs. We ignore distortions due to cheating other than the welfare loss and the re-distribution from breeder to farmer. For example, we ignore any costs incurred by the farmer to conceal cheating. In addition, in Australia, less than full-declaration on end-point royalties will reduce the amount of the R&D levy paid, which will reduce R&D funding; such funding would have benefited the farmer.

The results of this model with the possibility of under-declaration and with all three royalties available are included in Table 4.1 and are now summarised.

- A benevolent social planner maximises the social surplus by choosing royalties so that
$$\frac{P_b - P_s}{1 - r} = g.$$
They can then affect the allocation of the surplus by changing the saved-seed and point-of-sale royalty by the same amount; increasing the royalties increases the breeder's profits at the expense of the farmer's profits.
- The maximum level of social welfare obtainable in this model with less than full-declaration is below that of the model in the previous chapter when declaration was full.
- The farmer chooses the declaration rates so that
$$r(1-d)q + P_s\psi(1-m)(1-b) = \frac{a}{f^2}.$$
Under-declaring saved seed and under-declaring output are substitutes from the perspective of the farmer.

- If enforcement costs are above zero, there is less than full-declaration on saved seed or output ($m^*,\ d^* < 1$). If enforcement is costless, the breeder exerts sufficient effort to prevent any cheating.
- The breeder exerts some effort in investigating the farmer because there is some cheating; the probability of investigating the farmer is given by $\phi^* = \frac{1}{2f}$. As fines increase, the breeder reduces the probability of investigating the farmer, because increased fines serve to deter cheating. Since $f > 1$ was assumed, then $0 < \phi^* < 1$ as required. Enforcement effort and fines are substitutes for the breeder in their effort to detect illegal false declaration.
- A monopolist breeder chooses royalties so that

$$\frac{P_b - P_s}{1 - r} = g \quad \text{and} \quad \pi_f = 0.$$

  This maximises *and* extracts the surplus for the breeder, although their profit is lower than in the corresponding full-declaration case.
- The farmer chooses the same level of new and saved seed as in the previous full-declaration model; this gives the same seed quality. However, their expected profit is higher with the possibility of under-declaring saved seed or output.

	Royalty scheme: All three royalties, EPR & POS, POS & SSP	POS only	EPR & SSP, EPR only	No royalties, SSP only
Social planner outcome				
Condition	$\frac{P_b - P_s}{1-r} = g$ (***)	$P_b = g$	-	-
Social welfare	$\tilde{SW}^{SW} = SW^{SW} - \frac{a}{4f^2}$	SW^{SW}	$\tilde{SW}^0 = SW^0 - \frac{a}{4f^2}$	SW^0
Bought seed	b^{SW}	b^{SW}	1	1
Seed quality	q^{SW}	q^{SW}	$\bar{q}$	$\bar{q}$
Allocation	determined by planner	negative breeder profit	determined by planner	negative breeder profit
Monopolist breeder outcome				
Condition	$\frac{P_b - P_s}{1-r} = g$ (***) and $\pi_f = 0$	$g < P_b < \frac{\bar{q}}{\psi(1-\theta)}$	$r = 1 + \frac{a}{2f^2\bar{q}} - \frac{C}{\bar{q}}$	-
Social welfare	$\tilde{SW}^{SW} = SW^{SW} - \frac{a}{4f^2}$	$< SW^{SW}$	$\tilde{SW}^0 = SW^0 - \frac{a}{4f^2}$	SW^0
Bought seed	b^{SW}	$\neq b^{SW}$	1	1
Seed quality	q^{SW}	$\neq q^{SW}$	$\bar{q}$	$\bar{q}$
Allocation	$\pi_f = 0$ and breeder can allocate	breeder can allocate	$\pi_f = 0$ and breeder can allocate	$\pi_B < 0$ and breeder cannot allocate

(***): Where a royalty is not allowed, the respective parameter takes the value 0.

$$SW^{SW} = q^{SW} - g\psi b^{SW} - C - K.$$
$$SW^0 = \bar{q} - g\psi - C - K < SW^{SW}.$$
$$\tilde{SW}^{SW} = SW^{SW} - \frac{a}{4f^2}.$$
$$\tilde{SW}^0 = SW^0 - \frac{a}{4f^2}.$$

Table 4.1: Results of the model with less than full-declaration

		Level of social welfare achieved				
		SW^{SW}	$\tilde{SW}^{SW}$	$\tilde{SW}^0 <$ $\tilde{SW}^{SW}$	$SW^0 <$ SW^{SW}	
social planner	can determine allocation		All 3 royalties EPR & POS SSP & POS	EPR & SSP EPR only		
	cannot determine allocation	POS only			No royalties SSP only	
		Level of breeder profit achieved				
			$\pi_B = \tilde{SW}^{SW}$	$\pi_B = \tilde{SW}^0 <$ $\tilde{SW}^{SW}$	$\pi_B <$ SW^{SW}	$\pi_B < 0$
monopolist breeder	can determine allocation		All 3 royalties EPR & POS SSP & POS	EPR & SSP EPR only	POS only	
	cannot determine allocation					No royalties SSP only

Table 4.2: Summary of the model with less than full declaration

4.3.7 Less than three royalties

So far, we have discussed the social optimum and the optimum outcome for the monopolist breeder when all three royalties are allowed; now, we turn to schemes in which a subset of the royalties is available. If there are no royalties at all, there can be no cheating; this scheme is the same as in the previous chapter. If there is no end-point royalty, there cannot be cheating on output; and if there is no saved-seed royalty, there cannot be cheating on saved seed. Hence, many schemes will reduce to a single form of cheating. The various schemes are solved in Appendix D.4 and the results included in Tables 4.1 and 4.2.

4.3.8 Discussion

First, we discuss the outcomes if a benevolent social planner determines the royalties. Social welfare, as measured in this thesis by the sum of farmer and breeder profits, is maximised with a point-of-sale royalty on its own because there cannot be any cheating in this scheme, and the benevolent social planner can set the royalty rate equal to the breeder's marginal cost and maximise the surplus. However, without additional intervention of some form, this is not sustainable as the breeder's profit is negative. The social planner cannot use royalties to alter the distribution between farmer and breeder as there is only one royalty in this scheme and that has been used to maximise the surplus.

The worst scheme, in terms of social welfare, is an end-point royalty on its own or with a saved-seed royalty. In these schemes, the farmer never saves seed, but instead uses all new seed and seed quality is at its maximum. This gives less than maximum social welfare but the split of the welfare surplus can be influenced by the social planner.

The rankings of the schemes with respect to social welfare are shown in Table 4.3. The first two columns show the social welfare rankings for the schemes without the possibility of cheating, when declaration is full. The next two columns are for the model with less than full-declaration but high fines and low enforcement costs whilst the last two columns are for the model with incomplete declaration and low fines and high enforcement costs. These rankings depend on the institutions of the country. For example, if institutions are 'weak' so that enforcement is costly or fines are low, the second-best scheme may be either no royalty at all or a saved-seed royalty only, which reduces to no royalties since it results in zero saved seed. However, if the institutions are 'strong' so that enforcement is cheap or fines are high, the second-best scheme may be a point-of-sale royalty with one or both of the other royalties.

However, it is not only the level of the social-welfare surplus that matters; it is also the split between the farmer and the breeder. If the profits of either are negative, some other intervention will be required to ensure continued participation by the agents. In some schemes, a benevolent so-

Full declaration		Less than full declaration			
		"Strong" institutions a low, f high		"Weak" institutions a high, f low	
Social welfare rank	Scheme	Social welfare rank	Scheme	Social welfare rank	Scheme
Highest, SW^{SW}	All 3 royalties POS and EPR POS and SSP POS only	Highest, SW^{SW}	POS only	Highest, SW^{SW}	POS only
		$\tilde{SW}^{SW}$	All 3 royalties POS and EPR POS and SSP	SW^0	No royalties SSP only
Lowest, SW^0	No royalties SSP only EPR only EPR and SSP	SW^0	No royalties SSP only	$\tilde{SW}^{SW}$	All 3 royalties POS and EPR POS and SSP
		Lowest, $\tilde{SW}^0$	EPR only EPR and SSP	Lowest, $\tilde{SW}^0$	EPR only EPR and SSP

$$SW^{SW} = q^{SW} - g\psi b^{SW} - C - K.$$
$$SW^0 = \bar{q} - g\psi - C - K < SW^{SW}.$$
$$\tilde{SW}^{SW} = SW^{SW} - \frac{a}{4f^2}.$$
$$\tilde{SW}^0 = SW^0 - \frac{a}{4f^2}.$$

Table 4.3: Ranking of schemes with respect to social welfare in the models with full declaration and less than full declaration.

Re-allocation not possible	Re-allocation possible
No royalties	All 3 royalties
SSP only	POS and SSP
POS only	POS and EPR
	SSP and EPR
	EPR only

Table 4.4: Re-allocating the surplus: less than full-disclosure, social planner.

cial planner can use royalties to alter the distribution of the surplus. Table 4.4 shows which schemes allow this re-allocation.

So, for example, a point-of-sale royalty only, whilst maximising the social surplus, cannot be used to then re-distribute from farmer to breeder. Under this scheme, breeder profits are negative and intervention additional to the point-of-sale royalty is required to maintain the breeders viability.

However, if the point-of-sale royalty was combined with, for example, a saved-seed royalty, the social planner could set the difference between the two royalties at a level to maximise the surplus and then change both royalties together to achieve their desired re-allocation.

Table 4.5 shows when declarations are full or less than full.

Under-declaration of saved seed will only occur if there is a saved-seed and a point-of-sale royalty with or without an end-point royalty. If there is no saved-seed royalty, there is no royalty to cheat on and cheating cannot occur by definition; a saved-seed royalty on its own or with an end-

Less than full declaration occurs on ...			
output only	output and saved seed	saved seed only	neither output nor saved seed
EPR only POS and EPR SSP and EPR	all 3 royalties	POS and SSP	no royalties POS only SSP only

Table 4.5: Schemes in which less than full declaration may occur.

point royalty will not lead to under-declaration of saved seed because under these schemes, saved seed is more expensive than bought seed but no more productive so farmers will not use saved seed and so will not cheat on it. With a saved-seed but no point-of-sale royalty, the farmer would never save seed as it would be more expensive than new seed but no more productive. However, with a saved-seed and point-of-sale royalty, or with all three royalties, the royalty on the new and saved seed can be set so that the farmer uses some saved seed and the farmer then has some incentive to mis-declare the saved seed.

Under-declaration of output may occur whenever there is an end-point royalty on its own or with another royalty or royalties since the farmer balances the expected fines with the royalty savings from not declaring all output. With no end-point royalty, there is no royalty to cheat on.

Next, we summarise the results from the breeder's perspective. Tables 4.6 and 4.7 are analogous to Tables 4.3 and 4.4 but from the breeder's viewpoint rather than the social planner.

Full declaration		Less than full declaration	
Breeder profit rank	Scheme	Breeder profit rank	Scheme
Highest, $\pi_B = SW^{SW}$	All 3 royalties POS and EPR POS and SSP		
		$\pi_B = S\tilde{W}^{SW}$	All 3 royalties POS and EPR POS and SSP
$\pi_B = SW^0$	EPR and SSP EPR only		
		$\pi_B = S\tilde{W}^0$	EPR and SSP EPR only
Lowest, Negative	No royalties SSP only	Lowest, Negative	No royalties SSP only

$$SW^{SW} = q^{SW} - g\psi b^{SW} - C - K.$$
$$SW^0 = \bar{q} - g\psi - C - K < SW^{SW}.$$
$$S\tilde{W}^{SW} = SW^{SW} - \frac{a}{4f^2}.$$
$$S\tilde{W}^0 = SW^0 - \frac{a}{4f^2}.$$
Negative breeder profit $= -g\psi - K$.
POS only: Breeder profit is below SW^{SW} but not determined.

Table 4.6: Ranking of schemes with respect to breeder profit in the models with full declaration and less than full declaration, monopolist breeder.

Re-allocation not possible	Re-allocation possible
No royalties	All 3 royalties
SSP only	POS and SSP
	POS and EPR
	SSP and EPR
	EPR only
	POS only

Table 4.7: Re-allocating the surplus: less than full-disclosure, monopolist breeder.

The highest level of profit the breeder can extract is when they can use a point-of-sale royalty with either or both of the other royalties. Their profit then is the same as the level of social welfare in these schemes under a social planner. However, the profit achieved is below the best a social planner could achieve (which was with a point-of-sale royalty only).

The worst schemes for a monopolist breeder are no royalties or a saved-seed royalty only, as they receive no royalty revenue and earn negative profits.

The point-of-sale royalty only scheme gives a different result in this monopolist breeder case than in the social planner outcome with respect to allocation of the surplus. The social planner uses the point-of-sale royalty to maximise the social surplus but was unable to re-distribute it. The monopolist breeder uses the point-of-sale royalty to extract all the surplus but cannot maximise the surplus.

Breeders exert effort to enforce compliance; the cost of doing so is inversely proportional to fines. The intuition is that if fines are higher, the breeder needs to exert less effort to enforce compliance.

The values of the institutional parameters are critical as they help determine the optimal declaration rates. If enforcement is costless, detection is certain, declaration is total and the results are the same as in the previous chapter. However, as enforcement costs increase and fines decrease, there is some cheating on the end-point or the saved-seed royalty.

In Australia, both point-of-sale and end-point royalties are allowed, whilst in the UK, both saved-seed and point-of-sale royalties are allowed. The model presented here shows that with 'strong' institutions, both of these schemes lead to the second highest level of social welfare; but are the best in terms of social welfare if the social planner wishes to use royalties to re-distribute the surplus. These schemes are also the best from the perspective of the monopolist breeder.

4.4 Comparison of full and less than full declaration

The model in the previous chapter, in which declaration was full, is a benchmark against which we compare the model with less than full declaration. With the set-up of our model, social welfare is reduced by cheating because the enforcement effort is a loss to society. The extent of mis-declaration depends on the level of fines and enforcement costs: declaration is higher if fines are higher and enforcement costs lower, and then the realised value of social welfare is closer to the maximum obtained when farmers declare all saved seed and output. If enforcement was costless, there would be no cheating. However, this is not realistic and we assume there is some cost to enforcing and hence some possibility of cheating.

With no opportunity to cheat, Table 4.3 showed the maximum level of social welfare could be attained under several schemes including a point-of-sale royalty only, although under this single royalty, the surplus cannot be re-allocated by a social planner. The same result holds if we allow for the possibility of cheating. However, with no opportunity to cheat, this maximum level of social welfare could also be attained by using a point-of-sale royalty with either or both of the other two royalties; then the benevolent social planner can use the instruments to re-allocate the surplus between the farmer and the breeder. In countries with 'strong' institutions, with the possibility of cheating, these schemes—a point-of-sale royalty with one or both of the other two royalties—yield the second-best rather than first-best level of social welfare; but do allow for re-distribution by the social planner.

As for the monopolist breeder, with full declaration, they can achieve the maximum social welfare and extract all of it as their profit; with the possibility of less than full-declaration, they will not reach this level of profit although the same schemes still maximise their profit. With or without full-declaration, the monopolist breeder is worst off with no royalties or a saved-seed royalty only—then they have negative profits. We are unable to rank all schemes as we cannot solve the game for the point-of-sale royalty only scheme.

In our model, the farmer is better off and the breeder worse off than under the same scheme without cheating; the sum of farmer and breeder profits falls. This transfer from breeder to farmer is a result of the assumption of the model that enforcement costs are borne by breeders. We assume the farmer does not incur concealment costs. Had the farmer incurred these costs, in addition to the breeder incurring enforcement costs, this transfer would not have occurred to the same extent. However, an overall decline in social welfare would still occur.

4.5 Policy implications

The model in this chapter shows the optimal royalty scheme depends on the level of fines and enforcement costs as well as whether or not royalties are required to re-allocate the surplus between the farmer and the breeder according to some policy objective.

Maximum social welfare is obtained by setting the point-of-sale royalty equal to the breeder's marginal costs. The breeder's profits will then be negative and intervention additional to the point-of-sale royalty will be required to maintain the breeder's viability in the long run. This other intervention could involve a transfer from the farmer or tax-payer to the breeder. This scenario occurred historically in Australia before the passage of PBR legislation and the introduction of end-point royalties.

Alternatively, policy-makers could perform this re-allocation by using royalties, in which case another royalty instrument is needed. This additional instrument can be either or both of a saved-seed or end-point royalty. At the extremes, either the social planner can set royalties to achieve the desired re-allocation or the monopolist breeder can use royalties to extract the surplus.

To achieve these dual objectives of maximising the surplus and allocating or extracting it, only two royalties are needed, not all three, although one must be the point-sale-royalty. This is the situation in both the UK and Australia—although the UK uses a saved-seed with the point-of-sale royalty whilst Australia uses an end-point royalty with the point-of-sale royalty.

Geographical, institutional, historical and cultural factors could lead to under-declaration being more likely on saved seed than on output, or vice versa. In a geographically large country such as Australia with many farmers spread over a vast area, enforcing a saved-seed royalty will be costly and under-declaring saved seed may be more likely than under-declaring output. Conversely, the previous single desk marketing system and the well established wheat delivery silo system might reduce enforcement costs for an end-point royalty so under-declaration of output may be less likely. An effective legal system might reduce enforcement costs or increase fines for both types of evasion, thus benefiting breeders. Since the cost of such a legal system is borne by society as a whole, this is a transfer from society to breeders. As mentioned previously, the wider issue of whether this transfer from taxpayer to breeder is appropriate is beyond the scope of this thesis.

4.6 Conclusion

In the previous chapter, we modelled the diminished appropriability of the breeder's returns on new varieties caused by farmer-saved seed, assuming full declaration of output and saved seed. Whilst zero royalties maximise social welfare, further intervention is required to implement this scheme. If we restrict attention to schemes which require no intervention beyond the royalties, we concluded that the scheme that both maximised farmer and breeder profits combined, and allowed for a re-distribution between the two agents is a point-of-sale royalty along with either or both of the other royalties.

This chapter extends the analysis by allowing the possibility of the farmer not declaring all output on which end-point royalties are due or not declaring all saved seed on which saved-seed royalties are due. To simplify the analysis, we consider only the welfare loss due to cheating and the re-distribution from breeder to farmer. The same general result holds as in the previous chapter: the scheme that maximises social welfare and allows its distribution is a point-of-sale royalty with either or both of the other royalties although the maximum level of social welfare achieved is below the full-declaration case due to the enforcement effort and costs.

The distribution of welfare between agents depends, as before, on the choice of royalties and the degree of market power of the breeder, but now also the institutional parameters. The values of the institutional parameters are important in determining which royalty scheme is the best. When fines are low or enforcement costs high, the breeder devotes little effort to detect cheating. Farmers know this and may choose to cheat on declarations. In our model, there is an overall loss in welfare because of the extra enforcement effort. There is no change to production compared to the full-declaration model of the previous chapter. These results diverge from those found in other studies—for example, in the case of smuggling in the presence of high input tariffs or quotas (see Bhagwati and Hansen 1973 or Pitt 1981). This difference may be due to the timing of decisions in our model or the particular functional forms used.

The UK scheme—point-of-sale and saved-seed royalties—and the Australian system—point-of-sale and end-point royalties—are both optimal for welfare if policy-makers wish to have a scheme in which royalties can be used to determine allocation. This is the case regardless of whether institutions are strong or weak; however, the maximum realisable level of social welfare is lower if institutions are weak.

This chapter introduced the possibility of under-declaration. It showed the importance of the likely form of cheating, the values of the institutional parameters and the goals of policy-makers. In Chapter 2, we also noted the importance of risk sharing, and the following chapter uses a Principal–Agent model to analyse risk sharing between the risk-averse farmer and the risk-neutral breeder. The final substantive chapter extends this model by including enforcement costs.

Chapter 5

A Principal–Agent model without enforcement costs

5.1 Introduction

The previous two chapters modelled the diminished appropriability of breeders' returns from crop breeding due to farmer-saved seed. This was identified in Chapter 2 as one reason why end-point royalties are used. Another motive for introducing end-point royalties is risk sharing; this is the subject of this chapter. In its fact-sheet on end-point royalties, the GRDC (2011a, p. 2) states "Under an EPR system breeders and growers share the production risk". Similarly, Marino (2008) uses the title "EPRs designed to share risks and rewards" in their article describing possible changes to the EPR system.

One way of modelling the risk-sharing feature of end-point royalties is to use a Principal–Agent model. Such models have been applied to agriculture previously: Huffman and Just (2000) model the optimal compensation for agricultural workers, Allen and Lueck (2002) describe in detail a Principal–Agent model of agricultural share contracts and Fraser (2001, 2002) applies such a model to agricultural policy in the EU. In this chapter, we apply a Principal–Agent model to crop breeding.

However, Allen and Lueck argue transactions costs are important and should therefore be included in their analysis. They do this by setting up a transactions-cost model, instead of a Principal–Agent model, and conclude this transactions-cost model is a better model, both theoretically and empirically. We take a different approach and in the next chapter combine both the transactions cost and the Principal–Agent aspects of the situation into one model.

Principal–Agent models previously applied to agriculture do not model royalties; and Principal–Agent models previously applied to royalties do not model crop breeding. Moreover, Principal–Agent models which have been used for situations other than crop breeding cannot be directly applied to crop breeding, because the timing of crop breeding is different—in crop breeding, the uncertainty occurs and the state of nature is revealed after the contract has been agreed, and after decisions have been made.

In the Principal–Agent model used in this chapter, the breeder is the principal and acts as a Stackelberg leader, developing new varieties and making them available to the farmer. The farmer acts as the agent, taking the seed and growing the wheat. However, there is risk and uncertainty due to the impact of the weather, the overall performance of the new variety and its suitability for a particular farm. Moral hazard arises because the breeder cannot verify the effort of the farmer.

We saw in Chapter 2 that, typically, farmers are assumed to be relatively risk averse—see Kingwell (1994, 2001) for example—and in the model in this Chapter, we assume farmers are relatively more risk averse than breeders. This assumption about the relative risk aversion of the agents can be justified since breeders are generally large and the failure of one farmer is small compared to their over-all operation, while a failure for the farmer has a large negative impact on the farmer and his family. The differing relative risk aversion provides the potential for risk sharing to be Pareto improving.

The model is developed in the next section, and the section after that derives the first-best solution. However, due to moral hazard, this first-best outcome is not implementable, and so the following section derives the optimal solution that could be implemented. The final section discusses and compares the results.

5.2 The model

5.2.1 The timing of the game

The timing of the game is

- The breeder offers the farmer a take-it-or-leave-it contract consisting of $\{p,\ r,\ l\}$, the three royalty instruments the breeder can choose between: a fixed license fee $\$l$ paid by the farmer up-front; a point-of-sale royalty of $\$p$ per kilogram of seed, paid by the farmer when the seed is purchased; and an end-point royalty r which is a proportion of output paid by the farmer after production.
- The farmer either accepts the offer or refuses it.
- If the farmer refuses the contract, he receives the return on his next-best alternative, assumed to be 0, and the process stops.
- If the farmer accepts the contract, he determines the amount of seed he will buy, denoted b and measured in kilograms, pays the breeder the license fee l and the point-of-sale royalty pb, exerts effort, denoted e and measured in labour units, and grows wheat.
- Wheat is produced according to a production function, $F(b, e)$.
- There is uncertainty in the weather, the growing season and the performance of the new variety. This uncertainty is included in the production function through a stochastic term ϵ with mean 0 and variance σ^2.

- The farmer reaps the wheat and pays the end-point royalty on all wheat produced, whether it is sold to his neighbour, kept as farmer-saved seed or sold on the market.
- Profits are realised.

We now further discuss the model and its assumptions.

The breeder has monopoly rights over a new variety but neither breeder nor farmer have knowledge about the variety that the other does not have: ex ante, information is symmetric.

The level of output depends on the amount of seed used and the effort applied by the farmer, who could buy the seed and then do very little or could be a good farmer and work hard in a "farmer-like manner" (Allen and Lueck 2002, p. 33). The breeder is uncertain as to the effort the farmer will exert and the level of production that will be realised. There is also uncertainty due to weather, the actual performance of the variety at the farmer's location and so on.

In our model, the contract is offered and closed, and the agents determine $p,\ r,\ l$ and b *before* the uncertainty of production is resolved. Other contractual arrangements differ in this regard, and agents may be able to determine output *after* the state of nature is revealed and quantity determined. For example, publishers may pay royalties to authors on the basis of the number of books sold, after the sales were made. This difference partly explains why the results in this model may differ from those of standard models.

There is no re-negotiation: once offered, the breeder cannot change the contract. Once accepted or rejected, the farmer cannot change the quantity demanded. Specifically, neither the breeder nor farmer can change the contract after the uncertainty is resolved. The bargaining process is not repeated so there are no repeated-game effects.

The farmer is risk averse with the usual strictly concave utility function, and maximises expected utility. The breeder is risk neutral, and maximises expected profit.

For simplicity, seed merchants are ignored; the breeder is assumed to supply the seed to the farmer. In addition, we ignore any price on bought seed except the point-of-sale royalty as including this adds no insights but makes the model more complicated. The seeding rate is not modelled explicitly for the same reason.

5.2.2 The game

The breeder will offer a contract such that the farmer, in the process of maximising his own expected utility, also acts to maximise the breeder's expected profit. Hence, the contract will maximise the breeder's expected profit, provided it satisfies three constraints. First, the breeder must ensure the farmer accepts the contract: this is the farmer's individual rationality (IR) constraint, and states that the farmer's expected utility must be at least that of the outside option (0, by assumption). The farmer's outside option determines his reservation utility—the utility he must at least match if he is to accept the contract. Second, the breeder must take into account the farmer's best response: that is, the breeder anticipates the level of seed the farmer will choose to buy once the royalty terms are set, assuming the farmer acts to maximise his expected utility. This is the farmer's incentive compatible (IC) constraint. Third, the contract must ensure the farmer will provide the level of effort implied in the contract; that is, the contract must be implementable in the sense that, having accepted a contract, the farmer will be better off by exerting effort than by shirking. This is the implementability constraint (ImpC).

The farmer's effort e is important for the production of wheat; both seed and effort are required to grow the grain. We use a fixed proportion Leontief production function. This implies seed and effort are perfect complements, and will be used in fixed proportions since there is no substitutability between them.

If there was no uncertainty in the production process, the production function would be of the form

$$F(b, e) = \min{(vb, he)}$$

where F is the production function, b and e are the seed and effort inputs, and the constants v and h depend on the wheat production process. Perfect complementarity is a simplifying assumption that allows for easy closed form solutions to our Principal–Agent problem. While in reality there might be some degree of substitutability between seed input and other inputs such as labour or capital use, substitution is limited. Without any harvesting work there is no output; similarly, without seed, no amount of work will produce wheat.

In reality, there is uncertainty due to the weather, pests, growing season, variety characteristics and variety/location interactions; we include this uncertainty by adding a random error term ϵ with mean 0 and variance σ^2 into the production function, which then becomes

$$F(b, e) = min\left\{(v + \epsilon)b, (h + \epsilon)e\right\}$$

where ϵ is the random error term. The output price is normalised to 1 so $F(b, e)$ represents both the level and value of production.

The costs of production (the costs of growing the wheat) are assumed to vary with the effort the farmer exerts and the cost of seed, with positive marginal costs and, at this stage, are given by $\tilde{c}(b + e),\ \tilde{c'} > 0$. Other costs are ignored because they do not add to the understanding of the model.

The farmer's profit is the value of production, less end-point and point-of-sale royalties, license fees and production costs. There are two cases to consider: $e = 0$ and $e > 0$.

First, consider $e = 0$. In this case, the farmer shirks; they buy the seed but exert no effort and grow no wheat. Production is zero, as are growing costs, whilst the cost of the point-of-sale royalty is pb where p represents the point-of-sale royalty and the license fee is l. Hence, in this case,

$$\pi_f = -pb - l.$$

Next, consider $e > 0$. In this case, the value of production was given previously as

$$F(b, e) = min\left\{(v + \epsilon)b, (h + \epsilon)e\right\}.$$

The cost of the end-point royalty is $rF(b, e)$ where r is the rate of the end-point royalty, the cost of the point-of-sale royalty and the license fee were given above as pb and l and the costs of production were given above as $\tilde{c}(b + e)$. Hence, in this case, the farmer's profit is given by

$$\pi_f = (1 - r)min\left((v + \epsilon)b, (s + \epsilon)e\right) - pb - l - \tilde{c}(b + e).$$

Putting the two expressions for farmer profit together gives

$$\pi_f = \begin{cases} -pb - l & \text{if } e = 0 \\ (1 - r)min\left\{(v + \epsilon)b, (h + \epsilon)e\right\} - pb - l - \tilde{c}(b + e) & \text{if } e > 0. \end{cases} \tag{5.1}$$

The license fee has no effect on the optimal quantity of seed the farmer purchases because it is constant from the farmer's perspective, and only affects the level of profits.

Since the farmer is risk averse, he maximises the expected utility derived from his profit, $EU[\pi_f]$. This expected utility cannot be determined without some further assumption regarding the functional form of the utility function or the distribution of the random production component.

We know, by Jensen's Inequality,[1] that the expected utility of π_f must be below the utility of the expected value of π_f, but further general results do not hold.

Instead, we apply a mean–variance (MV) model [2] which shows that, under certain assumptions, maximising the expected utility of profit can be simplified to maximising $\mu - \frac{1}{2}\gamma\sigma^2$ where μ and σ^2 are the mean and variance of profits and γ is the appropriate coefficient of risk aversion. To derive this result, we define the certainty-equivalent of profit as the certain value that makes the farmer indifferent between this value and the risky value of π_f. In other words, it is the value Z such that $E[U(\pi_f)] = U(Z)$. It is standard practice to estimate this certainty-equivalent by subtracting a risk premium from the mean value. The risk premium L is the difference between the certainty-equivalent of profit and its expected value; that is, the amount of the profit the farmer is willing to give up to remove the risk. Hence, $L = E[\pi_f] - Z$. This gives $Z = E[\pi_f] - L$ and so

$$E[U(\pi_f)] = U(E[\pi_f] - L). \tag{5.2}$$

[1] See, for example, Mas-Colell *et al.* 1995, p. 185.
[2] See Gravelle and Rees (2004) and Kim and Chavas (2003) for more details.

The farmer wishes to maximise the expected utility of profit as given in the equation above. We could model this expression but it is intractable so instead, we use a Taylor series expansion and work through the moments of the distribution. This is a standard procedure. As is common, following Pratt (1964), we use up to the first two moments, which is valid if higher order terms in the Taylor series are small, as is the case "in the small", that is for small risks close to their mean, and not for extreme values of π_f.

We take the expression for the expected utility of farmer profit and derive the mean–variance formulation. We start with Equation 5.2 and take the Taylor series expansion of the left-hand side of this expression around $E[\pi_f]$, to the third term only. This gives

$$\begin{aligned} E[U(\pi_f)] & \\ &= E\left[U(E[\pi_f]) + U'(E[\pi_f])(\pi_f - E[\pi_f]) + \frac{U''(E[\pi_f])}{2}(\pi_f - E[\pi_f])^2\right] \\ &= U(E[\pi_f]) + \frac{U''(E[\pi_f])}{2}V(\pi_f). \end{aligned} \tag{5.3}$$

Next, take the Taylor series expansion of the right-hand side of this expression around $E[\pi_f]$, to the second term only. This gives

$$U(E[\pi_f] - L) = U(E[\pi_f]) + U'(E[\pi_f])(E[\pi_f] - L - E[\pi_f]) \tag{5.4}$$

$$= U(E[\pi_f]) - LU'(E[\pi_f]). \tag{5.5}$$

Next, set these two equal to each other to give

$$U(E[\pi_f]) + \frac{U''(E[\pi_f])}{2}V(\pi_f) = U(E[\pi_f]) - LU'(E[\pi_f])$$

which in turn gives

$$L = \frac{1}{2}\gamma V(\pi_f)$$

where γ is the Arrow-Pratt coefficient of absolute risk aversion,

$$\gamma = \frac{-U''(E[\pi_f])}{U'(E[\pi_f])}.$$

Finally, in Equation 5.2, substitute this expression for L and denote $E[\pi_f]$ and $V(\pi_f)$ by μ_f and σ_f^2, giving

$$\begin{aligned} E[U(\pi_f)] =& U(\mu_f - L) \\ =& U(\mu_f - \frac{1}{2}\gamma\sigma_f^2). \end{aligned}$$

That is, under the MV model, the farmer maximises the expected utility of π_f by maximising the utility of

$$Z = \mu_f - \frac{1}{2}\gamma\sigma_f^2.$$

In turn, since the utility function is increasing, maximizing the utility from Z occurs at the same value of Z as maximizing Z itself. Hence, we can approximate maximising the expected utility of π_f by maximising the certainty equivalent Z.

This approach has been used extensively. In agriculture, it has been applied by Kingwell (2000, 2001) to Bt cotton and wheat royalties in Australia, by Kim and Chavas (2003) to corn in the US, by Sherrick *et al.* (2004) to crop insurance, and Fraser (1992, 1998, 2000, 2001, 2002) to crop insurance, agriculture and resources in Australia.

The MV model is useful because it provides a tractable model so we can see underlying characteristics of the equilibrium. However, it does require certain assumptions. Hanson and Ladd (1991) show the model will be *consistent* if at least one of three sufficient conditions hold. These conditions are

- a quadratic utility function,
- a concave utility function with normally distributed errors, and
- the random terms are linear monotonic functions of a single random variable.

The first of these assumptions is unlikely since it implies that absolute risk-aversion increases as wealth increase; it is generally considered farmers show decreasing absolute risk-aversion (Kim and Chavas, 2003, p. 125). In addition, quadratic utility functions will show negative marginal-utility at some point, which is unrealistic. The second assumption is often hard to maintain as a normal model implies a symmetric distribution and an infinite range of values, although the extremes are unlikely.

The MV model is *exact* only in the case of normal errors and a negative exponential utility function. A negative exponential utility function is of the form

$$U(y) = C - exp^{-\rho y}$$

and shows constant absolute risk-aversion (CARA) with coefficient ρ and increasing relative risk-aversion. Again, these are restrictive assumptions and results.

However, these assumptions are sufficient, not necessary, and Hanson and Ladd (1991, p. 437) conclude "…most studies have been willing to accept the assumption of CARA to obtain the desirable properties of the standard MV model."

When these assumptions do not hold, the MV model may still give good approximations; Hanson and Ladd (1991, p. 437) summarize the literature and conclude the model is a reasonable approximation and "there is some support, both empirical and deductive, for the use of the MV framework even when its sufficient conditions are violated."

The MV model is simple and tractable so next, we apply it to our model by taking the expression for farmer profit from Equation 5.1 and calculating the approximate value of the certainty equivalent Z. There are several cases to consider.

In the first case, suppose $e^* = 0$. Then

$$\pi_f = -pb - l$$

with mean $-pb - l$ and variance 0, so that for this case,

$$Z = -pb - l.$$

For the remaining cases, with $e > 0$, we show that a rational profit-maximising farmer will combine the two inputs so that

$$he^* = vb^* \text{ or } e^* = \frac{vb^*}{h}$$

where the star superscript indicates an optimum value. We do this by looking at the implications if this does not hold.

Consider the case $vb^* < he^*$. Then,

$$\pi_f = (1-r)(v+\epsilon)b - pb - l - \tilde{c}(b+e)$$

with mean

$$(1-r)vb - pb - l - \tilde{c}(b+e)$$

and variance

$$(1-r)^2b^2\sigma^2$$

so that

$$Z = (1-r)vb - pb - l - \tilde{c}(b+e) - \frac{\gamma(1-r)^2b^2\sigma^2}{2}.$$

The farmer will wish to maximise the certainty equivalent, Z. However, starting from $vb^* < he^*$, if we were to marginally change e by $de < 0$, we have

$$dZ = -\tilde{c}'(b+e)de > 0.$$

That is, the certainty equivalent is higher by decreasing effort below the level where $vb^* < he^*$.

Now consider $vb^* > he^*$. Then

$$\pi_f = (1-r)(h+\epsilon)e - pb - l - \tilde{c}(b+e)$$

with mean

$$(1-r)he - pb - l - \tilde{c}(b+e)$$

and variance

$$(1-r)^2e^2\sigma^2$$

so that

$$Z = (1-r)he - pb - l - \tilde{c}(b+e) - \frac{\gamma(1-r)^2e^2\sigma^2}{2}.$$

Again, the farmer will wish to maximise the certainty equivalent, Z. Now, starting from $vb^* > he^*$, if we were to marginally change b by $db < 0$, we have

$$dZ = -pdb - \tilde{c}'(b+e)db > 0.$$

That is, the certainty equivalent is higher by decreasing seed below the level where $vb^* < he^*$.

These two cases show that in equilibrium, a rational farmer will combine the two inputs so that

$$he^* = vb^* \text{ or } e^* = \frac{vb^*}{h}.$$

We can use this equilibrium condition for seed quantity and effort above to rewrite total inputs as

$$b + \frac{vb}{h} \text{ or } (1 + \frac{v}{h})b.$$

In turn, we use this expression to rewrite costs, which were given by $\tilde{c}(b + e)$, as $c(b)$. A suitable form for costs is a quadratic function, giving

$$\frac{cb^2}{2}.$$

This is the same general form used in the previous two chapters on farmer-saved seed and has similar properties and Inada conditions.[3]

With this form of the cost function, and $vb^* = he^*$, we have

$$\pi_f = (1 - r)(v + \epsilon)b - pb - l - \frac{cb^2}{2}$$

with mean

$$(1 - r)vb - pb - l - \frac{cb^2}{2}$$

[3] In the farmer-saved seed chapters, however, the parameter c was normalised to 1.

and variance

$$(1-r)^2 b^2 \sigma^2$$

so that

$$Z = (1-r)vb - pb - l - \frac{cb^2}{2} - \frac{\gamma(1-r)^2 b^2 \sigma^2}{2}.$$

Putting the two cases together, we have the approximate certainty-equivalent of farmer profit is

$$Z = \begin{cases} (1-r)vb - pb - l - \frac{cb^2}{2} - \frac{\gamma(1-r)^2\sigma^2 b^2}{2} & \text{if } vb = he \\ -pb - l & \text{if } e = 0. \end{cases} \tag{5.6}$$

Thus, maximising the expected utility of farmer profit is approximately the same as maximising the certainty-equivalent Z in Equation 5.6. In addition, when farmer profit is zero, so too are Z, $U(Z)$ and $EU(\pi_f)$.

Next, we use these results and look at two of the three constraints mentioned earlier—we discuss the third one, the incentive compatibility (IC) constraint, after solving the breeder's problem. First, consider the individual rationality (IR) constraint. Given the outside option has expected utility of 0, the IR constraint is written as $Z \geq 0$. Next, consider the implementability (Imp) constraint. This is the constraint that must hold to ensure the farmer will not shirk. The farmer will choose the level of effort $e^* = \frac{vb^*}{h}$ over $e^* = 0$, and thus not shirk, if the certainty-equivalent from working is greater than the profit from shirking. This is:

$$(1-r)vb - pb - l - \frac{cb^2}{2} - \frac{\gamma(1-r)^2\sigma^2 b^2}{2} > -pb - l$$

$$\text{or}\ \ (1-r)vb - \frac{cb^2}{2} - \frac{\gamma(1-r)^2\sigma^2 b^2}{2} > 0. \tag{5.7}$$

If this condition fails, the farmer is better off with zero effort. From now on, this constraint must be checked as well as the farmer's IR constraint and the IC constraint. The incentive compatibility constraint requires the breeder's actions so this is now solved.

The breeder's profit is given by royalty revenues less costs. Revenue from the end-point royalty is $rq = r(v+\epsilon)b$; revenue from the point-of-sale royalty is pb, and revenue from the license fee is l. The cost of supplying seed is assumed to be a simple cost function given by $gb+K$, with constant marginal costs g and fixed costs K. Hence, the breeder's profit is given by

$$\pi_B = r(v+\epsilon)b + pb + l - gb - K,$$

with expected profit

$$E\pi_B = rvb + pb + l - gb - K. \tag{5.8}$$

The breeder is assumed to be risk neutral, and so chooses the three royalty instruments in order to maximise expected profit, after anticipating the farmer's best response.

This is the basic setup of the model; the next Section determines the first-best social-optimum benchmark solution. However, this is not implementable, so the Section after derives the optimal implementable solution.

5.3 The first-best outcome

The social-planner solution is the first-best social optimum which maximises expected social welfare, by choice of seed quantity and effort. We measure social welfare by the sum of farmer and breeder profits, which is equivalent to the net value of production ignoring transfers, and is given by

$$SW = vb - gb - \frac{cb^2}{2} - K.$$

By inspection, the quantity of seed that maximises social welfare is

$$b^* = \frac{v - g}{c}$$

and the corresponding optimum level of effort is

$$e^* = \frac{vb^*}{s}.$$

These expressions for b^* and e^* ensure positive levels of seed and effort if we assume $v > g$. This is realistic as it implies the marginal product of seed v exceeds the marginal cost of producing the seed g. As expected, the optimal quantity of seed and effort increase as the marginal product of seed increases, and decrease as the marginal costs of the breeder or the farmer increase.

The optimum level of social welfare is given by $SW^* = \frac{(v-g)^2}{2c} - K$. This expression shows social welfare is higher the greater the gap between the marginal product and marginal cost of seed and the lower are the costs of production of wheat.

The next Section discusses this first-best outcome and shows it is not implementable due to moral hazard since the first-best outcome requires $e^* = b^*$ but effort cannot be contracted.

5.3.1 Implementing first-best

The first-best result obtained above can be derived in an alternative way, which shows the problem of implementing first-best. First, suppose the breeder was able to contract on the effort of the farmer and the resulting expected production. The breeder maximizes expected profit—given by Equation 5.8—subject to the farmer's IR constraint $Z \geq 0$. In fact, because the license fee affects the farmer's expected profits and expected utility, but not the optimal seed quantity, the breeder will increase the license fee—and thereby their profit—as far as possible, which means pushing

Z down to the outside option $Z = 0$, so this constraint will be binding at the optimal level of breeder profit.

Setting $Z = 0$ in Equation 5.6, and rearranging, gives

$$l^* = (1-r)vb - pb - \frac{cb^2}{2} - \frac{\gamma(1-r)^2\sigma^2 b^2}{2}, \tag{5.9}$$

and substituting into the expression for expected breeder profit, Equation 5.8, gives

$$E\pi_B = vb - gb - \frac{cb^2}{2} - \frac{\gamma(1-r)^2\sigma^2 b^2}{2} - K.$$

This is to be maximized subject to an individual rationality constraint for the breeder, $E\pi_B \geq 0$ or at least $E\pi_B \geq K$.

If the breeder can set the end-point royalty r independently of the quantity of seed b, we can see by inspection from the previous equation that the best they can do is set the end-point royalty to be $r^* = 1$. In that case, the optimal seed quantity will be

$$b^* = \frac{v-g}{c}. \tag{5.10}$$

This optimum seed quantity is the same as the first-best solution. However, the implications of this solution need to be understood. With optimal royalty $r^* = 1$, the license fee from Equation 5.9 becomes

$$-pb - \frac{cb^2}{2}.$$

This is negative, meaning that at the time when the contract is closed, the breeder pays the farmer a lump sum equal to the farmer's costs $\frac{cb^2}{2}$ and the point-of-sale royalties pb and then immediately gets back the point-of-sale royalties. Hence the point-of-sale royalty is redundant and is set to 0. The license fee is equal to the farmer's total production costs. Substituting optimal seed quantity b^* from Equation 5.10 above, gives

$$l^* = -\frac{cb^{*2}}{2} = -\frac{(v-g)^2}{2c}. \tag{5.11}$$

This guaranteed payment depends on the marginal costs and the marginal product, c, g and v. However, it is independent of the risk variables, γ (the farmer's risk-aversion coefficient) and σ^2 (the risk of this variety this season) because in this case, with an end-point royalty of 1, the breeder assumes all production risk. Being risk neutral, the breeder offers full insurance to the farmer, who is risk averse. Hence, the farmer's costs are covered at the time of getting the seed. This is as if the farmer is an employee only; the breeder pays him the license fee—which covers all production costs—in advance of production. Then the farmer sows and grows wheat, and, after production, the breeder takes the entire production as end-point royalties.

In this outcome,

$$RR^* = vb^* + l = \frac{v-g}{c} - -\frac{(v-g)^2}{2c} = \frac{v^2-g^2}{2c} \tag{5.12}$$

$$\text{and} \quad E\pi_B^* = \frac{(v-g)^2}{2c} - K. \tag{5.13}$$

Expected breeder profit is non-negative if the marginal product of seed is large or the marginal costs of the breeder and farmer, and the fixed cost of the breeder, are low.

However, under this scenario with a fixed wage, the implementability constraint from Equation 5.7 is not satisfied. This constraint was the one that ensured the farmer does not shirk. In the current scenario, with $r = 1$, the left hand side of the constraint becomes $-\frac{cb^2}{2}$ which is negative and the constraint is violated.

The first-best contract could be implemented if effort could be contracted, in which case Pareto optimality could be reached; the farmer could be as well off as under his outside option, the breeder could maximize expected profits, and the outcome could be the same as first-best. However, effort is not contractible; some form of government intervention would only succeed in implementing first-best if it could enforce the farmer's effort. This is unlikely so we refer to the first-best outcome as being "non-implementable", meaning even intervention may not be able to enforce the effort of the farmer.

We turn now to determining the best outcome which can be implemented without further intervention from government or the social planner other than allowing breeders to use a royalty. We take into account that the farmer only provides effort if the contract is such that this is in his best interest. For simplicity, we call this the best implementable outcome, meaning the best outcome which enforces effort and is obtained without intervention other than royalties.

5.4 The best implementable outcome

In practice, the breeder cannot enforce the farmer's effort or the expected output; the contract can only cover the royalty terms. Hence, the breeder must write the contract in such a way as to ensure the farmer's incentive constraint under this contract leads to the breeder's desired amount of seed. There will be *less than full* insurance in order to provide an incentive for the farmer to not shirk. There will be *some* insurance as the risk-neutral breeder takes some of the risk from the risk-averse farmer. However, royalties will distort the optimal quantity of seed demanded. The farmer will pay an up-front license fee to the breeder—not the other way around. The farmer is pushed down to an expected utility of 0, and the breeder maximizes his position.

5.4.1 The farmer problem

We will now solve the multi-stage game using SPNE as solution concept. To achieve this, we start at the last stage and work our way backwards.

We saw before that the farmer will maximize

$$Z = (1-r)vb - pb - l - \frac{cb^2}{2} - \frac{\gamma(1-r)^2\sigma^2 b^2}{2}$$

by choice of b, subject to the individual rationality constraint, $Z \geq 0$ and for $p \geq 0$, $0 \leq r < 1$.[4] As well, the implementability constraint, which was given in Equation 5.7, must hold to ensure the farmer will not shirk.

To find the optimal amount of seed the farmer buys from the breeder, we solve the first-order condition of Z with respect to b. This first-order condition is

$$(1-r)v - p - cb - \gamma(1-r)^2\sigma^2 b = 0,$$

and solving this gives the optimum amount of seed as

$$b_1 = \frac{(1-r)v - p}{c + \gamma(1-r)^2\sigma^2} \text{ for } 0 \leq r < 1, \tag{5.14}$$

where the subscript indicates this is the optimum for the first-best implementable model.

[4] If $r = 1$, the previous, first-best, solution is obtained in which there is no incentive for the farmer to grow the wheat so here $r < 1$ is assumed. Restricting $l \geq 0$ rules out $r = 1$.

The second derivative is $-c - \gamma(1-r)^2\sigma^2 < 0$ which is sufficient for a maximum.

To ensure $b_1 \geq 0$ requires

$$r \leq 1 - \frac{p}{v}.$$

When we solve the breeder problem, we will show the optimum point-of-sale royalty p is zero. and this condition will hold.

The equation for the optimal quantity of seed shows, as expected, this optimal amount increases if:

- The marginal product of seed v increases;
- The marginal cost of farming c decreases;
- The farmer is less risk averse; the coefficient of risk aversion γ falls;
- The point-of-sale royalty p decreases or
- The weather, season or variety becomes less variable; σ^2 decreases.

The end-point royalty enters the equation for optimal seed quantity twice: once in the numerator, through the mean return, and once in the denominator, through the variance or risk. As the end-point royalty changes, these effects oppose each other, and the overall effect on the optimal seed quantity is ambiguous. On one hand, a higher end-point royalty decreases the farmer's marginal return and reduces the optimal seed quantity; but on the other hand, it reduces the variance or risk of the farmer's return and, assuming CARA, increases the optimal seed quantity to return to the acceptable risk level. In fact, $\frac{\partial b_1}{\partial r}$ takes the same sign as

$$-vc + \gamma(1-r)^2 v\sigma^2 - 2\gamma p(1-r)\sigma^2.$$

The first term in the above expression is negative. The second is positive. For now, suppose the point-of-sale royalty is zero so the third term is zero.[5] With this restriction,

$$\frac{\partial b_1}{\partial r} < 0 \text{ if } r > 1 - \sqrt{\frac{c}{\gamma\sigma^2}}.$$

This condition is more likely to hold, implying that an increase in the end-point royalty will lead to a decrease in the optimal seed quantity, when the end-point royalty is high. The intuition is that the positive effect of the lower risk is outweighed by the negative effect of the decrease in return. A less risk-averse farmer (decreased γ) or a less risky variety (decreased σ^2) or higher marginal farming-costs also make it more likely the condition above will hold, and the optimal seed quantity will decrease as the end-point royalty increases. Again, the effect on risk is outweighed by the effect on the mean return.[6]

Here we have shown an end-point royalty has both a positive effect on output through reducing risk to the farmer, as well as a negative effect

[5] In fact, as we noted previously, when we solve the breeder problem in the next section, we show the optimal point-of-sale royalty is indeed 0.

[6] It turns out that this is indeed the case for our model. We do not show the proof but it derives from the expression for optimal b below.

through reducing the mean return. A point-of-sale royalty, though, has only the latter effect and so will not be used at the optimum. We show this next.

5.4.2 The breeder problem

The breeder chooses the royalties to maximise expected profit from Equation 5.8. In doing so, they anticipate the farmer's best response—the optimal amount of seed as in Equation 5.14—and also set l such that $Z = 0$, as in Equation 5.9. Substituting for b_1 and l_1, we have

$$E\pi_B = \frac{(v - rv - p)(v + rv + p - 2g)}{2(c + \gamma(1 - r)^2\sigma^2)} - K. \tag{5.15}$$

This is to be maximized with respect to p and r, subject to $0 \leq r \leq 1$ and $p \geq 0$. Appendix E.1 derives the unconstrained maximization; however, this maximisation results in $r = 1$ and $p < 0$ which, as seen previously, is not implementable. Instead, Appendix E.2 derives the constrained optimization result using the Kuhn Tucker method.

5.4.3 The optimal solution

The solution to the constrained optimisation gives the optimal end-point royalty as

$$r_1 = 1 + \frac{vc - \sqrt{v^2c^2 + 4\gamma(v - g)^2c\sigma^2}}{2(v - g)\gamma\sigma^2} \tag{5.16}$$

with $0 < r_1 < 1$. The actual value of the end-point royalty will vary with the parameters of the model. However, the important point is that it is below 1; the breeder allows the farmer to retain some production, so insurance is partial, not full. The farmer still bears some production risk, but the incentive to shirk has been reduced. This expression for r_1 is complex so in the following equations, we do not substitute for it.

The optimal point-of-sale royalty p_1 is zero. The intuition is that a positive point-of-sale royalty increases the price of seed and causes a decline in the quantity of seed demanded. This reduces revenue from both end-point and point-of-sale royalties; there is downward distortion to output without any reduction in risk. Therefore, the breeder will keep the point-of-sale royalty as low as possible, zero.

Substituting $p_1 = 0$ into Equation 5.14 for b_1 shows

$$b_1 = \frac{(1 - r_1)v}{c + \gamma(1 - r_1)^2\sigma^2} \tag{5.17}$$

and substituting this into Equation 5.9 for l_1 gives the optimal license fee

$$l_1 = \frac{(1 - r_1)^2 v^2}{2(c + \gamma(1 - r_1)^2\sigma^2)} \tag{5.18}$$

which is positive. Here, the breeder chooses the license fee so the farmer receives no more than his reservation utility. The positive licence fee helps ensure that a farmer who accepts the contract but shirks will be worse off than one who accepts the contract and exerts the effort. Appendix E.3

checks the implementability constraint and shows it does in fact hold. This guarantees the farmer, having accepted the contract, will exert the required effort and not shirk.

The breeder has three instruments to use to maximize their expected profit. In this Principal–Agent model, they use an end-point royalty to insure the farmer, and could then use either of the other two (license fee and point-of-sale royalty) to push the farmer down to reservation utility. However, since the license fee has no effect on the optimal level of seed, breeders use the license fee, and set the point-of-sale royalty to zero.

The breeder's optimal royalty revenue is made up of the license fee plus the end-point royalty payments and is

$$
\begin{aligned}
RR_1 =& r_1 v b_1 + l_1 \\
=& \frac{r_1 v(1-r_1)v}{c+\gamma(1-r_1)^2\sigma^2} + \frac{(1-r_1)^2 v^2}{2(c+\gamma(1-r_1)^2\sigma^2)} \\
=& \frac{(1-r_1^2)v^2}{2(c+\gamma(1-r_1)^2\sigma^2)}.
\end{aligned}
\tag{5.19}
$$

At this best-implementable partial-insurance outcome, farmer profit is zero, since the breeder pushes the farmer down to the reservation utility. The expected profit of the breeder, and hence the value of our measure of social welfare, is given by

$$
\begin{aligned}
E\Pi_{B1} =& RR_1 - gb_1 - K \\
=& \frac{(1-r_1^2)v^2}{2(c+\gamma(1-r_1)^2\sigma^2)} - \frac{g(1-r_1)v}{c+\gamma(1-r_1)^2\sigma^2} - K \\
=& \frac{(1-r_1)v(v+r_1v-2g)}{2(c+\gamma(1-r_1)^2\sigma^2)} - K.
\end{aligned}
$$

The optimal end-point royalty, license fee and quantity of seed vary depending on the parameters of the model. We derive comparative static results in Appendix E.4, summarise them in Table 5.1 and discuss them next.

It is not easy to determine the effect of changes in the model's parameters on the end-point royalty. This is because an increase in the end-point royalty decreases the mean return and tends to decrease the quantity of seed and production; it also decreases risk and increases seed use and production. These two effects counter each other. Furthermore, the breeder may trade-off the license fee and the end-point royalty. For example, if the farmer becomes more risk averse, or if the weather or variety becomes more variable, the breeder will decrease the license fee and increase the optimal end-point royalty. This example clearly illustrates the risk-sharing motive for an end-point royalty, which acts to insure the farmer against the uncertainty of production.

If the marginal product of seed increases, the yield, amount of new seed and expected profit of the farmer increases. We would expect the

Parameter	Effect of parameter on optimal ...			
	license fee	end-point royalty	seed quantity	expected breeder profit
Marginal product of seed (v)	indeterminate*	negative	positive	positive
Farmer cost parameter (c)	negative	negative	negative	negative
Breeder marginal cost (g)	negative	positive	negative	negative
Risk aversion of farmer (γ)	negative	positive	negative	negative
Variance of yield (σ^2)	negative	positive	negative	negative
Breeder fixed cost (K)	no effect	no effect	no effect	negative

*Indeterminate but indicative values suggest most likely positive

Table 5.1: Comparative statics in the Principal–Agent model

breeder to extract a higher up-front amount from the farmer due to the higher expected profit of the farmer and given our assumption of the breeder pushing the farmer down to zero profit. Extensive simulation under a reasonable range of illustrative parameter values suggests this is the case but we are unable to show this is generally true.

In our model, overall, an increase in the marginal product of seed will decrease the end-point royalty. This impact is complex and, as we have seen above, there are several channels through which it may work. The dominant effect seems to be an income effect on the breeder's side: the increased marginal product increases the size of the economic surplus and the breeder will extract this by increasing the license fee l, at the same time substituting the license fee for the end-point royalty, decreasing r. The decrease in the end-point royalty also increases the size of the surplus, allowing the breeder to extract even more.

On the other hand, the increased marginal product leads to an increase in the optimal level of new seed which increases risk, and the assumption of CARA implies we would expect the breeder to increase the end-point royalty, to take this extra risk and return the farmer to the original acceptable level of risk. It seems the first effect dominates.

The end-point royalty and the license fee do not always move inversely. For example, if the farmer's marginal cost increases, both the optimal end-point royalty and license fee fall. This is because the increased cost reduces the farmer's returns and reduces the amount of new seed. The license fee falls to ensure the individual rationality constraint of the farmer holds; and with lower returns and lower seed purchases, the farmer's risk has decreased so the breeder will reduce the end-point royalty to restore the level of risk to its original absolute value. As the end-point royalty falls, the level of new seed purchased will increase and this will help move the farmer back to equilibrium. However, this secondary effect does not outweigh the first effect; overall, less new seed is purchased.

The comparative statics for the optimal seed quantity are all straightforward and as expected. Optimal seed quantity increases if the marginal product of seed increases, the farmer's marginal cost decreases, the farmer becomes less risk averse, the weather or variety becomes less risky, or the breeder's marginal cost decreases.

Finally, the comparative static results for the breeder's expected profit are as expected. The breeder's expected profit increases as their marginal cost decreases or the marginal product of the seed increases. Also, the farmer will buy more seed and produce more if their marginal cost decreases, they become less risk averse, or the weather or variety become less variable. In this case, in order to ensure the farmer's IR constraint still binds, the breeder extracts more from the farmer, and the breeder's profit increases.

Of the models which are implementable without government or social planner intervention beyond allowing a set of royalties, the partial-insurance model is the best in terms of social welfare. In the next Section, we compare the outcome of this model with the first-best social-optimum outcomes.

5.5 Comparison of best-implementable and first-best outcomes

The previous section discussed the outcome and comparative statics for the best-implementable, partial-insurance model. Now, we compare this model with the first-best outcome that optimised social welfare in Table 5.2. The partial-insurance model does not yield simple expressions for the variables of interest and cannot be summarized neatly so Table 5.2 also shows the inequalities between values for the two models. These inequalities are derived in Appendix E.5.

The inequalities in Table 5.2 confirm that the breeder's expected profit is greater for the first-best case than the partial-insurance case, whilst the farmer is no worse off. This result follows from the construction of the model with the breeder able to push the farmer down to reservation utility; and this construct also means social welfare is given by breeder profit. The Table also shows the quantity of seed—and hence production—as well as royalty revenue are greater in the first-best case than in the partial-insurance case.

	First-best***		Partial-insurance
End-point royalty r	$r^* = 1$	$>$	$r_1 = 1 + \frac{vc - \sqrt{v^2c^2 + 4\gamma(v-g)^2 c\sigma^2}}{2\gamma(v-g)\sigma^2}$, $\frac{g}{v} < r_1 < 1$
Point-of-sale royalty p	0	$=$	0
Quantity of seed b	$\frac{v-g}{c}$	$>$	$\frac{(1-r_1)v}{c+\gamma(1-r_1)^2\sigma^2} = \frac{(1-r_1)v(v-g)}{c(v+r_1v-2g)}$
License fee l	$-\frac{(v-g)^2}{2c}$	$<$	$\frac{(1-r_1)^2v^2}{2(c+\gamma(1-r_1)^2\sigma^2)} = \frac{(1-r_1)^2v^2(v-g)}{2c(v+r_1v-2g)}$
Z so that farmer's $EU = U(Z)$	0		0
Royalty revenue RR	$\frac{v^2-g^2}{2c}$	$>$	$\frac{(1-r_1^2)v^2}{2(c+\gamma(1-r_1)^2\sigma^2)} = \frac{(1-r_1^2)v^2(v-g)}{2c(v+r_1v-2g)}$
Expected profit of breeder $E\pi_B$ Social welfare SW	$\frac{(v-g)^2}{2c} - K$	$>$	$\frac{(1-r_1)v(v+r_1v-2g)}{2(c+\gamma(1-r_1)^2\sigma^2)} - K = \frac{(1-r_1)v(v-g)}{2c} - K$
	*** Not implementable		

Table 5.2: Results of the partial-insurance model compared to first-best

Result 5.5.1 ***The first-best outcome.*** *The first-best social-optimum solution is for breeders to pay a sufficient amount to farmers to cover the farming costs, give them the seed for free and then, after production, take all the output. This is the full-insurance case, but is not implementable without further intervention as there is no incentive for farmers to do any work.*

Result 5.5.2 ***The best-implementable outcome.*** *The implementable scheme with the best social-welfare outcome is to have a license fee, under which the farmer pays the breeder a fixed up-front fee, along with an end-point royalty less than* 1*. This is not full insurance because the farmer receives some revenue after production and therefore has an incentive to work. There is, however, some insurance because the breeder takes some of the production risk. This is implementable because the farmer, having accepted the contact, is better off by working than shirking.*

Result 5.5.3 ***Instruments.*** *Two instruments are required for both the first-best and the best-implementable outcomes: a license fee and an end-point royalty.*

Result 5.5.4 ***Realised values.*** *Expected production of wheat, royalty revenue, breeder profit and social welfare (which we measure by the sum of farmer and breeder profits) are all lower in the best-implementable case than in the first-best social-optimum case. When constructing this model, we assumed breeders have market power and force farmers down to the return on their outside option (assumed to be zero); more generally, the social-welfare surplus could be split dif-*

ferently between farmer and breeder. However, in total it falls from the first-best level.

Result 5.5.5 ***Risk aversion of farmers.*** *If farmers are more risk averse, the gap between the first-best and the partial-insurance case increases: breeders will increase the insurance to farmers, by increasing the end-point royalty and decreasing the up-front license fee. This will decrease output, social welfare and breeder profit.*

Result 5.5.6 ***Point-of-sale royalty.*** *A point-of-sale royalty is never in the optimal scheme.*

Result 5.5.7 ***Different countries.*** *Table 5.1 shows the end-point royalty varies with the parameters of the model. Differing parameter values between countries could explain why some countries use an end-point royalty but others do not. For example, this model predicts the end-point royalty will be higher if farmers are more risk averse, varieties more risky, the marginal cost of farming decreases, the marginal product of seed decreases or the breeder's marginal costs increase.*

5.6 Conclusion

The first-best outcome maximises social welfare but, as discussed above, it is not implementable without further intervention beyond royalties because it is open to moral hazard; there is no incentive for the farmer to actually grow the crop, and a contract specifying effort is difficult to enforce. While quantity-forcing contracts are used in sectors other than agriculture, they are not feasible in agriculture because there are too many random elements. The breeder cannot show the farmer is at fault if the quantity target is not met, because, for example, there may have been a bad season. Also, the uncertainty and variability in agriculture occurs at a different time than in other sectors.

A partial-insurance model is implementable provided the individual rationality constraint, the incentive constraint and the implementability constraint of the farmer hold. In such a case, there is some insurance, so the breeder takes some of the risk from the farmer, but insurance is not complete in order to avoid the potential for the farmer to shirk. The individual rationality constraint ensures the farmer will opt into this contract, the incentive constraint ensures he will purchase the amount of seed which leads to the breeder's maximum profit and additionally, the implementability constraint ensures the farmer cannot gain from accepting the contract and shirking. The implementability constraint rules out negative licence fees (i.e. fixed wages).

The end-point royalty insures the farmer and allows for risk sharing. If the end-point royalty was 1, there would be full insurance, but this is not implementable due to the potential for shirking. To see this, note the IR constraint would require a fixed wage to compensate the farmer for his effort; but then the farmer would choose to take the fixed wage and shirk.

If full insurance is not used, the breeder combines the two instruments, the license fee and the end-point royalty. As the farmer's risk-aversion increases or the varieties or weather become more risky, the optimal end-point royalty increases.

In the model we present in this chapter, the breeder will not use a point-of-sale royalty because this royalty has no role. An end-point royalty allows for risk-sharing; a licence fee allows the breeder to push the farmer down to reservation profit but a point-of-sale royalty would reduce the quantity of seed bought and reduce the breeder's profit without any benefit of risk-sharing.

However, questions remain, such as why end-point royalties are not used worldwide, why there is not unanimous support for it in Australia, and why the end-point royalty in Australia is relatively low and unlikely to provide a real insurance effect. In the next chapter, we will consider one possible answer to these questions: enforcement costs.

Chapter 6

A Principal–Agent model with enforcement costs

6.1 Introduction

The previous chapter modelled royalties using a Principal–Agent model and concluded that the optimal royalty scheme that could be implemented without further intervention by government or a benevolent social planner is a fixed up-front license fee together with an end-point royalty, but no point-of-sale royalty. In practice, an end-point royalty is not used globally and when used, it may be set too low to provide any real insurance effect. An end-point royalty is seen to have problems; these problems are the subject of this chapter.

The Australian Government and the plant breeding industry realised there were problems with the plant breeder's rights legislation and institutions. In 2002, the *Plant Breeder's Rights Act* was amended to allow more efficient royalty collection methods (Walmsley, 2005). By 2005, the West Australian Department of Agriculture was reviewing the collection of end-point royalties (Walmsley, 2005) and in 2006 the Advisory Council on Intellectual Property (ACIP) was asked to undertake a review of enforcement of plant breeder's rights with a focus on enforcement. The Council released an Issues Paper in March 2007, and a Final Report in January 2010 in which it noted (ACIP, 2010, p. iii) "PBR owners face significant obstacles to the effective enforcement of their rights". The report highlighted high costs of enforcement—due to the complexity of the system—as well as problems with correct variety declaration (ACIP, 2010, p. 125). Australian Grain Technologies (AGT) (personal communication), a significant Australian wheat breeding company, agree that the main problem with an end-point royalty is compliance and enforcement. Whilst farmers agree in principle with an end-point royalty and do not deliberately not comply, the system of paperwork is complex and may lead to non compliance and misunderstanding. AGT advocates a simplified, centralized, independent enforcement agency, although they stand to benefit if enforcement is funded publicly by tax payers rather than privately.[1]

[1] I am indebted to an anonymous examiner for this useful point.

This discussion suggests one barrier to using an end-point royalty could be the high cost of enforcing compliance. This has been recognized by Wright and Pardey (2006, page 16):

> If high compliance can be sustained, the Australian experience might suggest that end point royalties could make plant breeders' rights a more significant and effective source of research incentives for low-value, broad-acre field crops with geographically dispersed, highly variable yield but centralised collection points.

In the 2007 issues paper, ACIP (2007) stressed the importance of variety identification to prevent farmers from falsely declaring a variety to be either one which is not covered by an end-point royalty, or covered by a lower end-point royalty. Breeders bear the cost of identifying varieties at the point of sale; however, with improving technology, this cost is decreasing, as reported in the ACIP Final Report (2010, p. 126) and Uthayakumaran, Batey and Wrigley (2005).

The extent of this incorrect declaration is unknown, although most sources believe it is low (see, for example, ACIP (2010, p. 128) reporting on the Australian Wheat Board estimates). Lazenby *et al.* (1994), reported in Kingwell and Watson (1998, p. 330), believe this rate to be less than 2%. Wright and Pardey (2006, p. 16) present further evidence and estimate up to 80% compliance. Incorrect declaration may be unintentional due to the complexity of the system or it may be the rational decision of a profit-maximising farmer. This was discussed in Chapter 4.

The director of UK crop development company Senova, Green (2008, p. 2), estimates that evasion of farmer-saved seed in cereal crops in the UK amounts to £2 million per annum or approximately 15% of the net total amount collected on cereals. This figure is likely to be an over-estimate as it it based on industry sources.

We saw in Chapter 2 that recent developments in the Australian wheat industry have reduced the problems of enforcement and compliance—for example, the introduction of standard industry royalty-agreements and forms, the formation of SeedVise Pty Ltd, the use of royalty managers, and the introduction of the on-line website VarietyCentral. These changes are aimed at reducing the costs of complying with and enforcing royalties.

The Principal–Agent model of the preceding chapter ignored the costs of enforcement, instead focusing on risk sharing. In this chapter, we extend the model by including these costs and then solve the model. This gives rise to a decision rule which determines whether a point-of-sale or an end-point royalty is better, along with a license fee, in terms of both social welfare and breeder profit. As expected, the lower are the costs of enforcing end-point royalties, the more likely they are to be optimal. Due to the complexity of the model, we are unable to determine the comparative statics analytically and instead turn to numerical methods. It would be nice if we could obtain numerical estimates for the required parameters of the model, using wheat breeding in Australia as a case study, and so conclude which royalty is optimal. However, we are unable to obtain reliable estimates. Instead, we use plausible, illustrative values of the parameters, where possible, and from these we can discuss the decision rule and the comparative statics of the model.

We then discuss the results and policy implications, concluding that enforcement costs are indeed important in determining optimal royalties.

6.2 Enforcement costs

Compliance refers to strategies used to ensure laws are followed, whilst enforcement refers to strategies used to ensure compliance if laws have not been followed. For simplicity, we use the term enforcement costs to refer to both costs, including the costs of enforcing plant breeder's rights and collecting an end-point royalty.

The Principal–Agent model discussed in the previous chapter assumed the breeder had market power, and drove the farmer down to reservation utility (zero), so that social welfare (defined as farmer plus breeder profit) took the same value as breeder profit. That model showed the breeder's expected profit, and hence social welfare, decreased as the breeder's costs increased, and so incorporating enforcement costs into the Principal–Agent model will reduce the breeder's expected profit. Breeders incur enforcement costs on an end-point royalty, but not a point-of-sale royalty, and so enforcement costs may switch the choice between an end-point and a point-of-sale royalty. As enforcement costs increase, there may come a point when breeders prefer to impose a point-of-sale royalty.

A partial-insurance model with a license fee l and end-point royalty r was described in Chapter 5 as the best implementable outcome. In that model, the expected profit of the breeder was given in Equation E.13 in Appendix E as

$$E\pi_{B1} = \frac{(1-r)v(v-g)}{2c} - K. \tag{6.1}$$

From Equation 5.16, the optimum rate for the end-point royalty is

$$r_1 = 1 + \frac{vc - \sqrt{v^2c^2 + 4\gamma(v-g)^2c\sigma^2}}{2(v-g)\gamma\sigma^2}. \tag{6.2}$$

Substituting for r_1 and simplifying gives

$$E\pi_{B1} = \frac{-v^2}{4\gamma\sigma^2} + \sqrt{\frac{v^4}{16\gamma^2\sigma^4} + \frac{v^2(v-g)^2}{4c\gamma\sigma^2}} - K. \tag{6.3}$$

Next, we include enforcement costs. These are given by $A + ab$, where A represents the fixed enforcement costs and ab the variable costs. The breeder's costs, which were $gb + K$, become $(g+a)b + K + A$. Hence, with an end-point royalty in a Principal–Agent model with enforcement costs, the breeder's expected profit is

$$E\pi^e_{B1} = \frac{-v^2}{4\gamma\sigma^2} + \sqrt{\frac{v^4}{16\gamma^2\sigma^4} + \frac{v^2(v-g-a)^2}{4c\gamma\sigma^2}} - K - A \tag{6.4}$$

and the optimum rate for the end-point royalty is

$$r_1^e = 1 + \frac{vc - \sqrt{v^2c^2 + 4\gamma(v-g-a)^2 c\sigma^2}}{2(v-g-a)\gamma\sigma^2}. \tag{6.5}$$

It is clear that society and the breeder are worse off with enforcement costs than without, and become worse off as the level of either the fixed or marginal compliance costs increases. The superscript e indicates this is an optimum value for the model with enforcement costs; the subscript 1 indicates this is the best-implementable model.

Now we consider a model with a licence fee l and a point-of-sale royalty p and we will compare the best-implementable outcome under this model with that for the best-implementable outcome when there is a licence fee and an end-point royalty.

Using the analysis in Chapter 5, the certainty equivalent of farmer profit where there is a only a point-of-sale royalty and a license fee and no end-point royalty is given by

$$Z = vb - pb - l - \frac{cb^2}{2} - \frac{\gamma\sigma^2 b^2}{2}.$$

Following Equation 5.14, the farmer maximises this with

$$b = \frac{v-p}{c+\gamma\sigma^2}.$$

The breeder sets the license fee so the farmer is forced down to reservation utility at $Z = 0$. Setting $Z = 0$ in the expression for the certainty equivalent of farmer profit above, and re-arranging, gives

$$l = (v - p)b - \frac{(c + \gamma\sigma^2)b^2}{2} = \frac{(v - p)^2}{2(c + \gamma\sigma^2)}.$$

There are no enforcement costs associated with a point-of-sale royalty only, so expected breeder profit for this model with a point-of-sale royalty instead of an end-point royalty is denoted $E\pi_{Bp}$ and is given by

$$pb + l - gb - K.$$

Substituting for b and l gives

$$E\pi_{Bp} = \frac{(v - p)(v + p - 2g)}{2(c + \gamma\sigma^2)} - K.$$

Differentiating with respect to p gives the first-order condition

$$\frac{-v - p + 2g + v - p}{2(c + \gamma\sigma^2)} = 0$$

with solution $p^p = g$. The second-order conditions hold for a maximum. Substituting p^p into the expression for the expected breeder profit gives

$$E\pi_{Bp} = \frac{(v - g)^2}{2(c + \gamma\sigma^2)} - K. \tag{6.6}$$

We have now obtained expressions for the breeder's profit under both scenarios: a license fee and end-point royalty in Equation 6.4 and a license fee and point-of-sale royalty in Equation 6.6. Next, we compare them in order to decide which scenario is better. In both scenarios, the measure of social welfare we use, the sum of farmer and breeder surplus, is simply the value of breeder profit since it is optimal for the breeder to use the license fee to push the farmer down to zero profit. Hence, a point-of-sale royalty is optimal, from the perspective of society as well as the breeder, if the breeder's profit under a point-of-sale royalty exceeds that under an end-point royalty; that is, if the following condition holds:

$$\frac{(v-g)^2}{2(c+\gamma\sigma^2)} + \frac{v^2}{4\gamma\sigma^2} - \sqrt{\frac{v^4}{16\gamma^2\sigma^4} + \frac{v^2(v-g-a)^2}{4c\gamma\sigma^2}} + A > 0.$$

This can be re-arranged to give a decision rule concerning enforcement costs that will determine whether a point-of-sale royalty or an end-point royalty (along with the license fee) is socially optimal. The rule is that a point-of-sale royalty is better than an end-point royalty if

$$A > \sqrt{\frac{v^4}{16\gamma^2\sigma^4} + \frac{v^2(v-g-a)^2}{4c\gamma\sigma^2}} - \frac{(v-g)^2}{2(c+\gamma\sigma^2)} - \frac{v^2}{4\gamma\sigma^2}. \tag{6.7}$$

Equation 6.7 is complex and cannot be further simplified. The comparative statics are not easy and likely effects of changes in parameter values cannot be always derived algebraically.

We can, however, replace the decision rule implied by Equation 6.7 by a decision frontier,

$$A = \sqrt{\frac{v^4}{16\gamma^2\sigma^4} + \frac{v^2(v-g-a)^2}{4c\gamma\sigma^2}} - \frac{(v-g)^2}{2(c+\gamma\sigma^2)} - \frac{v^2}{4\gamma\sigma^2}. \tag{6.8}$$

and depict this schematically as in Figure 6.1. In this Figure, fixed enforcement costs A are on the vertical axis, variable enforcement costs a are on the horizontal axis, and the line shows combinations of the two enforcement costs that make society and breeders as well off with either of point-of-sale or end-point royalties along with the license fee. This is the frontier that separates values of the enforcement costs where an end-point royalty is optimal from those where a point-of-sale royalty is optimal.

First, we show this line is downwards sloping by using implicit differentiation to find the derivative of fixed enforcement costs A with respect to variable enforcement costs a. The derivative

$$\frac{\partial A}{\partial a} = \frac{-v^2(v-g-a)}{4c\gamma\sigma^2\sqrt{\frac{v^4}{16\gamma^2\sigma^4} + \frac{v^2(v-g-a)^2}{4c\gamma\sigma^2}}} \tag{6.9}$$

is negative and the line shown in the Figure is indeed downward sloping. When enforcement costs are below (to the left of) the line, end-point royalties are optimal; when enforcement costs are above (to the right of) the line, point-of-sale royalties are optimal. The intuition is simple: point-of-

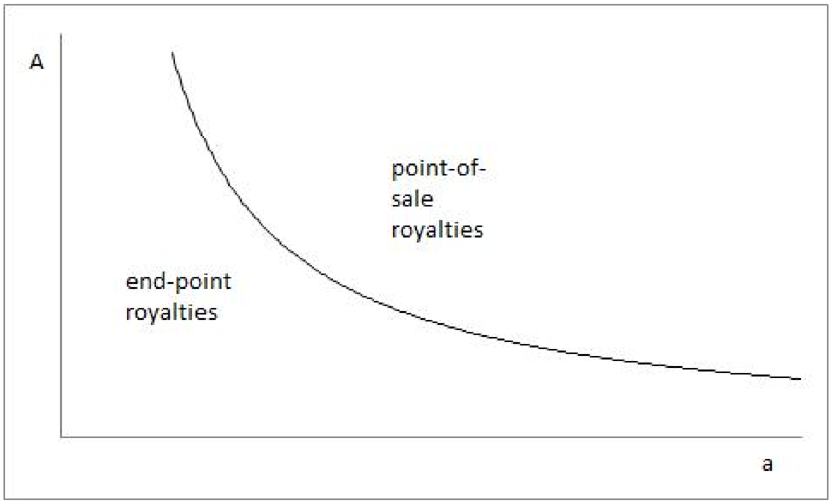

Figure 6.1: Optimum royalties for different fixed and marginal enforcement costs.

sale royalties are better than end-point royalties if the costs of enforcing end-point royalties become high.

For example, the Principal–Agent model of the previous chapter ignored enforcement costs, effectively setting A and a to zero, and hence the condition in Equation 6.7 fails, actual enforcement costs are at the origin in Figure 6.1, so below the frontier, and an end-point royalty is optimal.

It would be convenient if we could use the Australian wheat industry as an example, and estimate the parameters in Equation 6.7 or draw the frontier from Equation 6.8 and locate enforcement costs on the Figure, and hence be able to state which royalty is better. However, we will see shortly this is not possible.

Comparative statics are also not forthcoming from this model. An increase in marginal product, or a decrease in breeding costs, farming costs, risk aversion or the riskiness of the yields will each increase the expected breeder profit under both royalties. Hence, the overall effect on our decision rule of any of these is complicated and cannot be easily signed analytically. Instead, we turn now to numerical methods.

6.3 Numerical methods

In this section, we attempt to simulate the model by assuming plausible values for the parameters. It is important to understand that this does not provide a truly realistic analysis.

An alternative approach to our game-theoretic models could have been a more simple and straight-forward empirical model without strategic interaction that uses real-life numbers and estimates. This approach could be useful as an overall descriptor of the industry and to provide policy advice, but has no micro-economic foundations. The model we develop in this chapter is different—it has micro foundations so that we can capture and explore effects on a micro level that an empirical model would be unable to see. The numbers and values we use are illustrative only; they are not meant as an accurate prediction of what happens but rather to indicate what might happen. As we outlined in Chapter 2, many other papers and models rely on the use of illustrative values. Kennedy and Godden (1993, p. 110) justify using "parameter values [which] are notional rather than empirical" on the grounds that they, as we, are aiming "to illustrate the qualitative behaviour of the seed industry for different industry structures with and without PVR".

In particular, we use our plausible values to investigate what levels of fixed and variable enforcement costs lead to a point-of-sale royalty rather than an end-point royalty being better for society. After that, we investigate the effects of changing the parameter values, one at a time, on the choice of royalty.

This section describes how the plausible values for the model were chosen; the following section uses these values and discusses the results.

The model requires values for the output price, the marginal product of seed, the farmer's marginal cost, the farmer's coefficient of risk aversion, the variance of yields, the breeder's marginal breeding and enforcement costs. For each parameter, we report the actual value used, as well as lower and upper bounds. We show these values in Table 6.1 and the following sections explain how the values were obtained. Since the output price is normalised to 1, all monetary values are expressed in terms of this numeraire and are indicated by the units $\$N$.

6.3.1 The wheat output price

The output price varies over time. A media release of the former Australian Wheat Board (2010b) provided a representative value of $AUD260 per tonne. In the model used in this chapter, the wheat price is normalized

Parameter	minimum value	representative value	maximum value	units
Output price		260		\$A per tonne
		1		$\$N$ per tonne
Marginal product v	0.02	0.035	0.05	$\$N$ per kg of seed
Farmer cost coefficient c	0.000231	0.000269	0.0003	$\$N per kg^2$ of seed
Risk-aversion coefficient γ	0.00026	0.0026	0.26	$(\$N)^{-1}$
Variance of yield σ^2	0.0000004	0.000007	0.00001	$(\$N$ per kg of seed$)^2$
Variable breeding costs g	0	0.000423	0.000846	$\$N$ per kilogram

Table 6.1: Illustrative numerical values

to 1, so \$AUD260 per tonne is the numeraire unit of money, denoted $\$N1$. Any values measured in monetary terms will be converted to $\$N$.

6.3.2 The marginal product of wheat

Following the model we developed in the previous chapters, we require a value for the marginal product of wheat. Mr Rob Wheeler, Leader of New Variety Evaluation in the South Australian Research and Development Institute (SARDI) (personal communication) provided information about the marginal product of wheat. Mr Wheeler provided data on the typical seeding rates and average yields for the three rainfall zones of South Australia. These data were for the variety *Yitpi*, which is the most common variety grown in South Australia, and typical of many others.

The average yields are adjusted to be in the required units, which is the dollar-value of wheat output per kilogram of seed. For example, suppose the average yield was 3 tonnes per hectare, with a sowing rate of 80 kilograms of seed per hectare; this would correspond to 3 tonnes of wheat per 80 kilograms of seed or 0.0375 tonnes of wheat per kilogram of seed. With the output price of wheat normalised to \$1N, these values are also the marginal product in \$N.

Table 6.2 shows, for each of the rainfall zones, the value of marginal product obtained, along with the values of the sowing rate and the average yield used in the calculations. Since most of Australia's wheat production comes form low to medium rainfall zones, where yields typically average

Rainfall	average yield tonnes per hectare	sowing rate kg per hectare	marginal product tonnes /kg or $N per kg
Low	1.6	60	0.03
Medium	3	80	0.0375
High	3.5	85	0.0412
Marginal product=$\frac{\text{average yield}}{\text{sowing rate}}$			

Table 6.2: Values of the marginal product of wheat

less than 2.5 tonnes per hectare, we chose a representative value of 0.035, with minimum 0.02 and maximum 0.04.[2]

6.3.3 The coefficient of risk aversion of farmers

At the suggestion of Professor Ross Kingwell (personal communication), we took the value of the farmer's coefficient of risk aversion from a study by Ghadim (2000). This study computed the Arrow-Pratt coefficient of absolute risk-aversion for farmers who were adopting a crop innovation. The most likely value of the risk-aversion coefficient was 0.00001, with lower bound 0.000001 and upper bound 0.001. These values show risk-averse farmers with a low coefficient of risk aversion. This coefficient is in units of $(\$AUD)^{-1}$ and must be converted to the numeraire unit of currency. This is achieved through multiplying the original CARA by the numeraire, $260. Raskin and Cochran (1986) describes how to rescale changing the Arrow-

[2]This value was suggested by an anonymous examiner as being more likely to be representative of the marginal product for wheat in Australia.

Pratt coefficient of absolute risk-aversion; Example 1 on page 207 covers the case of converting the risk coefficient when changing currencies, exactly as we are doing.[3]

Converting to the numeraire in this way gives the minimum, representative and maximum values as $(\$N)^{-1}$ 0.00026, 0.0026 and 0.26 respectively.

6.3.4 The marginal cost of farmers

Mr Rob Wheeler, quoting sources at the Department of Primary Industries and Resources of South Australia, also provided data for the farmer's variable costs, from which can be calculated the marginal cost parameter.

For example, if the seeding rate was 80 kilograms per hectare, variable costs of \$AUD224 per hectare corresponds to \$AUD224 per 80 kilograms of seed or $224/80$ \$AUD per kilogram of seed.

It is not clear whether the data provided were marginal or average variable costs, although they are more likely to be average variable costs. Since total cost is given by

$$\frac{cb^2}{2},$$

[3]Consider an exponential utility function, the form required for the mean–variance model, $U(y) = C - exp^{-\rho y}$. Suppose we change the variable from y measured in $\$AUD$ to x measured in $\$N$. We want to find the new CARA, ρ' which is such that $\rho y = \rho' x$. Clearly, $\rho' = \rho\frac{y}{x}$. In our case, $y = 260x$ and hence $\rho' = 260\rho$.

Rainfall	variable cost per hectare	sowing rate	value of cost parameter c $\$A$ per kg^2	$\$N$ per kg^2
Low	112	60	0.06	0.000239
Medium	224	80	0.07	0.000269
High	308	85	0.085	0.000328
Marginal cost coefficient $c = \frac{2*\text{Variable cost per hectare}}{260*\text{sowing rate}^2}$				

Table 6.3: Values of the farmer's marginal cost coefficient

then average variable costs AVC are

$$AVC = \frac{cb}{2} \text{ and hence } c = \frac{2AVC}{b}.$$

In the current example, this expression becomes

$$c = (2 * 224)/(80 * 80) = 0.07.$$

This is in units of \$AUD per kilograms^2; to convert to $\$N$ per kilogram^2 requires dividing by the numeraire price of wheat, 260, giving in this example $\$N$ 0.000269 per kilogram^2.

Table 6.3 shows, for each of the three rainfall zones, the variable cost, sowing rate, and the resulting cost parameter, in units of both $\$A$ per kg^2 and $\$N$ per kg^2. The representative value is $\$A0.07$ per kilogram^2 or $\$N0.000269$ per kilogram^2, and the lower and upper values are $\$N0.0002$ and $\$N0.00033$.

6.3.5 The variance of yields

The values for the variance of the yield of wheat were based on data for South Australia from the National Variety Trials (2010a), adjusted to be in the required units. The data are in units of (tonnes per hectare)^2, whereas the parameter σ^2 requires units of (\$ /kilogram)^2.

For example, suppose the variance is 0.15 (tonnes per hectare)^2. Then the standard deviation is $\sqrt{0.15}$ tonnes per hectare, or, with a seeding rate of 60, $\sqrt{0.15}$ tonnes of wheat per 60 kilograms of seed, or $\frac{\sqrt{0.15}}{60}$ tonnes of wheat per kilogram of seed. With the wheat output price normalised to 1, this is also the value in \$N per kilogram of seed. The required value of σ^2 is

$$\frac{0.15}{3600} = 0.000042 \text{ (\$N/kilogram)}^2.$$

The general formula is

$$\sigma^2 = \frac{\text{variance of yield}}{(\text{sowing rate})^2}.$$

The variances of the yields are not readily available but coefficients of variation (CV) are, and the standard deviations of the yields are easily obtained as

$$\frac{\text{CV} * \text{mean yield}}{100},$$

and hence

$$\sigma^2 = \left[\frac{\text{CV} * \text{mean yield}}{100 * \text{sowing rate}}\right]^2.$$

Rainfall	sowing rate	values of variance σ^2		
		minimum	maximum	median
Low	60	0.00000043	0.000012	0.0000020
Medium	80	0.0000043	0.0000087	0.0000065
High	85	0.0000015	0.0000080	0.0000038
Variance of yield $\sigma^2 = \left[\frac{\text{CV} * \text{mean yield}}{100 * \text{sowing rate}}\right]^2$ in (\$N per kilograms)^2.				

Table 6.4: Values of the variance of yields

Using the sowing rates for the three rainfall zones gives values of σ^2 ranging from 0.00000043 to 0.000012 with a median of 0.0000027. These values and associated data are shown in Table 6.4.

There is evidence that the variance of wheat yields is increasing over time (Kingwell, 2011) and therefore it is likely that the values obtained from our calculations were too low.[4] Hence the representative value was taken as the median of the medium rainfall zone 0.000007; the minimum value is 0.0000004 and the maximum is 0.00001.

6.3.6 The breeder's marginal cost of production

Data on the breeder's marginal cost are not available; if the seed industry was competitive, we could take the price of seed as the marginal cost. However, this is not the case. For a monopolist breeder the price is above marginal cost. The price of wheat seed varies considerably by variety—

[4]This was confirmed by an anonymous examiner.

for example, seed of several varieties including *Lancer* costs farmers \$AUD 0.73 per kilogram (Grainland, 2014) whilst other sources[5] quote \$AUD 0.22 per kilogram. We used the value \$AUD 0.22 per kilogram as our upper value for marginal breeding cost and the value 0 as the minimum; the representative was simply the average, \$AUD 0.11 per kilogram. These values were converted to numeraire units by dividing by 260, giving \$N0, 0.000423 and 0.000846.[6]

6.3.7 Enforcement costs

In our model, enforcement costs fall on the breeder; in the real world, the farmer may also incur costs of concealment. For the breeder, fixed enforcement costs could include the cost of maintaining an in-house legal department or a system and infrastructure for testing varieties and investigating farms for potential under-declaration of seed or output. The variable costs could include the costs of extra legal advice or employing investigators to go out into the field and check seed stocks and outputs.

We do not have data for enforcement costs; both fixed and variable enforcement costs, A and a, are non-negative; and, at this stage, all we can say is variable enforcement costs are below $v - g$. If this condition fails,

[5] See `www.cavrep.com.au/G/GROSSMARGINS.html`

[6] Since these values are unreliable, all modelling was carried out using a wide range of values for this parameter. These checks are not shown in the thesis but we draw attention to them as required.

the marginal product of wheat is less than the breeders marginal costs of production and enforcement and breeding would not be viable.

Hence, we have $A > 0$ and $a \in [0, v - g]$. In what follows, we apply the model to a number of values of fixed and marginal enforcement costs over their ranges. We will see below that the condition on a can be tightened somewhat.

6.3.8 The results

Once the plausible values for the parameters of the model have been obtained, we construct the enforcement costs frontier by varying the value of variable enforcement costs a and evaluating fixed enforcement costs A using Equation 6.8. The enforcement costs frontier for our illustrative values is shown in Figure 6.2.

From this Figure, we can see that if actual enforcement costs are high, the breeder will prefer a point-of-sale rather than an end-point royalty, along with the license fee; and as actual enforcement costs increase, a point-of-sale royalty becomes relatively better. Moreover, as we mentioned earlier, if actual enforcement costs are zero, as we assumed in the previous Chapter, an end-point royalty is optimal.

Three things are worth discussing about this plot.

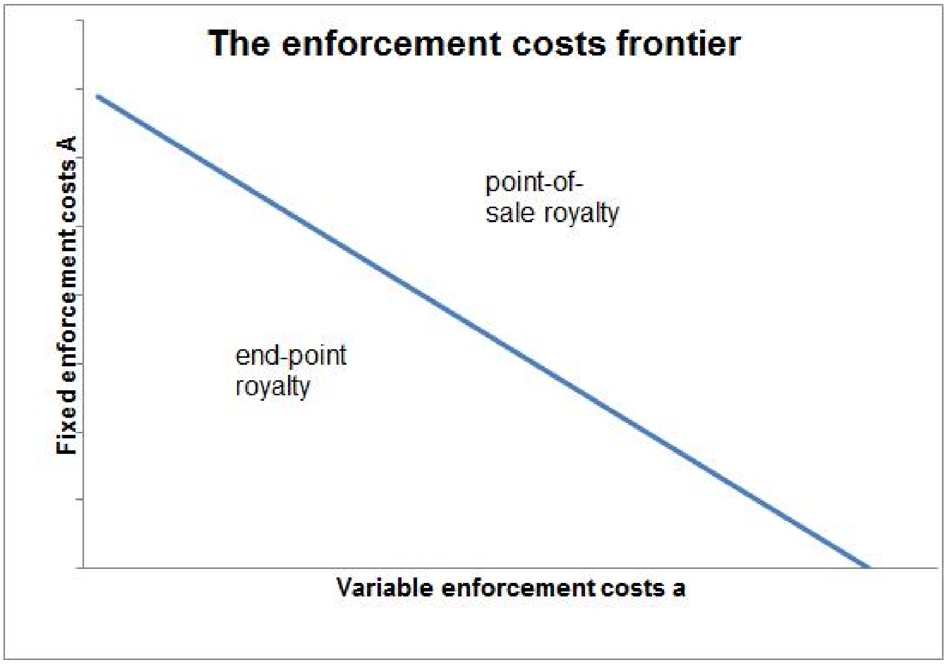

Figure 6.2: The enforcement costs frontier

First, we do not show the scale because the absolute numbers are meaningless since the model we have used is based on a unit sized farm and a numeraire unit of money. We are interested in the trade-offs and direction of change rather than absolute numbers. However, from the position of the frontier, in particular the horizontal intercept, we can say that if fixed enforcement costs were zero, a point-of-sale royalty would be optimal if variable enforcement costs are above about 0.02% of marginal product v or 2% of the breeder's marginal cost g.

This provides our second point of interest: if variable enforcement costs exceed the horizontal intercept, given fixed costs A are non-negative, the breeder will never use end-point royalties and this intercept gives us a tighter upper bound for a than we developed in the previous Section.

The third interesting feature of this plot is that the frontier appears to be linear. This is due to the low values we observed for the parameters of the model; both the risk coefficient γ and the variance of yields σ^2 are low and their product is close to 0. Equation 6.9 for the slope of the frontier can be re-arranged to give

$$\frac{-v^2(v-g-a)}{\sqrt{c^2v^4+4c\gamma\sigma^2v^2(v-g-a)^2}}$$

and if $\gamma\sigma^2$ is appropriately zero, as in our example, the slope becomes

$$\frac{-(v-g-a)}{c}.$$

Over the range of values of marginal enforcement costs we use, a takes on very low values and does not vary much relative to the remaining parameters in the model and the slope appears constant although over a wider range of values of a, the frontier would be seen to be convex.

Our parameter values are questionable and we check their reliability by using Equation 6.5 to evaluate the end-point royalty implied by our parameter values. Since we do not have a value for marginal enforcement costs a, we calculate the end-point royalty over the range of possible values, $0 < a < v - g$. This gives an end-point royalty varying from \$3.16 when variable enforcement costs are 0 to \$226 when variable enforcement costs are so high that the entire marginal product is taken up by the breeder's variable costs (that is, $v = g + a$). Clearly, values such as $226 are totally unrealistic; however, when variable enforcement costs are this high, and fixed enforcement costs are non-negative, the breeder will not be using an end-point royalty but will use a point-of-sale royalty instead. If we restrict fixed enforcement costs to be non-negative and so restrict a to be below the value of the horizontal intercept on our frontier diagram, we obtain estimates of the end-point royalty of $\$3.16$. We saw in Chapter 2 that end-point royalties in Australia are currently as high as $\$4.25$ per tonne so our estimate is of the correct order of magnitude. Whilst many varieties have an end-point royalty below $\$3.16$, we explained in Chapter 2 that end-point royalty rates are rising and breeders may have kept the rate below the optimum until end-point royalties become the norm so varieties which attract an end-point royalty are not at a disadvantage compared to varieties which do not incur end-point royalties.

We said earlier the value that we use for variable breeding costs g is particularly unreliable. Our sensitivity checks show a positive relationship between g and r; from an end-point royalty of $0.02 when $g = 0$ to an end-point royalty of $\$8.59$ when $g = 30$. However, when the variable costs are very low, the enforcement costs frontier has shifted so close to the origin that end-point royalties are unlikely to be used.

Next, we turn to the comparative static results. To see what happens to the enforcement costs frontier and the choice between royalties, each of the parameters is varied one at a time, holding all others constant and these partial responses are shown as a new frontier in the accompanying diagram, Figure 6.3.

For example, the new frontier coloured red shows what happens when the marginal product of wheat increases, with all other parameters unchanged; this frontier is steeper than the original frontier although the horizontal intercept varies little. The remaining revised frontiers are also on the Figure. The effects of an increase in the variance of yields and the coefficient of risk aversion are the same and the two frontiers for these effects are the same so they appear on the Figure as one line only.

Figure 6.3 shows an end-point royalty is more likely to be optimal if the marginal product of seed increases, the marginal costs of the breeder increases, the variance of yields or the coefficient of risk aversion increases or the farmer's marginal costs decrease. We discuss these results next.

6.4 Discussion

As a caveat, it is important to realise that the model we present is not intended to be an accurate description of the Australian wheat breeding industry; the parameter values used and the numerical answers obtained are illustrative and indicative rather than realistic. Our objective was to explore likely relationships, trends and equilibrium trade-offs rather than

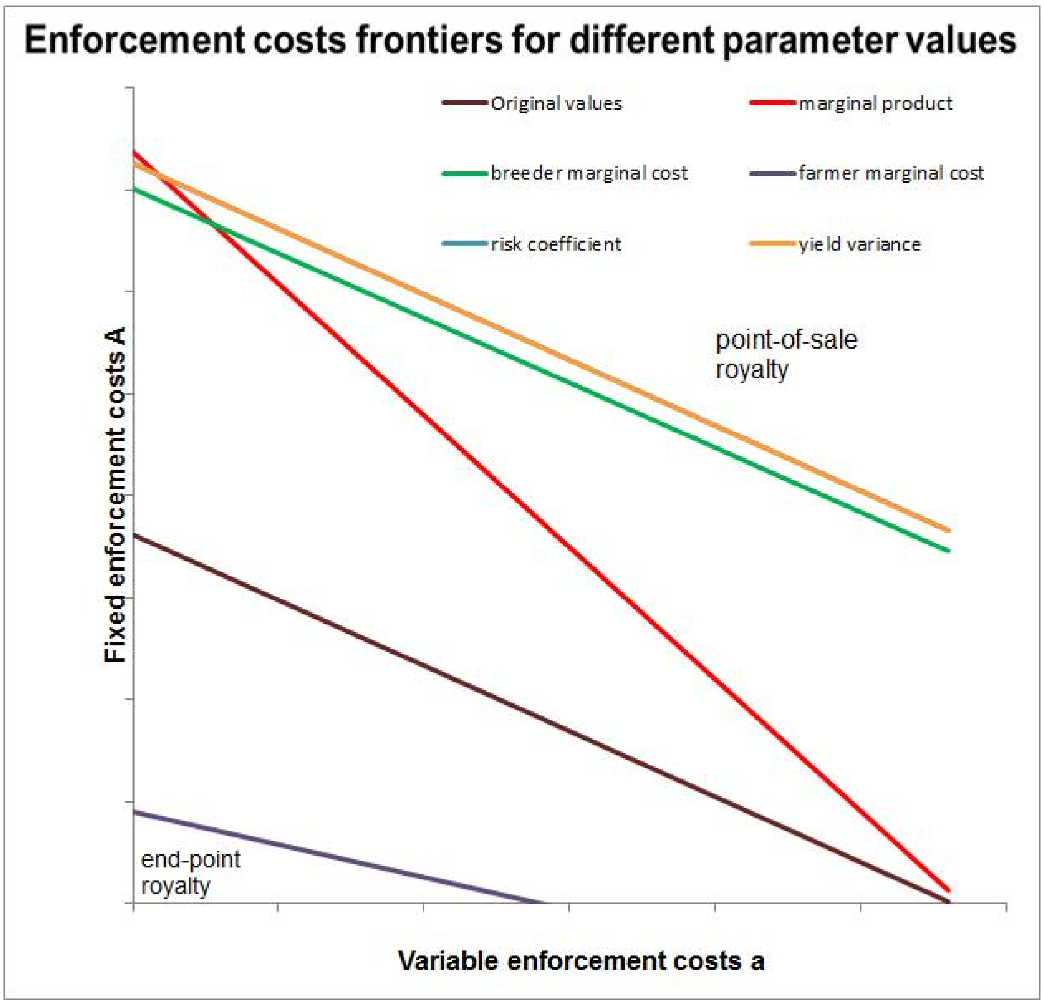

Figure 6.3: The enforcement costs frontiers as parameter values vary

mirror and estimate realistic values. Hence, we are only able to draw qualitative conclusions. In addition, our model is complex and the effects of a change in one parameter are likely to affect the equilibrium through many channels. We cannot always be sure of the mechanisms underlying our results, but we can suggest likely reasons. One possible channel that appears to be important is risk and insurance.

However, our analysis does show it is possible for either an end-point or point-of-sale royalty to be optimal with the license fee depending on the value of enforcement costs. In Section 6.2, we showed algebraically an end-point royalty is more likely to be optimal as fixed or variable enforcement costs decrease. The intuition is that these costs affect the end-point but not point-of-sale royalty so as they decrease, the end-point royalty becomes relatively cheaper to enforce and is more likely to be optimal.

An end-point royalty is more likely to be preferred to a point-of-sale royalty if the variance of yields or the risk aversion of the farmer increases. This is illustrated by an outward shift in the enforcement costs frontier in Figure 6.3. If the variance of yields increases, so does the farmer's risk; given our assumption of CARA, equilibrium will be restored only if risk returns to the original level. This could occur through the farmer decreasing production; in that case, the social surplus falls, and both breeder and farmer are worse off. An alternative would be for the breeder to take some of the extra risk by partly insuring the farmer through the end-point royalty. In the process, the farmer is returned to their constant level of risk, the social surplus may not fall as much and breeders may be better off than if they do not use end-point royalties to insure the farmer.

Similarly, if the farmer becomes more risk averse, they will only tolerate a lower level of risk and again the breeder has an incentive to take on some risk through an end-point royalty.

An increase in the farmer's costs will reduce their output and profit, reducing their seed purchases and level of risk. Given our assumption of CARA, insurance may be less valuable to the farmer and breeders may no longer use an end-point royalty but will instead use a point-of-sale royalty. This is demonstrated in Figure 6.3 by an inwards shift of the enforcement costs frontier as farmer costs increase.

Next, we consider the marginal product of seed. The enforcement costs frontier in Figure 6.3 rotates outwards as the marginal product of seed increases. From an equilibrium position, if the marginal product of seed increases, production and the social surplus increases. As production increases, so does the farmer's risk and with our assumption of constant absolute risk aversion, insurance becomes more valuable to the farmer. The breeder can provide the insurance through end-point royalties, which reduce the farmer's risk to the constant equilibrium level.

An increase in the marginal cost of the breeder shifts the enforcement costs frontier outwards in Figure 6.3 and an end-point royalty is more likely. One possible reason for this is that the increased costs reduce breeder profits and the breeder will wish to raise the level of whichever royalty they are using in order to compensate for this. If the breeder is using a point-of-sale royalty and they increase this, the farmer will buy less seed; this distorts output downwards. If, instead, they use an end-point royalty and increase this to compensate for the lower profit per unit sold, they avoid the output distortion but will now pay enforcement costs. It might become worthwhile to pay for enforcement of an end-point royalty in order to avoid further downward distortion of output.

6.5 Conclusion

The previous chapter used a Principal–Agent model and concluded end-point royalties are better than point-of-sale royalties in conjunction with a fixed up-front license fee. However, end-point royalties are not widely used. Anecdotal evidence points to enforcement costs as one possible barrier to their implementation so this Chapter added these costs to the Principal–Agent model. The enhanced model shows enforcement costs are important. However, general comparative static results or necessary conditions for optimisation are not tractable and so numerical values are obtained, and the model simulated as far as possible. This produces an enforcement cost frontier—a locus of fixed and variable enforcement costs that separates values of enforcement costs where a point-of-sale royalty is optimal from those where an end-point royalty dominates.

The frontier shows the level of enforcement costs could be such that either a point-of-sale or an end-point royalty is optimal, but that lower enforcement costs will favour an end-point royalty. These costs may be lower due to factors such as the institutional and legal framework of a country or its geography. Using end-point royalties may boost efficiency, as the welfare-damaging quantity effects of the point-of-sale royalty would be eliminated.

It is, perhaps, not surprising that wheat in Australia is one of the few crops with an end-point royalty: there are relatively few marketing points, which eases the problem of locating output; there is a strong institutional and industry structure; breeders have been successful in disseminating information about royalties; and the Australian Government, through ACIP, seems ready to improve compliance and enforcement practices.

Chapter 7

Policy implications and conclusions

This dissertation set out to determine which is the best royalty or combination of royalties to allow on crop varieties. The system that prevailed in Australia until the 1980s was no royalties with public funding of R&D and the research and breeding mainly conducted by state government departments and universities. Since then, breeders are increasingly self-funding through royalties, and public funding has diminished, although the direction of causation is uncertain. To a large extent, private breeding companies have taken over from the state agricultural breeders; this means it is difficult and therefore unlikely that the privatisation process would be reversed and public breeding become dominant again. Australia allows an end-point royalty, and other countries are interested to judge its success. This dissertation identifies and models two features that distinguish crop breeding from other activities: farmer-saved seed, and the attitude of farmers and breeders towards risk. Our models are based on microeconomic theory and are qualitative, not empirical, models; they cannot be used for forecasting or estimating particular values or trends. Instead, our models allow us to explore the trade-offs and qualitative equilibrium effects of variables that are considered important in determining the best royalty system. As our measure of social welfare, we use the sum of farmer and breeder profits. We consider two extremes—the benevolent social planner whose aim is to maximise social welfare and allocate it according to some policy goal, and the monopolist breeder who aims to maximise their own surplus.

In our first set of models, we use a game-theoretic approach in which breeders set royalty rates bearing in mind the anticipated best response of farmers. With full and complete declaration by farmers, the best for either society or the monopolist breeder is a point-of-sale royalty with either or both of the other two royalties. Both the planner and breeder can attain the maximum level of social welfare and extract it to suit their goals. At the optimum, there will be some saved seed since saved seed is relatively cheaper than bought seed as a point-of-sale royalty is not due on saved seed. However, we assume saved seed is less productive than new seed, so not all the seed used will be saved seed.

The schemes currently in place in the UK and Australia, although different to each other, are both ones that our model identifies as optimal.

Next, we incorporate into the model the possibility of farmers declaring less than the full amount of saved seed or output. Whilst the same schemes are optimal as when declaration was full, the level of social welfare attainable is below that of the full-declaration model by an amount related to the institutional factors—enforcement costs and fines. Both the social planner and the monopolist breeder can allocate the surplus if they have a point-of-sale royalty and at least one other royalty.

At this point, our models have not identified a unique best royalty scheme and we turn to another possible determinant of optimal royalties: risk-sharing between breeder and farmer.

Anecdotal evidence suggests risk-sharing between farmers and breeders is an important justification for an end-point royalty. We model this in a Principal–Agent framework. Whilst the first-best royalty scheme is for breeders to pay farmers a fixed up-front license fee, akin to a wage, and then extract the full value of production through an end-point royalty of 1, this is open to moral hazard—a rational profit-maximising farmer would shirk. Intervention beyond royalties would be required to implement this outcome. We restrict attention to schemes which require no such additional intervention and show that then, in the absence of enforcement costs, the optimal scheme is to have an end-point royalty of less than 1, along with a license fee which farmers pay to breeders. The end-point royalty provides partial insurance to the farmers but since it is less than 1, there is still the incentive for farmers to do the work. The breeder has taken some of the risk from the farmer.

The final model incorporates enforcement and compliance costs into the Principal–Agent model and we show the level of these costs may determine which of an end-point or point-of-sale royalty is better in conjunction with the license fee. The higher these compliance costs are, the more likely it is that a point-of-sale royalty is better than an end-point-royalty.

The Australian wheat industry currently faces structural issues which have potential impacts on the choice of royalty. Whilst we have not analysed these changes specifically, our models provide some insights.

For example, as mentioned in Chapter 2, the de-regulation of the grain market and the increased number of selling points will cause difficulties for the administration of end-point royalties and would favour point-of-sale royalties instead. On the other hand, attempts to reduce royalty leakage and transactions costs could favour end-point royalties since, as shown in Chapter 6, the choice between point-of-sale and end-point royalties depends on enforcement and compliance costs. In addition, if these attempts are successful and reduce the incentive for farmers to under-declare output or saved seed, we saw in Chapter 4 that welfare could increase if the social loss due to cheating is eliminated, although this did not change the optimum royalty scheme.

We explained in Chapter 2 how the use of farmer-saved seed meant breeders can not fully appropriate all their returns. If technological change, such as enhanced hybridisation or genetic modification, increases the natural appropriability of returns, the position of breeders would improve at the expense of farmers by making it harder or less worthwhile for farmers to save seed. This corresponds to a decrease in the value of saved seed which we analysed in Chapter 3 and our results showed there were two opposing effects from this: on one hand, it discourages the use of saved seed which has a negative effect on production and welfare, at the same time as encouraging the use of new seed which has positive effects on production and welfare. Overall, the impact of changing the worth of saved seed is uncertain.

Finally, future climate change could increase the variability of yields and as we have seen in Chapter 5, the breeder may increase the use of end-point royalties to take some of this extra risk from the farmer.

This dissertation uses simple models but, even so, the results are not always tractable, and further analysis required specific functional forms. A next step in research could be to use more general functional forms, and establish which results are robust to the forms used. A parametrisation of some variables could also simplify the model without loss of generality. Further work to quantify compliance costs could improve the results and interpretation of the model, and allow for a more definite conclusion as to the best royalty scheme.

Appendices

Appendix A

Appendix to Chapter 2: Background

A.1 Source of data for EPR rates

The following Table lists wheat varieties, their year of release, their end-point royalty rates and the year the variety was released. The list of varieties and the end-point royalty rates for the 2014/2015 harvest are from the *VarietyCentral* website (VarietyCentral, 2014). The year of release data are from various sources, which are noted in the Table and detailed below the Table. Varieties are ordered by year of release and the EPR rate within each year.

Variety name	Year of release	EPR $/t	Source of data for year of release
Camm	1998	0.95	Wheat variety guide 2008 Western Australia
Goldmark	1998	1	Brennan and Quade (2004)
Baxter	1998	1.45	NVT Queensland 2010 Wheat Varieties

Variety name	Year of release	EPR $/t	Source of data for year of release
Kennedy	1998	1.45	NVT Queensland 2010 Wheat Varieties
Giles	1999	1	NVT Queensland 2010 Wheat Varieties
Chara	1999	1	SARDI sowing guide 2014
Kukri	1999	1	SARDI sowing guide 2014
Yitpi	1999	1	GRDC WA variety guide 2013
H45	2000	1	Brennan and Quade (2004)
Lang	2000	1	NVT Queensland 2010 Wheat Varieties
Petrie	2000	1	NVT Queensland 2010 Wheat Varieties
Strzelecki	2000	1	NVT Queensland 2010 Wheat Varieties
Thornbill	2000	1	Brennan and Quade (2004)
Babbler	2000	1.5	Brennan and Quade (2004)
Mitre	2000	1.5	Wheat variety guide 2008 Western Australia
QAL2000	2000	2	NVT Queensland 2010 Wheat Varieties
Braewood	2001	1	Wheat variety guide 2008 Western Australia
Drysdale	2001	1	NVT Online Brochures
Marombi	2001	1	Cornish (2002)
Wylah	2001	1	Brennan and Quade (2004)
Clearfield JNZ	2001	1.12	Wheat variety guide 2010 Western Australia
Clearfield STL	2001	1.12	GRDC WA variety guide 2013
Harrismith	2001	1.12	Cornish (2002)
Annuello	2001	1.65	NVT Online Brochures
Wyalkatchem	2001	1.92	GRDC WA variety guide 2013
Wedgetail***	2002	1.45	Wheat Varieties, Victoria
Pugsley	2002	1.5	SARDI sowing guide 2014
QALBis	2002	2	NVT Queensland 2010 Wheat Varieties
Bellaroi	2002	2.5	NVT Queensland 2010 Wheat Varieties

Variety name	Year of release	EPR $/t	Source of data for year of release
Bonnie Rock	2002	2.5	GRDC WA variety guide 2013
Kalka	2003	1.5	SARDI sowing guide 2014
Castle Rock	2003	1.67	Intergrain website
Ellison	2003	2	NVT Queensland 2010 Wheat Varieties
Jitarning	2003	2.7	Wheat variety guide 2008 Western Australia
Ruby	2003	3	NVT Queensland 2010 Wheat Varieties
Sapphire	2003	3	GRDC WA variety guide 2013
Scythe	2004	1.5	SARDI sowing guide 2014
Ventura	2004	2	NVT Queensland 2010 Wheat Varieties
Gregory	2004	2.1	NVT Queensland 2010 Wheat Varieties
Wentworth	2004	2.1	Wheat variety guide 2010 Western Australia
Wylie	2004	2.1	NVT Queensland 2010 Wheat Varieties
Eagle Rock	2004	2.5	GRDC WA variety guide 2013
EGA2248	2004	3.62	GRDC WA variety guide 2013
H46	2005	1	Wheat variety update for 2008
Amarok	2005	1.5	NVT Online Brochures
Young	2005	1.7	NVT Online Brochures
Sentinel	2005	1.8	NVT Queensland 2010 Wheat Varieties
Bullaring	2005	2.5	Wheat variety guide 2010 Western Australia
Tammarin Rock	2005	2.5	GRDC WA variety guide 2013
Correll	2006	2	SARDI sowing guide 2014
Yenda	2006	2	NVT Online Brochures
Bolac	2006	2.1	SARDI sowing guide 2014
Burke	2006	2.1	NVT Queensland 2010 Wheat Varieties
Catalina	2006	2.5	SARDI sowing guide 2014
Gladius	2006	2.5	SARDI sowing guide 2014

Variety name	Year of release	EPR $/t	Source of data for year of release
Guardian	2006	2.5	SARDI sowing guide 2014
Jandaroi	2006	2.5	NVT Queensland 2010 Wheat Varieties
Lincoln	2006	2.5	SARDI sowing guide 2014
Derrimut	2006	2.95	SARDI sowing guide 2014
Binnu	2006	3	NVT Online Brochures
Sunzell	2007	2	NVT Queensland 2010 Wheat Varieties
Axe	2007	2.5	SARDI sowing guide 2014
Eagle Hawk	2007	2.5	NVT Queensland 2010 Wheat Varieties
Naparoo	2007	2.5	Wheat Varieties, Victoria
Peake	2007	2.95	SARDI sowing guide 2014
Magenta	2007	3	GRDC WA variety guide 2013
Yandanooka	2007	3	NVT Online Brochures
Kidman	2008	n.a.	NVT Queensland 2010 Wheat Varieties
Carinya	2008	2	NVT Queensland 2010 Wheat Varieties
Wills	2008	2.1	NVT Queensland 2010 Wheat Varieties
Dakota	2008	2.2	NVT Queensland 2010 Wheat Varieties
Espada	2008	2.5	SARDI sowing guide 2014
Livingston	2008	2.5	NVT Queensland 2010 Wheat Varieties
Merinda	2008	2.5	NVT Queensland 2010 Wheat Varieties
Caparoi	2008	2.6	SARDI sowing guide 2014
Crusader	2008	2.7	NVT Queensland 2010 Wheat Varieties
Beaufort	2008	3	NVT Online Brochures
Bounty	2008	3	NVT Queensland 2010 Wheat Varieties
Bumper	2008	3	Wheat variety guide 2010 Western Australia
Endure	2008	3	NVT Online Brochures

Variety name	Year of release	EPR $/t	Source of data for year of release
Fang	2008	3	NVT Online Brochures
Fortune	2008	3	GRDC WA variety guide 2013
Mace	2008	3	GRDC WA variety guide 2013
Stampede	2008	3	NVT Queensland 2010 Wheat Varieties
Zippy	2008	3	NVT Online Brochures
Preston	2009	2.2	SARDI sowing guide 2014
Zebu	2009	2.5	NVT Queensland 2010 Wheat Varieties
Zulu	2009	2.5	NVT Queensland 2010 Wheat Varieties
Sunvex	2009	2.75	NVT Queensland 2010 Wheat Varieties
Scout	2009	2.8	GRDC WA variety guide 2013
Hyperno	2009	3	SARDI sowing guide 2014
Katana	2009	3	SARDI sowing guide 2014
King Rock	2009	3	GRDC WA variety guide 2013
Saintly	2009	3	SARDI sowing guide 2014
Waagan	2009	3	Wheat Varieties, Victoria
Revenue	2009	3.5	Wheat Varieties, Victoria
Estoc	2010	3	GRDC WA variety guide 2013
Orion	2010	3	SARDI sowing guide 2014
Tjilkuri	2010	3	SARDI sowing guide 2014
Kunjin	2010	3.5	GRDC WA variety guide 2013
Spitfire	2010	3.5	NVT Online Brochures
Wedin	2010	3.5	GRDC WA variety guide 2013
Envoy	2011	2.8	GRDC WA variety guide 2013
Corack	2011	3	GRDC WA variety guide 2013
Gauntlet	2011	3	NVT Online Brochures
Sunguard	2011	3	NVT Online Brochures
Wallup	2011	3	NVT Online Brochures
Cobra	2011	3.5	GRDC WA variety guide 2013
Emu Rock	2011	3.5	GRDC WA variety guide 2013
Forrest	2011	3.5	NVT Online Brochures
Impala	2011	3.5	SARDI sowing guide 2014
Impose CL	2011	3.5	NVT Online Brochures
Elmore	2011	3.55	NVT Online Brochures

Variety name	Year of release	EPR $/t	Source of data for year of release
Justica	2011	3.55	GRDC WA variety guide 2013
Kord	2011	3.55	SARDI sowing guide 2014
WID802	2012	3	NVT Online
Yawa	2012	3	NVT Online
Shield	2012	3.25	NVT Online
Suntop	2012	3.25	NVT Online
Grenade	2012	3.8	NVT Online
Harper	2013	3.8	NVT Online
Merlin	2012	3.8	NVT Online
Phantom	2012	3.8	NVT Online
Dart	2012	4	NVT Online
Gazelle	2012	4	NVT Online
Trojan	2013	4	NVT Online
Lancer	2013	4.25	NVT Online

Table A.1: EPR rates over time

*** Note that for the variety Wedgetail, the year of registration is given, not the year of release.

Data sources:

Brennan and Quade (2004)	`http://ageconsearch.umn.edu/bitstream/42505/2/ERR25.pdf`
Cornish (2002)	`http://ses.library.usyd.edu.au/bitstream/2123/2699/1/VAWCRC%20Report%208.pdf`
GRDC WA variety guide 2013	`http://www.grdc.com.au/~/media/01683407F02341A0AEE60A27DA36830B.pdf`
Intergrain website	`http://intergrain.cloudapp.net/WheatDetail.aspx?VarietyId=29`
NVT Online brochures	`http://www.nvtonline.com.au/variety-brochures/`
NVT Online	`http://www.nvtonline.com.au/new-varieties/`
NVT Queensland 2010 Wheat Varieties	`http://www.grdc.com.au/~/media/6871461681814AE1A2A657C170A42939.pdf`
SARDI sowing guide 2014	`http://www.sardi.sa.gov.au/__data/assets/pdf_file/0010/45955/Wheat_variety_sowing_guide_2014.pdf`
Wheat Varieties, Victoria	`http://www.dpi.vic.gov.au/agriculture/grain-crops/crop-production/growing-wheat/wheat-varieties`
Wheat variety guide 2008 Western Australia	`http://www.agric.wa.gov.au/objtwr/imported_assets/content/fcp/cer/2008wheatbulletin.pdf`
Wheat variety update for 2008	`http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2008/06/Wheat-variety-update-for-2008`

A.2 Papers

The following Table classifies the papers reviewed in the text according to the year of the paper, the country and crop covered, the type of PVP, the data and the methodology used.

Author	Year	Country			Crop			Type of PVP			Date		Methodology
		North America	AUS	other	general	wheat	other	general	PVPA patents	royalties	type	date	
Godden and Powell	1981				x			x					Various—yield functions, production functions, welfare measures
Butler and Marian	1985	x				x	x		x		Trial; survey; other	various 1960 to 1982	Descriptive statistics; time series
Knudson and Pray	1991	x				x	x		x		Various	1968 to 1988	Regression of R&D; with PVPA as dummy variable
Babcock and Foster	1991	x					x		x		Trial	1954 to 1987	Regression yield function with standard varieties and time
Kennedy and Godden	1993				x			x			Illustrative		2 sector game theory model, with and without PVR
Perrin	1983	x				x	x		x		Survey; trial	1960 to 1980	Descriptive statistics; regression with dummy variables

Author	Year	Country			Crop			Type of PVP			Date		Methodology
		North America	AUS	other	general	wheat	other	general	PVPA patents	royalties	type	date	
Lesser	1994	x					x		x		Trial	1992	Hedonic pricing regression; dummy variable for protection under PVPA.
Pray and Knudson	1994	x				x			x		Various	1968 to 1988	Regression with dummy for PVPA
Perrin	1994				x			x					Supply and demand curve shifts with welfare measures.
Moschini and Lapan	1997	x			x			x			Illustrative		Aggregate supply and demand; welfare measures.
Kingwell	2000		x				x				Illustrative		Illegal use and piracy. Profit maximising farmer with mean-variance formulation of utility
Kingwell	2001		x			x				x	Illustrative		Expected farmer profit and mean and variance formulation of farmer utility

Author	Year	Country			Crop			Type of PVP			Date		Methodology
		North America	AUS	other	general	wheat	other	general	PVPA patents	royalties	type	date	
Alston and Venner	2002	x			x				x		Various	1950 to 1994	Two-stage game-theory model with breeders and farmers.
Carew and De-vadoss	2003	x					x	x			Actual	1995 to 2001	Regression yield function with % covered by PBR
Naseem et al	2005	x					x		x		Actual	1950 to 2000	Regression yield function with PVP % of area, PVP % of varieties.
Leger	2005			x			x	x			interview	2000	Descriptive statistics and time series
Carew and Smith	2006	x					x	x			Actual	1995 to 2003	Regression mean function
Basu and Qaim	2007			x			x	x					Game-theory model with Bertrand competition; farmer-saved seed and cheating included.

Author	Year	Country			Crop			Type of PVP			Date		Methodology
		North America	AUS	other	general	wheat	other	general	PVPA patents	royalties	type	date	
Beard	2008					x				x			Steady-state, optimal-control model.
Perrin and Fulginiti	2008				x				x		Illustrative		Game-theory model with price discrimination over time, welfare measures.
Kolady and Lesser	2009	x				x		x			Trial	1975 to 2006	Regression yield function; PVP as dummy variable.
Thomson	2013		x			x		x			Trial	1976 to 2011	Regression value added function with PVP as structural shift and % of PVP varieties.
Campi	2013			69	x			x			Actual	1970 to 2010	Regression yield function with lagged index of IP protection.

Table A.2: Summary of papers

Appendix B

Appendix to Chapter 3: A game-theoretic model with full declaration

B.1 Interior conditions in the baseline model

Lifetime farmer profit was given in Equation 3.4 as

$$\Pi = \sum_{t=0}^{\infty} \beta^t \left[(1-r)F(q_{t-1}) - P_b \psi b_t - P_s \psi (1-b_t) - C \right]. \tag{B.1}$$

We use this, along with the expression for seed quality, Equation 3.2,

$$q_t = b_t \bar{q} + \theta(1-b_t) q_{t-1}.$$

To check the interior conditions, we sign the relevant partial derivatives at the end points of the range of values of the variables.

Interior conditions for proportion of bought seed

The partial derivative of the farmer's lifetime profit with respect to bought seed is

$$\frac{\partial \Pi}{\partial b_t^*} = \beta^t \left\{ \beta(1-r)F'(q_t)(\bar{q} - \theta q_{t-1}) - (P_b - P_s)\psi \right\}$$

Evaluating the partial derivative at $b_t = 0$ gives

$$\beta^t \left\{ \beta(1-r)F'(\theta q_{t-1})(\bar{q} - \theta q_{t-1}) - (P_b - P_s)\psi \right\}$$

and we need this expression to be positive to give $b_t^* > 0$.

Evaluating this partial derivative at $b_t = 1$ gives

$$\beta^t \left\{ \beta(1-r)F'(\bar{q})(\bar{q} - \theta q_{t-1}) - (P_b - P_s)\psi \right\}$$

and we need this expression to be negative to give $b_t^* < 1$. Hence, we require

$$\begin{aligned} &\beta^t \left\{ \beta(1-r)F'(\bar{q})(\bar{q} - \theta q_{t-1}) - (P_b - P_s)\psi \right\} < 0 \\ &\qquad < \beta^t \left\{ \beta(1-r)F'(\theta q_{t-1})(\bar{q} - \theta q_{t-1}) - (P_b - P_s)\psi \right\} \end{aligned} \tag{B.2}$$

which can be re-arranged to give

$$F'(\bar{q}) < \frac{(Pb - Ps)\psi}{\beta(1-r)(\bar{q} - \theta q_{t-1})} < F'(\theta q_{t-1}).$$

This condition holds due to the Inada conditions and the assumption $P_b > P_s$.

Interior conditions for seed quality

Next, we take the partial derivative of lifetime farmer profit with respect to q_t.

$$\frac{\partial \Pi}{\partial q_t} = \beta^t \left\{ -P_b \psi \frac{\partial b_t}{\partial q_t} + P_s \psi \frac{\partial b_t}{\partial q_t} \right\} + \beta^{t+1}(1-r)F'(q_t),$$

where the partial derivative $\frac{\partial b_t}{\partial q_t} = (\bar{q} - \theta q_{t-1})^{-1}$.

Evaluating the partial derivative at $q_t = 0$ gives

$$\beta^t \left\{ \beta(1-r)F'(0) - \frac{(P_b - P_s)\psi}{\bar{q} - \theta q_{t-1}} \right\}$$

and we need this expression to be positive to give $q_t^* > 0$.

Evaluating the partial derivative at $q_t = \bar{q}$ gives

$$\beta^t \left\{ \beta(1-r)F'(\bar{q}) - \frac{(P_b - P_s)\psi}{\bar{q} - \theta q_{t-1}} \right\}$$

and we need this expression to be negative to give $q_t^* < \bar{q}$.

Hence, we require

$$\beta(1-r)F'(\bar{q}) - \frac{(P_b - P_s)\psi}{\bar{q} - \theta q_{t-1}}\} < 0$$
$$< \beta(1-r)F'(0) - \frac{(P_b - P_s)\psi}{\bar{q} - \theta q_{t-1}}$$

which can be re-arranged to give

$$F'(\bar{q}) < \frac{(P_b - P_s)\psi}{\beta(1-r)(\bar{q} - \theta q_{t-1})} < F'(0). \tag{B.3}$$

This condition holds due to the Inada conditions and the assumption $P_b > P_s$.

B.2 Comparative statics in the baseline model

This section describes how to determine the comparative static results. We rewrite the first-order condition from Equation 3.5 as $X = 0$ where

$$X = \beta(1-r)F'(q_t)(\bar{q} - \theta q_{t-1}) - (P_b - P_s)\psi.$$

Now, we find find the comparative static results with respect to seed quality in year t, q_t. For example,

$$\frac{\partial q_t}{\partial x} = \frac{-\frac{\partial X}{\partial x}}{\frac{\partial X}{\partial q_t}}.$$

However,

$$\frac{\partial X}{\partial q_t} = \beta(1-r)F''(q_t)(\bar{q} - \theta q_{t-1})$$

is negative or zero so $\frac{\partial q_t}{\partial x}$ takes the same sign as $\frac{\partial X}{\partial x}$.

End-point royalty rate r

$\frac{\partial X}{\partial r} = -\beta F'(q_t)(\bar{q} - \theta q_{t-1})$. This is negative so $\frac{\partial q_t}{\partial r}$ is negative.

Point-of-sale royalty P_b

$\frac{\partial X}{\partial P_b} = -\psi$. This is negative so $\frac{\partial q_t}{\partial P_b}$ is negative.

Saved-seed royalty P_s

$\frac{\partial X}{\partial P_s} = \psi$. This is positive so $\frac{\partial q_t}{\partial P_s}$ is positive.

Quality of bought seed $\bar{q}$

$\frac{\partial X}{\partial \bar{q}} = \beta(1-r)F'(q_t)$. This is positive so $\frac{\partial q_t}{\partial \bar{q}}$ is positive.

Seeding rate ψ

$\frac{\partial X}{\partial \psi} = -(P_b - P_s)$. This is negative so $\frac{\partial q_t}{\partial \psi}$ is negative given the assumption $P_b > P_s$.

Discount factor β

$\frac{\partial X}{\partial \beta} = (1-r)F'(q_t)(\bar{q} - \theta q_{t-1})$. This is positive so $\frac{\partial q_t}{\partial \beta}$ is positive.

Saved-seed quality factor θ

$\frac{\partial X}{\partial \theta} = -\beta(1-r)F'(q_t)q_{t-1}$. This is negative so $\frac{\partial q_t}{\partial \theta}$ is negative.

Next, we find find the comparative static results with respect to the proportion of bought seed in year t, b_t. From the seed-quality equation,

Equation 3.2, we have

$$\frac{\partial q_t}{\partial b_t} = \bar{q} - \theta q_{t-1}$$

which is positive and the comparative static results for the proportion of bought seed b_t take the same sign as those for seed quality q_t.

B.3 Farmer profit in the steady-state model.

From Equation 3.9 in the text, the farmer chooses seed quality q in order to maximise

$$\pi_f = (1+\beta)\left\{(1-r)q - (P_b - P_s)\psi b - P_s\psi - C\right\}.$$

First consider the case when $P_s \geq P_b$. The middle term in the above expression is positive and by inspection, farmer profit is maximised for the highest possible value of q. Hence, $q^* = \bar{q}$; then $b^* = 1$.

Now consider the case when $P_s < P_b$. We find the first-order condition with respect to q; this will require the partial derivative $\frac{\partial b}{\partial q}$ which is obtained from the steady-state seed-quality equation Equation 3.8 and is

$$\frac{(1-\theta)\bar{q}}{(\bar{q}-\theta q)^2}.$$

The first-order condition is

$$\frac{\partial \pi_f}{\partial q} = (1+\beta)\left\{1 - r - \frac{(P_b - P_s)\psi(1-\theta)\bar{q}}{(\bar{q}-\theta q^*)^2}\right\} = 0$$

which gives the optimum seed quality in the steady state as

$$q^* = \frac{\bar{q}}{\theta} - \frac{1}{\theta}\sqrt{\frac{(P_b - P_s)\psi(1-\theta)\bar{q}}{1-r}}$$

The second order derivative is

$$(1+\beta)\frac{-2(P_b - P_s)\psi\theta(1-\theta)\bar{q}}{(\bar{q}-\theta q^*)^3}$$

which is negative, as required for a maximum, since $P_b > P_s$ was assumed.

We now check the conditions required for a valid, interior, solution. For $q^* \leq \bar{q}$, we have

$$\frac{\bar{q}}{\theta} - \frac{\sqrt{\frac{(P_b - P_s)\psi(1-\theta)\bar{q}}{1-r}}}{\theta} \leq \bar{q},$$
$$\text{or } \bar{q} \leq \frac{\psi(P_b - P_s)}{1-r}\frac{1}{(1-\theta)}.$$

For $q^* \geq 0$, we have

$$\frac{\bar{q}}{\theta} - \frac{\sqrt{\frac{(P_b - P_s)\psi(1-\theta)\bar{q}}{1-r}}}{\theta} \geq 0,$$
$$\text{or } \bar{q} \geq \frac{(P_b - P_s)\psi}{1-r}(1-\theta).$$

This gives the condition for an interior solution in optimum seed quality q^* as

$$\frac{(P_b - P_s)\psi(1-\theta)}{1-r} \leq \bar{q} \leq \frac{(P_b - P_s)\psi}{(1-r)(1-\theta)}.$$

Hence

$$q^* = \begin{cases} 0, & \bar{q} < \frac{(P_b-P_s)\psi(1-\theta)}{1-r} \\ \frac{\bar{q}}{\theta} - \frac{1}{\theta}\sqrt{\frac{(P_b-P_s)\psi(1-\theta)\bar{q}}{1-r}}, & \frac{(P_b-P_s)\psi(1-\theta)}{1-r} \leq \bar{q} \leq \frac{(P_b-P_s)\psi}{(1-\theta)(1-r)} \\ \bar{q}, & \bar{q} > \frac{(P_b-P_s)\psi}{(1-\theta)(1-r)} \end{cases} \tag{B.4}$$

The last row of this expression covers the case $P_s \geq P_b$ since then the right hand side of the inequality is negative and the inequality holds.

We now consider the required conditions for an interior solution in b^*, the optimum proportion of new seed bought. We showed above that $b^* = 1$ for $P_s \geq P_b$. Now consider $P_s < P_b$.

For $b^* \leq 1$, we have

$$1 - \frac{1}{\theta} + \frac{1}{\theta}\sqrt{\frac{(1-r)(1-\theta)\bar{q}}{(P_b - P_s)\psi}} \leq 1$$

$$\text{or } \bar{q} \leq \frac{(P_b - P_s)\psi}{(1-r)(1-\theta)}.$$

For $b^* \geq 0$, we have

$$0 \leq 1 - \frac{1}{\theta} + \frac{1}{\theta}\sqrt{\frac{(1-r)(1-\theta)\bar{q}}{(P_b - P_s)\psi}}$$
$$\text{or} \quad \frac{(P_b - P_s)\psi(1-\theta)}{1-r} \leq \bar{q}.$$

This gives the condition for an interior solution in the optimum proportion of new, bought, seed b^* as

$$\frac{(P_b - P_s)\psi}{1-r}(1-\theta) \leq \bar{q} \leq \frac{(P_b - P_s)\psi}{1-r}\frac{1}{(1-\theta)} \tag{B.5}$$

which is the same as the condition for the interior solution for optimum seed quality q^*.

B.4 The comparative statics of the steady-state model

This section derives comparative static results for interior values for both seed quality and the proportion of new seed, in the steady-state model. The partial derivatives with respect to each of b^* and q^* take the same sign so we only show the derivation of the sign for the partial derivatives with respect to b^*. These use Equation 3.12,

$$b^* = 1 - \frac{1}{\theta} + \frac{1}{\theta}\sqrt{\frac{(1-r)(1-\theta)\bar{q}}{(P_b - P_s)\psi}}.$$

The derivatives with respect to $\bar{q}$, ψ, r, P_b and P_s follow by inspection. The remaining one, for θ, is now discussed.

This derivative $\frac{\partial b^*}{\partial \theta}$ is as follows:

$$\frac{1}{\theta^2} - \sqrt{\frac{(1-r)\bar{q}}{(P_b - P_s)\psi}}\frac{\sqrt{1-\theta} + \frac{\theta}{2\sqrt{1-\theta}}}{\theta^2}.$$

This can be re-arranged to give

$$\frac{1}{\theta^2}\left[1 - \sqrt{\frac{(1-r)\bar{q}}{(P_b - P_s)\psi}}\frac{2-\theta}{2\sqrt{(1-\theta)}}\right]. \tag{B.6}$$

Now take the interior conditions for b^* or q^*, Equation B.5, re-arrange by multiplying through by $\frac{(1-r)(1-\theta)}{(P_b - P_s)\psi}$ and taking the square root of the resulting expression (which is valid as all terms are non-negative), giving

$$(1-\theta) \leq \sqrt{\frac{(1-r)(1-\theta)\bar{q}}{(P_b - P_s)\psi}} \leq 1.$$

Next, multiply the whole expression by $\frac{-(2-\theta)}{2(1-\theta)} < 0$, to get:

$$\frac{-(2-\theta)}{2(1-\theta)} \leq \frac{-(2-\theta)}{2}\sqrt{\frac{(1-r)\bar{q}}{(P_b - P_s)\psi(1-\theta)}} \leq \frac{-(2-\theta)}{2}.$$

Finally, add 1 to all terms and divide by θ^2. This gives:

$$\frac{1}{\theta^2}\left\langle 1-\frac{(2-\theta)}{2(1-\theta)}\right\rangle \leq \frac{\partial b^*}{\partial \theta} \leq \frac{1}{\theta^2}\left\langle 1-\frac{(2-\theta)}{2}\right\rangle$$

which is

$$\frac{-1}{2\theta(1-\theta)} \leq \frac{\partial b^*}{\partial \theta} \leq \frac{1}{2\theta},$$

showing that the partial derivative of b^* with respect to θ can be positive or negative.

Finally, we derive the conditions under which the partial derivative $\frac{\partial b^*}{\partial \theta}$ is positive, by re-arranging Equation B.6 to show $\frac{\partial b^*}{\partial \theta} > 0$ if

$$1-\sqrt{\frac{(1-r)\bar{q}}{(P_b-P_s)\psi}}\frac{2-\theta}{2\sqrt{(1-\theta)}} > 0,$$

or

$$\frac{(1-r)\bar{q}}{4(P_b-P_s)\psi} < \frac{1-\theta}{(2-\theta)^2}.$$

The expression on the right-hand side decreases monotonically as θ increases so this condition is more likely to hold for small value of θ than for large values. Hence, the partial derivative $\frac{\partial b^*}{\partial \theta}$ is more likely to be positive for small values of θ.

B.5 Breeder optimisation

In this section, we consider the problem from the perspective of the breeders and equate their marginal cost and marginal revenue. Suppose the farmer increases the proportion of the area sown to new, bought, seed by δ. Then, the farmer buys $\delta\psi$ more kilograms of new seed on which the breeder receives an extra \$ $\delta\psi P_b$ in point-of-sale royalty revenue. This implies the farmer saves $\delta\psi$ less kilograms of seed on which the breeder receives \$ $\delta\psi P_s$ less in saved-seed royalty revenue.

Now consider the flow-on effects. The extra new seed has increased the quality of the seed mix by $\frac{\partial q}{\partial b}\delta$. In turn, this increases production by $\frac{\partial q}{\partial b}\delta$ kilograms with a value of \$ $\frac{\partial q}{\partial b}\delta$, and the breeder receives an extra end-point royalty revenue of \$ $r\frac{\partial q}{\partial b}\delta$. The equation for seed quality in the steady state, Equation 3.7, can be re-written as

$$q = \frac{\bar{q}}{1-\theta(1-b)}.$$

Hence

$$\frac{\partial q}{\partial b} = \frac{(1-\theta)\bar{q}}{(1-\theta+\theta b)^2.}$$

However, from Equation 3.17,

$$1-\theta+\theta b = \sqrt{\frac{(1-\theta\bar{q}}{g\psi}}.$$

Hence, $\frac{\partial q}{\partial b} = g\psi$ and so the increase in end-point royalties that flows from the quality effect is $r\delta g\psi$.

In total, the effect on marginal revenue to the breeder is the sum of these effects,

$$\delta \left\{ P_b - P_s + rg \right\} \psi.$$

The marginal cost to the breeder of an extra $\delta\psi$ seed is $g\delta\psi$, so equating the breeder's marginal cost and revenue gives

$$\delta g\psi = \delta \left\{ P_b - P_s + rg \right\} \psi \quad \text{or} \quad g = \frac{P_b - P_s}{1 - r}.$$

B.6 The Social Welfare Optimum Solution

We now evaluate the level of farmer profit, breeder profit and social welfare at the maximum social-welfare outcome. Re-arranging Equation 3.10 for farmer profit and using the social welfare optimisation condition from Equation 3.18 along with Equations 3.16 and 3.17 for the welfare maximising seed quality and proportion of new seed, we have

$$
\begin{aligned}
\pi_f^{SW} =&(1-r)q^{SW} - (P_b - P_s)\psi b^{SW} - P_s\psi - C \\
=&(1-r)q^{SW} - (1-r)g\psi b^{SW} - P_s\psi - C \\
=&\frac{(1-r)\bar{q}}{\theta} - \frac{1-r}{\theta}\sqrt{g\psi(1-\theta)\bar{q}} - g\psi(1-r) + \frac{g\psi(1-r)}{\theta} \\
&- \frac{(1-r)g\psi}{\theta}\sqrt{\frac{(1-\theta)\bar{q}}{g\psi}} - P_s\psi - C \\
=&\frac{1-r}{\theta}\left\{\bar{q} - 2\sqrt{g\psi(1-\theta)\bar{q}} + g\psi(1-\theta)\right\} - P_s\psi - C \\
=&\frac{1-r}{\theta}\left\{\sqrt{\bar{q}} - \sqrt{g\psi(1-\theta)}\right\}^2 - P_s\psi - C.
\end{aligned}
$$

Re-arranging Equation 3.13 for breeder profit and using Equations 3.18, 3.16 and 3.17, we have

$$
\begin{aligned}
\pi_B^{SW} =&rq^{SW} + (P_b - P_s - g)\psi b^{SW} + P_s\psi - K \\
=&rq^{SW} - rg\psi b^{SW} + P_s\psi - K \\
=&\frac{r\bar{q}}{\theta} - \frac{r}{\theta}\sqrt{g\psi(1-\theta)\bar{q}} - rg\psi + \frac{rg\psi}{\theta} - \frac{rg\psi}{\theta}\sqrt{\frac{(1-\theta)\bar{q}}{g\psi}} + P_s\psi - K \\
=&\frac{r}{\theta}\left\{\bar{q} - 2\sqrt{g\psi(1-\theta)\bar{q}} + g\psi(1-\theta)\right\} + P_s\psi - K \\
=&\frac{r}{\theta}\left\{\sqrt{\bar{q}} - \sqrt{g\psi(1-\theta)}\right\}^2 + P_s\psi - K.
\end{aligned}
$$

Finally, SW^{SW} can be evaluated in the same way, or equivalently by summing farmer and breeder profit from the previous results; and is

$$\begin{aligned}SW^{SW} =& q^{SW} - g\psi b^{SW} - C - K \\ =& \frac{1}{\theta}\left\{\sqrt{\bar{q}} - \sqrt{g\psi(1-\theta)}\right\}^2 - C - K.\end{aligned}$$

B.7 A monopoly breeder with all three royalties

In this section, we assume breeders have monopoly power over their new varieties. Recall from Equation 3.13

$$\pi_B = rq + P_b\psi b + P_s\psi(1-b) - g\psi b - K.$$

We take the derivatives with respect to each of the royalties, giving:

$$\frac{\partial \pi_B}{\partial P_b} = r\frac{\partial q}{\partial P_b} + (P_b - P_s - g)\psi\frac{\partial b}{\partial P_b} + \psi b, \tag{B.7}$$

$$\frac{\partial \pi_B}{\partial P_s} = r\frac{\partial q}{\partial P_s} + (P_b - P_s - g)\psi\frac{\partial b}{\partial P_s} - \psi b + \psi \tag{B.8}$$

and

$$\frac{\partial \pi_B}{\partial r} = q + r\frac{\partial q}{\partial r} + (P_b - P_s - g)\psi\frac{\partial b}{\partial r}. \tag{B.9}$$

To find the optimum royalties, we wish to set these each to 0 and solve. This is not tractable.

However, suppose the breeder sets the three royalties so Equation 3.18, the condition for maximising social welfare, holds; this results in the maximum level of social welfare surplus SW^{SW} with $q^* = q^{SW}$ and $b^* = b^{SW}$. Now suppose breeders increase the point-of-sale and saved-seed royalties by the same amount, say δ. The required condition for maximising social welfare still holds, but consider the change to the breeder's profits. The total differential is

$$\begin{aligned} d\pi_B =& \frac{\partial \pi_B}{\partial P_b} dP_b + \frac{\partial \pi_B}{\partial P_s} dP_s \\ =& \delta \left\{ (r + (P_b - P_s - g)\psi)(\frac{\partial q^{SW}}{\partial P_b} + \frac{\partial q^{SW}}{\partial P_s}) + \psi \right\}. \end{aligned}$$

From the expression in Equations 3.11 for q^*, it is clear

$$\frac{\partial q}{\partial P_s} = -\frac{\partial q}{\partial P_b}$$

and hence

$$d\pi_B = \delta\psi > 0.$$

That is, increasing both P_b and P_s by the same amount, from a level which gave the social optimum, will increase the breeder's profits whilst maintaining the maximum level of social welfare.

B.8 A monopoly breeder with less than three royalties

In this section, we consider what happens if not all the royalties are available. For completeness, we fist discuss the case when no royalties are allowed; then we take the royalties one at a time and finally, two at a time.

B.8.1 No royalties

With no royalties, we have $P_b = P_s = r = 0$. Then,

$$\pi_f = q - C$$

and the farmer optimises at the highest value of production possible $\bar{q}$ with $b^* = 1$. This gives

$$\pi_B = -g\psi - K$$

and the breeder makes a loss. The level of social welfare is denoted SW^0 and is given by

$$SW^0 = \bar{q} - C - g\psi - K.$$

The social planner cannot re-allocate this social welfare surplus through royalties as there are none, so must use other interventions if required. Similarly, the monopolist breeder cannot extract the surplus.

By comparing the expression above for SW^0 with Equation 3.21 for SW^{SW}, we can see the difference in social welfare for this no royalty case compared to the benchmark maximum level of social welfare is given by

$$
\begin{aligned}
&SW^{SW} - SW^0 \\
&\qquad = \frac{\bar{q}}{\theta} + \frac{g\psi(1-\theta)}{\theta} - \frac{2\sqrt{g\psi(1-\theta)\bar{q}}}{\theta} - \bar{q} + g\psi \\
&\qquad = \bar{q}\frac{(1-\theta)}{\theta} + \frac{g\psi}{\theta} - \frac{2\sqrt{g\psi(1-\theta)\bar{q}}}{\theta} \\
&\qquad = \frac{1}{\theta}\left\{\sqrt{(1-\theta)\bar{q}} - \sqrt{g\psi}\right\}^2 > 0.
\end{aligned}
$$

Hence $SW^0 < SW^{SW}$.

B.8.2 EPR only

With an end-point royalty only, we have $P_b = P_s = 0$ and we saw in the text that the farmer will never save seed so $b^* = 1$ and $q^* = \bar{q}$.

Then

$$\pi_f = (1-r)\bar{q} - C,$$

$$\pi_B = r\bar{q} - g\psi - K$$

and the level of social welfare is

$$SW^0 = \bar{q} - g\psi - C - K.$$

In this scenario, the social planner or the monopolist breeder could use the end-point royalty to allocate the surplus.

For example, if the end-point royalty is set to 0,

$$\pi_f = \bar{q} - C,$$

$$\pi_B = -g\psi - K$$

and the breeder makes a loss. If, instead, the end-point royalty is set to 1,

$$\pi_f = -C,$$

the farmer makes a loss, and

$$\pi_B = \bar{q} - g\psi - K.$$

However, suppose

$$r = 1 - \frac{C}{\bar{q}},$$

then

$$\pi_f = 0$$

and

$$\pi_B = \bar{q} - g\psi - C - K = SW^0.$$

This last example shows the monopolist breeder could achieve SW^0, the highest value of social welfare attainable in this scenario, by using the end-point royalty to maximise their profit through increasing r to the point where farmer profit has fallen to 0; that is,

$$r^* = 1 - \frac{C}{\bar{q}}.$$

B.8.3 SSP only

With a saved-seed royalty only, we have $P_b = r = 0$ and hence $P_s - P_b \geq 0$ so again we have $b^* = 1$ and $q^* = \bar{q}$.

Then

$$\pi_f = \bar{q} - C,$$

$$\pi_B = -g\psi - K,$$

the breeder makes a loss, and the level of social welfare is

$$SW^0 = \bar{q} - g\psi - C - K.$$

In this scenario, neither the social planner nor the monopolist breeder can allocate the surplus because the only instrument available is the saved-seed royalty and its value is irrelevant as the farmer never saves seed.

B.8.4 POS only

With a point-of-sale royalty only, we have $P_s = r = 0$ and

$$\pi_f = q - P_b \psi b - C.$$

This gives

$$\begin{aligned} q^* =& \frac{\bar{q}}{\theta} - \frac{1}{\theta}\sqrt{P_b \psi (1-\theta)\bar{q}}, \\ b^* =& 1 - \frac{1}{\theta} + \frac{1}{\theta}\sqrt{\frac{(1-\theta)\bar{q}}{P_b \psi}}, \\ \pi_B =& (P_b - g)\psi b - K \\ \text{and} \ \ SW =& q - \psi g b - C - K. \end{aligned}$$

As explained in the text, the maximum level of social welfare SW^{SW} is attained when the condition in Equation 3.18 holds. The social planner can implement the maximum by setting $P_b = g$. Then,

$$\pi_B = -K,$$

the breeder makes a loss, whilst

$$\pi_f = SW^{SW} + K.$$

In this scenario, the social planner can achieve the maximum surplus but cannot allocate it.

Now consider the monopolist breeder. They will not want to implement the maximum level of social welfare because this gives them negative profit, and having used the point-of-sale royalty to achieve the maximum surplus, there would be no instrument available to extract the surplus. Instead, they will seek to set the point-of-sale royalty to maximise their own profit rather than to maximise social welfare.

We wish to find a value of P_b that will maximise π_B, if such a value exists. An analytic solution to this maximisation is not forthcoming. Instead, we consider the behaviour of π_B as the point-of-sale royalty varies, in order to determine if there is a value of P_b that will maximise π_B. For ease of exposition, we ignore the constant $-K$ and define

$$\pi = \pi_B + K = (P_b - g)\psi b.$$

The following are true about π:

- By inspection, $\pi < 0$ when $P_b < g$.
- By inspection, $\pi = 0$ when $P_b = g$.
- By substituting into the expression above for b^*, we have $b^* = 0$ when

$$P_b = \frac{\bar{q}}{\psi(1-\theta)}$$

and then q^* and $\pi = 0$.

- $\pi = 0$ when

$$P_b > \frac{\bar{q}}{\psi(1-\theta)}$$

since then $q = b = 0$.

- There is some value of $P_b \in (g, \frac{\bar{q}}{\psi(1-\theta)})$ for which $\pi > 0$. For example, we show below that such a value is

$$P_b = \frac{1}{2}(g + \frac{\bar{q}}{\psi(1-\theta)}).$$

With these values, there must be a local maximum of π for some $P_b \in (g, \frac{\bar{q}}{\psi(1-\theta)})$ and this is the value the monopolist breeder would choose, provided both farmer and breeder profits are non-negative. This point-of-sale royalty rate is above marginal cost g but below the threshold where $q = b = 0$. Since $P_b > g$, the farmer and society is worse off than under the social planner outcome.

It remains to show $\pi > 0$ when

$$P_b = \frac{1}{2}(g + \frac{\bar{q}}{\psi(1-\theta)}).$$

Rewrite this value of P_b as

$$\frac{\bar{q} + g\psi(1-\theta)}{2\psi(1-\theta)}$$

so that

$$
\begin{aligned}
\pi =&(P_b - g)\psi b \\
=&\frac{\bar{q} - g\psi(1-\theta)}{2(1-\theta)} \left\{ \frac{-(1-\theta)}{\theta} + \frac{1}{\theta}\sqrt{\frac{(1-\theta)\bar{q}2\psi(1-\theta)}{\psi(\bar{q} + g\psi(1-\theta))}} \right\} \\
=&\left\{ \frac{-(\bar{q} - g\psi(1-\theta))}{2\theta} \right\} \left\{ \frac{\sqrt{\bar{q} + g\psi(1-\theta)} - \sqrt{2\bar{q}}}{\sqrt{(\bar{q} + g\psi(1-\theta))}} \right\}
\end{aligned}
$$

If $\bar{q} = g\psi(1-\theta)$, π is trivially 0.

If $\bar{q} < g\psi(1-\theta)$, then $\bar{q} - g\psi(1-\theta) < 0$ and $\sqrt{\bar{q} + g\psi(1-\theta)} > \sqrt{2\bar{q}}$ so π is positive.

If $\bar{q} > g\psi(1-\theta)$, then $\bar{q} - g\psi(1-\theta) > 0$ and $\sqrt{\bar{q} + g\psi(1-\theta)} < \sqrt{2\bar{q}}$ so π is positive.

B.8.5 EPR and SSP

With an end-point and saved-seed royalty but no point-of-sale royalty, we have $P_b = 0$ and

$$\pi_f = (1-r)\bar{q} - P_s\psi(1-b) - C.$$

Again, the farmer maximises by choosing b and q to be as high as possible, $b^* = 1$ and $q^* = \bar{q}$.

Then

$$\pi_f = (1-r)\bar{q} - C,$$

$$\pi_B = r\bar{q} - g\psi - K$$

and the level of social welfare is

$$SW^0 = \bar{q} - g\psi - C - K.$$

This is the same outcome as the scenario with an end-point royalty only which was discussed in Section B.8.2, because the farmer never saves seed so the saved-seed royalty is irrelevant. Again, the social planner or the monopolist breeder could use the end-point royalty rate r to allocate the surplus. For the monopolist breeder we have

$$r^* = 1 - \frac{C}{\bar{q}}.$$

B.8.6 POS and SSP

With a saved-seed and point-of-sale royalty but no end-point-royalty, we have $r = 0$. Hence,

$$\begin{aligned}
\pi_f &= q - (P_b - P_s)\psi b - P_s\psi - C, \\
q^* &= \frac{\bar{q}}{\theta} - \frac{1}{\theta}\sqrt{(P_b - P_s)\psi(1-\theta)}\bar{q}, \\
b^* &= 1 - \frac{1}{\theta} + \frac{1}{\theta}\sqrt{\frac{(1-\theta)\bar{q}}{(P_b - P_s)\psi}} \\
\text{and} \quad \pi_B &= (P_b - P_s - g)\psi b + P_s\psi - K.
\end{aligned}$$

Social welfare is given by $q - g\psi b - C - K$ and, as shown in the text, the maximum level of social welfare SW^{SW} is attained when the condition in Equation 3.18 holds. The social planner can implement the maximum by setting $P_b - P_s = g$. This condition also allows the monopolist breeder to implement the maximum level of social welfare, and both the social planner and the monopolist breeder can allocate the surplus by increasing both royalties by the same amount, fulfilling the required condition. The monopolist will continue to do this until farmer profits fall to zero.

B.8.7 POS and EPR

With a point-of-sale and end-point royalty but no saved-seed royalty, we have $P_s = 0$. Then,

$$\begin{aligned}
\pi_f =& (1-r)q - P_b\psi b - C, \\
q^* =& \frac{\bar{q}}{\theta} - \frac{1}{\theta}\sqrt{\frac{P_b\psi(1-\theta)\bar{q}}{1-r}}, \\
b^* =& \frac{-(1-\theta)}{\theta} + \frac{1}{\theta}\sqrt{\frac{(1-r)(1-\theta)\bar{q}}{P_b\psi}}, \\
\pi_B =& rq + (P_b - g)\psi b - K \\
\text{and} \quad SW =& q - \psi g b - C - K.
\end{aligned}$$

As shown in the text, the maximum level of social welfare SW^{SW} is attained when the condition in Equation 3.18 holds. The social planner can implement the maximum by setting

$$\frac{P_b}{1-r} = g.$$

This condition also allows the monopolist breeder to implement the maximum level of social welfare, and both the social planner and the monopolist breeder can allocate the surplus by changing the royalties whilst fulfilling the required condition. The monopolist will continue to do this until farmer profits fall to zero. Thus, from the perspective of the breeder, optimum royalties are such that

$$\frac{P_b}{1-r} = g \text{ and } \pi_f = 0.$$

Appendix C

An alternative specification of the full-declaration model

C.1 Introduction

This section investigates the model presented in Chapter 3 under the alternative assumption that end-point royalties are paid on production net of saved seed rather than all production. Here, we concentrate on the algebra and algebraic differences between this model and the original one whilst a description of these differences and their interpretations and implications is given in Section 3.4.

The set-up of this model is the same as in Chapter 3 except the end-point royalty becomes

$$r[q_t - \psi(1 - b_t)]$$

and hence the farmer's expected profit for year t is given by:

$$\pi_{ft} = (1-r)Q_t - (P_b + r - P_s)\psi b_t - (P_s - r)\psi - C. \tag{C.1}$$

The main differences in the algebra are

- the expression $P_b - P_s$ is replaced by $P_b + r - P_s$. This is because the end-point royalty is no longer paid on the saved seed so it is as if saved seed now has a royalty of $P_s - r$ and
- the expression $P_s\psi$ is replaced by $-(P_s - r)\psi$ which has the same intuition as above.

These two changes carry through the entire analysis.

The production function and the seed quality function are the same as in the main chapter.

The farmer maximises the discounted sum of future expected profits, which is now given by

$$\begin{aligned}\Pi &= \sum_{t=0}^{\infty} \beta^t \pi_{ft} \\ &= \sum_{t=0}^{\infty} \beta^t \left[(1-r)F(q_{t-1}) - (P_b + r - P_s)\psi b_t - (P_s - r)\psi - C\right].\end{aligned} \tag{C.2}$$

The first-order condition $\frac{\partial \Pi}{\partial b_t} = 0$ can be re-arranged to give

$$\beta^t \left\{\beta(1-r)F'(q_t)(\bar{q} - \theta q_{t-1}) - (P_b + r - P_s)\psi\right\} = 0. \tag{C.3}$$

The second order condition gives $\beta^{t+1}(1-r)F''(q_t)(\bar{q}-\theta q_{t-1})^2$ which is non-positive, since the production function is assumed to have non-positive second derivative.

As with the model in the main chapter, an explicit solution is not forthcoming.

The intuition behind this first-order condition is similar, but varies slightly from the main chapter, due to the slightly different effect of the end-point royalty. The value of the choice variable, at the optimum, balances marginal costs and marginal returns. Consider the farmer's profit for an arbitrary year. At the start of the year, suppose the farmer buys seed to sow a unit area instead of saving seed to do this. This means the farmer will buy ψ units more seed and retain ψ units less seed. The marginal cost of buying seed increases by $P_b\psi$ but the marginal cost of saving seed decreases by $P_s\psi$. The amount formerly saved is now sold, increasing revenue by ψ; however, end-point royalties are paid on this so the net return is $(1-r)\psi$. Hence, at the start of the year, the farmer's profits increase by

$$(1-r)\psi - P_b\psi + P_s\psi.$$

At the end of the year, there is an increase in production (and hence revenue, given the output price is normalised to 1) of

$$\frac{\partial F(q_t)}{\partial q_t} * \frac{\partial q_t}{\partial b_t} = F'(q_t)(\bar{q} - \theta q_{t-1}).$$

This increase in production (and revenue) is made up of the extra production from increasing the quality of seed and the marginal change in quality that took place due to buying more seed. However, an end-point royalty is payable on this production so the net return is

$$(1 - r)F'(q_t)(\bar{q} - \theta q_{t-1})$$

and, finally, this is discounted by 1 period as the revenue occurs at the end of the time period.

Thus, adding the two effects, we get the marginal change in profit as

$$(1 - r)\psi - P_b\psi + P_s\psi + \beta(1 - r)F'(q_t)(\bar{q} - \theta q_{t-1}).$$

This can be re-arranged to give the first-order condition in Equation C.3 above.

The interior solutions in both seed quality and the proportion of bought seed are the same as those in the original model except that the expression $P_b - P_s$ is replaced by $P_b + r - P_s$. We now derive the interior conditions for the proportion of bought seed.

The partial derivative of the farmer's lifetime profit with respect to bought seed is

$$\frac{\partial \Pi}{\partial b_t} = \beta^t \left\{\beta(1 - r)F'(q_t)(\bar{q} - \theta q_{t-1}) - (P_b + r - P_s)\psi\right\}$$

and the only difference between this and the corresponding Equation in Chapter 3 is that we have replaced $P_b - P_s$ by $P_b + r - P_s$.

Evaluating the partial derivative at $b_t = 0$ gives

$$\beta^t \left\{ \beta(1-r)F'(\theta q_{t-1})(\bar{q} - \theta q_{t-1}) - (P_b + r - P_s)\psi \right\}$$

and we need to show this is positive to give $b_t^\dagger > 0$. The superscript † denotes the optimum value obtained under this alternative specification.

Evaluating this partial derivative at $b_t = 1$ gives

$$\beta^t \left\{ \beta(1-r)F'(\bar{q})(\bar{q} - \theta q_{t-1}) - (P_b + r - P_s)\psi \right\}$$

and we need to show this is negative to give $b_t^\dagger < 1$.

Hence, we require

$$\begin{aligned} &\beta^t \left\{ \beta(1-r)F'(\bar{q})(\bar{q} - \theta q_{t-1}) - (P_b + r - P_s)\psi \right\} < 0 \\ &\qquad < \beta^t \left\{ \beta(1-r)F'(\theta q_{t-1})(\bar{q} - \theta q_{t-1}) - (P_b + r - P_s)\psi \right\} \end{aligned} \tag{C.4}$$

which can be re-arranged to give

$$F'(\bar{q}) < \frac{(Pb + r - Ps)\psi}{\beta(1-r)(\bar{q} - \theta q_{t-1})} < F'(\theta q_{t-1}).$$

The same condition is required for seed quality to be a valid interior solution.

Comparative static results for an interior solution take the same sign as those of the original model which were shown in shown in Table 3.1. We now derive these results from the first-order condition. First, we rewrite the first-order condition from Equation C.3 as $X = 0$ where

$$X = \beta(1-r)F'(q_t)(\bar{q} - \theta q_{t-1}) - (P_b + r - P_s)\psi.$$

Now, we find find the comparative static results with respect to seed quality in year t q_t. For example,

$$\frac{\partial q_t}{\partial x} = \frac{-\frac{\partial X}{\partial x}}{\frac{\partial X}{\partial q_t}}.$$

However,

$$\frac{\partial X}{\partial q_t} = \beta(1-r)F''(q_t)(\bar{q} - \theta q_{t-1})$$

is negative or zero so $\frac{\partial q_t}{\partial x}$ takes the same sign as $\frac{\partial X}{\partial x}$.

End-point royalty r

$\frac{\partial X}{\partial r} = -\beta F'(q_t)(\bar{q} - \theta q_{t-1}) - \psi$. This is negative so $\frac{\partial q_t}{\partial r}$ is negative.

Point-of-sale royalty P_b

$\frac{\partial X}{\partial P_b} = -\psi$. This is negative so $\frac{\partial q_t}{\partial P_b}$ is negative.

Saved-seed royalty P_s

$\frac{\partial X}{\partial P_s} = \psi$. This is positive so $\frac{\partial q_t}{\partial P_s}$ is positive.

Quality of bought seed $\bar{q}$

$\frac{\partial X}{\partial \bar{q}} = \beta(1-r)F'(q_t)$. This is positive so $\frac{\partial q_t}{\partial \bar{q}}$ is positive.

Seeding rate ψ

$\frac{\partial X}{\partial \psi} = -(P_b + r - P_s)$. This is negative so $\frac{\partial q_t}{\partial \psi}$ is negative if $P_b + r > P_s$.

Discount factor β

$\frac{\partial X}{\partial \beta} = (1 - r)F'(q_t)(\bar{q} - \theta q_{t-1})$. This is positive so $\frac{\partial q_t}{\partial \beta}$ is positive.

Saved-seed quality factor θ

$\frac{\partial X}{\partial \theta} = -\beta(1 - r)F'(q_t)q_{t-1}$. This is negative so $\frac{\partial q_t}{\partial \theta}$ is negative.

The only difference between these results and those of the original model is that we have replaced $P_b - P_s$ by $P_b + r - P_s$.

Next, consider the comparative static results with respect to the proportion of bought seed in year t b_t. These take the same sign as those for seed quality q_t, for the same reasons as given in Appendix B.2 for the original model.

As we did with the original model, we will now consider a steady-state model.

C.1.1 Simplifying the model to a steady-state

The steady-state expressions for q and b are the same as in the original model, Equations 3.7 and 3.8, and a linear production function $F(q) = q$ is chosen, as in the original model.

Hence, the farmer's problem is to choose seed quality $q^\dagger$ in order to maximise

$$\pi_f = (1 + \beta)\left\{(1 - r)q - (P_b + r - P_s)\psi b + (r - P_s)\psi - C\right\}. \tag{C.5}$$

As we did in the original model in Chapter 3, we drop the discount factor as it has no effect on where the maximum occurs.

First consider the case when $P_s \geq P_b + r$. This is different from the original model because the condition now includes the end-point royalty as well as the other two royalties. By inspection, farmer profit is maximised for the highest possible value of q. Hence, $q^\dagger = \bar{q}$ and then $b^\dagger = 1$.

Now consider the case when $P_s < P_b + r$. The first-order condition is

$$\frac{\partial \pi_f}{\partial q} = 1 - r - \frac{(P_b + r - P_s)\psi(1-\theta)\bar{q}}{(\bar{q} - \theta q^\dagger)^2} = 0$$

which gives the optimum seed quality in the steady-state as

$$q^\dagger = \frac{\bar{q}}{\theta} - \frac{1}{\theta}\sqrt{\frac{(P_b + r - P_s)\psi(1-\theta)\bar{q}}{1-r}}$$

The second-order derivative is

$$\frac{-2(P_b + r - P_s)\psi(1-\theta)\theta\bar{q}}{(\bar{q} - \theta q^\dagger)^3}$$

which is negative, as required for a maximum, since this is the case where $P_b + r > P_s$.

We now check the conditions required for a valid, interior, solution. For $q^\dagger \leq \bar{q}$, we have

$$\begin{aligned}
&\frac{\bar{q}}{\theta} - \frac{1}{\theta}\sqrt{\frac{(P_b + r - P_s)\psi(1-\theta)\bar{q}}{1-r}} \leq \bar{q} \\
\text{or } \; &\bar{q} \leq \frac{(P_b + r - P_s)\psi}{(1-r)(1-\theta)}.
\end{aligned}$$

For $q^\dagger \geq 0$, we have

$$\begin{aligned}
&\frac{\bar{q}}{\theta} - \frac{1}{\theta}\sqrt{\frac{(P_b + r - P_s)\psi(1-\theta)\bar{q}}{1-r}} \geq 0 \\
\text{or } \; &\bar{q} \geq \frac{(P_b + r - P_s)\psi(1-\theta)}{1-r}.
\end{aligned}$$

This gives the condition for an interior solution in optimum seed quality $q^\dagger$ as

$$\frac{(P_b + r - P_s)\psi(1-\theta)}{1-r} \leq \bar{q} \leq \frac{(P_b + r - P_s)\psi}{(1-r)(1-\theta)}. \tag{C.6}$$

Hence

$$q^\dagger = \begin{cases} 0, & \bar{q} < \frac{(P_b+r-P_s)\psi(1-\theta)}{1-r} \\ \frac{\bar{q}}{\theta} - \frac{\sqrt{\frac{(P_b+r-P_s)\psi(1-\theta)\bar{q}}{1-r}}}{\theta}, & \frac{(P_b+r-P_s)\psi(1-\theta)}{1-r} \leq \bar{q} \leq \frac{(P_b+r-P_s)\psi}{(1-\theta)(1-r)} \\ \bar{q}, & \bar{q} > \frac{(P_b+r-P_s)\psi}{(1-\theta)(1-r)} \end{cases} \tag{C.7}$$

Notice that the last row of this expression covers the case $P_s \geq P_b + r$ since then the right hand side of the inequality is negative and the inequality holds.

The conditions for an interior solution in $b^\dagger$, the optimum proportion of new seed bought, are the same as the condition for the interior solution for optimum seed quality $q^\dagger$ and the interior solution for $b^\dagger$ is

$$b^\dagger = 1 - \frac{1}{\theta} + \frac{1}{\theta}\sqrt{\frac{(1-r)(1-\theta)\bar{q}}{(P_b + r - P_s)\psi}}. \tag{C.8}$$

Compared to the model in the main chapter, the only difference is that we have replaced $P_b - P_s$ by $P_b + r - P_s$.

The comparative static results for this steady-state model are derived below and are the same as those for the model used in Chapter 3 which are in Table 3.2. Again, the sign of the partial derivatives of farmer profit with respect to each of $b^\dagger$ and $q^\dagger$ are the same so we only show the derivation of the sign for the partial derivatives with respect to $b^\dagger$. These use Equation C.8. The derivatives with respect to $\bar{q}$, ψ, P_b and P_s follow by inspection. The remaining two, for r and for θ, are now discussed.

First, the derivative with respect to r:

$$\frac{\partial b^\dagger}{\partial r} = \frac{1}{\theta}\sqrt{\frac{(1-\theta)\bar{q}}{\psi}}\left\{\frac{-(P_b - P_s + 1)}{2\sqrt{(1-r)(P_b + r - P_s)}(P_b + r - P_s)}\right\}$$

is clearly negative for $r < 1$ and $P_b + r - P_s > 0$.

Next, the derivative with respect to θ is as follows:

$$\frac{\partial b^\dagger}{\partial \theta} = \frac{1}{\theta^2}\left[1 - \sqrt{\frac{(1-r)\bar{q}}{(P_b + r - P_s)\psi}}\frac{(2-\theta)}{2\sqrt{(1-\theta)}}.\right]$$

Now take the interior conditions for $b^\dagger$ or $q^\dagger$, Equation C.6, re-arrange by multiplying through by

$$\frac{1-r}{(P_b + r - P_s)\psi(1-\theta)}$$

and take the square root of the resulting expression (which is valid as all terms are non-negative), giving

$$1 \leq \sqrt{\frac{(1-r)\bar{q}}{(P_b + r - P_s)\psi(1-\theta)}} \leq \frac{1}{1-\theta}.$$

Next, multiply the whole expression by $\frac{-(2-\theta)}{2} < 0$, to get:

$$\frac{-(2-\theta)}{2(1-\theta)} \leq \frac{-(2-\theta)}{2}\sqrt{\frac{(1-r)\bar{q}}{(P_b + r - P_s)\psi(1-\theta)}} \leq \frac{-(2-\theta)}{2}.$$

Finally, add 1 to all terms and divide by θ^2. This gives:

$$\frac{1}{\theta^2}\left\langle 1 - \frac{(2-\theta)}{2(1-\theta)} \right\rangle \leq \frac{\partial b^\dagger}{\partial \theta} \leq \frac{1}{\theta^2}\left\langle 1 - \frac{(2-\theta)}{2} \right\rangle,$$

which is

$$\frac{-1}{2\theta(1-\theta)} \leq \frac{\partial b^\dagger}{\partial \theta} \leq \frac{1}{2\theta}$$

showing the partial derivative of $b^\dagger$ with respect to θ can be positive or negative.

C.1.2 Maximising social welfare

With the set-up of this new model, breeder profit is given for an arbitrary year t by

$$\begin{aligned}\pi_B &= r\left\{q-\psi(1-b)\right\}+P_b\psi b+P_s\psi(1-b)-g\psi b-K\\ &= rq+(P_b+r-P_s-g)\psi b+(P_s-r)\psi-K. \end{aligned}\tag{C.9}$$

Social welfare is simplified to

$$SW=\pi_f+\pi_B=q-g\psi b-C-K=q-\frac{g\psi(1-\theta)q}{\bar{q}-\theta q}-C-K. \tag{C.10}$$

This expression for social welfare is the same as in the original model, because we assumed the same production and cost functions; its optimisation is the same as in Chapter 3. This gives q^{SW} and b^{SW} as in Equations 3.16 and 3.17, and comparing Equation 3.16 with Equation C.7, we see a social planner could implement the optimum welfare outcome if royalties are set so that

$$g=\frac{P_b+r-P_s}{1-r}$$

where again, compared to Chapter 3, P_b-P_s is replaced by P_b+r-P_s.

Substituting this condition for optimum social welfare into Equations C.7 and C.8 gives the welfare maximising seed quality and proportion of new seed as

$$q^{\dagger} = \frac{\bar{q}}{\theta} - \frac{\sqrt{g\psi(1-\theta)\bar{q}}}{\theta} \quad \text{and} \quad b^{\dagger} = 1 - \frac{1}{\theta} + \frac{1}{\theta}\sqrt{\frac{(1-\theta)\bar{q}}{g\psi}}.$$

We use these results to derive expressions for social welfare, farmer and breeder profit, for this social planner optimum. The level of social welfare is the same as in the original model, as given in Appendix B.6, and is

$$\begin{aligned}
SW^{SW} =& q^{SW} - g\psi b^{SW} - C - K \\
=& \frac{1}{\theta}\left\{\sqrt{\bar{q}} - \sqrt{g\psi(1-\theta)}\right\}^2 - C - K.
\end{aligned}$$

Using the expression for farmer profit, Equation C.5, without the discount factor, we get the optimum farmer profit at the maximum social welfare outcome is

$$\begin{aligned}
\pi_f^{SW\dagger} =& (1-r)q^{SW} - (P_b + r - P_s)\psi b^{SW} + (r - P_s)\psi - C \\
=& (1-r)q^{SW} - (1-r)g\psi b^{SW} + (r - P_s)\psi - C \\
=& \frac{1-r}{\theta}\left\{\bar{q} - 2\sqrt{g\psi(1-\theta)\bar{q}} + g\psi(1-\theta)\right\} + (r - P_s)\psi - C \\
=& \frac{1-r}{\theta}\left\{\sqrt{\bar{q}} - \sqrt{g\psi(1-\theta)}\right\}^2 + (r - P_s)\psi - C.
\end{aligned}$$

This differs from the expression for farmer profit at the maximum social welfare outcome in the original model by the addition of the term $r\psi$ due to the different impact of end-point royalties which are no longer paid on saved seed.

Finally, consider the breeder's profit function at this maximum social welfare outcome. This differs from the model in the main chapter by the subtraction of the term $r\psi$. This is a transfer from breeder to farmer.

$$\begin{aligned}
\pi_B^{SW} =& rq^{SW} + \psi(P_b + r - P_s - g)b^{SW} - (r - P_s)\psi - K \\
=& rq^{SW} - rg\psi b^{SW} - (r - P_s)\psi - K \\
=& \frac{r}{\theta}\left\{\bar{q} - 2\sqrt{g\psi(1-\theta)\bar{q}} + g\psi(1-\theta)\right\} - (r - P_s)\psi - K \\
=& \frac{r}{\theta}\left\{\sqrt{\bar{q}} - \sqrt{g\psi(1-\theta)}\right\}^2 - (r - P_s)\psi - K.
\end{aligned}$$

These expressions differ from the model in the main chapter only by the different effect of end-point royalties. Instead of $P_s\psi$ we have $(P_s - r)\psi$ and $P_b - P_s$ is replaced by $P_b + r - P_s$.

C.1.3 A monopolist breeder

Next we consider a breeder with monopoly power—the polar case to the benevolent social planner.

Equation C.9 gives the expression for breeder profit in this model. The first-order derivatives with respect to each of the royalties are:

$$\frac{\partial \pi_B}{\partial P_b} = r\frac{\partial q}{\partial P_b} + (P_b + r - P_s - g)\psi\frac{\partial b}{\partial P_b} + \psi b, \tag{C.11}$$

$$\frac{\partial \pi_B}{\partial P_s} = r\frac{\partial q}{\partial P_s} + (P_b + r - P_s - g)\psi\frac{\partial b}{\partial P_s} - \psi b + \psi \tag{C.12}$$

and

$$\frac{\partial \pi_B}{\partial r} = q + r\frac{\partial q}{\partial r} + (P_b + r - P_s - g)\psi\frac{\partial b}{\partial r} + b\psi - \psi. \tag{C.13}$$

Again, we are unable to set these equal to 0 and solve. Instead, we follow the method used in the original model, explained in Appendix B.7, and suppose the breeder sets the three royalties so that

$$\frac{P_b + r - P_s}{1 - r} = g.$$

This leads to the maximum level of social welfare surplus SW^{SW}; we now show the monopolist breeder is able to extract this surplus.

Suppose the breeder increases the point-of-sale and saved-seed royalty by the same amount, say δ and consider the change to the breeder's profits. The total differential is

$$\begin{aligned} d\pi_B =& \frac{\partial \pi_B}{\partial P_b}dP_b + \frac{\partial \pi_B}{\partial P_s}dP_s \\ =& \delta\left\{(r + (P_b + r - P_s - g)\psi g)(\frac{\partial q^\dagger}{\partial P_b} + \frac{\partial q^\dagger}{\partial P_s}) + \psi\right\}. \end{aligned}$$

From the expressions in Equations C.7 and C.8 for $q^\dagger$ and $b^\dagger$, it is clear $\frac{\partial q}{\partial P_s} = -\frac{\partial q}{\partial P_b}$. Hence,

$$d\pi_B = \delta\psi > 0.$$

That is, increasing both P_b and P_s by the same amount, from a level which gave the social optimum, will increase the breeder's profits. The breeder will continue doing this until they push farmer profit down to 0 and the breeder receives the full amount of the social welfare surplus. Thus, the breeder's strategy would be to set royalties subject to the conditions

$$\frac{P_b + r - P_s}{1 - r} = g \quad \text{and} \quad \pi_f = 0.$$

This is analogous to the original model.

Now we consider what happens if not all three royalties are available. First, we look at the cases where there are no end-point royalties, then an end-point royalty only and finally, an end-point royalty with either of the remaining royalties.

C.1.4 No end-point royalty

In all the schemes where there are no end-point royalties, this model is identical to that in the original model. This covers the schemes with no royalties at all, a saved-seed royalty only, a saved-seed and point-of-sale royalty, and a point-of-sale royalty only.

C.1.5 EPR only

With an end-point royalty only, we have $P_b = P_s = 0$,

$$\begin{aligned}
\pi_f &= (1-r)q - r\psi b + r\psi - C, \\
q^{\dagger} &= \frac{\bar{q}}{\theta} - \frac{1}{\theta}\sqrt{\frac{r\psi(1-\theta)\bar{q}}{1-r}}, \\
b^{\dagger} &= 1 - \frac{1}{\theta} + \frac{1}{\theta}\sqrt{\frac{(1-r)(1-\theta)\bar{q}}{r\psi}}, \\
\pi_B &= rq + (r-g)\psi b - r\psi - K \text{ and} \\
SW &= q - g\psi b - C - K.
\end{aligned}$$

The social welfare maximising seed quality and proportion of bought seed (q^{SW} and b^{SW}) are again given in Equations 3.16 and 3.17 and the social planner can implement the maximum social welfare by setting

$$g = \frac{r}{1-r}$$

which can be re-arranged to give

$$r = \frac{g}{g+1}.$$

In this way, the social planner can implement the maximum social welfare; but they cannot alter the allocation. This is not the same as the original model because end-point royalties fall differently on output sold and saved in this model whereas in the original model, they fell equally on output sold and saved. This difference is further explained in Section 3.4 of Chapter 3.

With only an end-point royalty, the monopolist breeder may no longer want to implement the maximum social welfare because they will not be able to alter the allocation and so cannot fully extract the surplus: they may be better off by extracting a larger share of a smaller total surplus. We wish to determine the level of EPR the monopolist breeder will choose to maximise their profit. Unfortunately, the analysis becomes difficult at this point. The derivative of breeder profit with respect to the end-point royalty is

$$\frac{\partial \pi_B}{\partial r} = q + r\frac{\partial q}{\partial r} + b\psi + (r-g)\psi\frac{\partial b}{\partial r} - \psi$$
$$= \frac{\bar{q}}{\theta} - \frac{r}{\theta}\sqrt{\frac{\psi(1-\theta)\bar{q}}{r(1-r)}} - \frac{r}{2\theta(1-r)}\sqrt{\frac{\psi(1-\theta)\bar{q}}{r(1-r)}} - \frac{\psi}{\theta} + \frac{1-r}{\theta}\sqrt{\frac{\psi(1-\theta)\bar{q}}{r(1-r)}} - \frac{r-g}{2\theta r}\sqrt{\frac{\psi(1-\theta)\bar{q}}{r(1-r)}}$$
$$= \frac{\bar{q}-\psi}{\theta} + \frac{1}{\theta}\sqrt{\frac{\psi(1-\theta)\bar{q}}{r(1-r)}}\left\{\frac{4r^3-6r^2+r+g(1-r)}{2r(1-r)}\right\}.$$

This is complex; we cannot set equal to 0 and solve, nor can we sign the expression, even using the required conditions for an interior solution for $q^\dagger$. Instead, to proceed, we follow two alternative approaches: we attempt to show the derivative of π_B with respect to r is positive at the welfare-maximising value of r; and we simulate the breeder profit function under possible parameter values.

C.1.5.1 Evaluate the partial derivative

We showed previously the social welfare maximising end-point royalty was

$$r = \frac{g}{g+1} \text{ or } g = \frac{r}{1-r}.$$

If the partial derivative of breeder's profits with respect to r is positive when evaluated at that point, the profit-maximising breeder will choose a higher end-point royalty, above the value that maximises social welfare. Using the previous expression for the partial derivative and evaluating at this point gives

$$\frac{\partial \pi_B}{\partial r} \mid_{g=\frac{r}{1-r}} = \frac{\bar{q}-\psi}{\theta} + \frac{1}{\theta}\sqrt{\frac{\psi(1-\theta)\bar{q}}{r(1-r)}} \left\{ \frac{4r^3 - 6r^2 + 2r}{2r(1-r)} \right\}.$$

Whilst this expression cannot be signed for all values of the parameters, it would be positive if (but not only if) we can assume $\bar{q} > \psi$ and $0 \leq r \leq 0.5$. The first condition is plausible because it says the output from one hectare exceeds the amount of seed required to seed it. Likewise, the second is plausible as it can be re-written as $0 \leq g < 1$ which means the the marginal cost of producing seed is less than the price of grain. If this was not true, it would be cheaper for a breeder to buy grain than to produce it. Assuming these conditions hold, the partial derivative evaluated at this point is positive, meaning the monopolist breeder will increase the end-point royalty above the welfare-maximising point. This means total welfare is below the maximum but the monopolist breeder is able to extract a large enough share of this, via the end-point royalties, so that they are better off than with their share of the welfare-maximising surplus. We have not proved this is the case, but it is likely to be so under reasonable assumptions.

C.1.5.2 Simulations

So far, we have neither optimised breeder profit nor established in general that the monopolist breeder will increase end-point royalties above the social welfare maximising level. To demonstrate if this could be the case, extensive simulations were carried out using a range of parameter values. The results of these simulations are available on request from the author. In these simulations, we calculate the value of breeder profit for values of the end-point royalty including the limits of the interior conditions and the welfare maximising value $\frac{g}{g+1}$, and use EXCEL's solver tool to find the end-point royalty that maximises breeder profit. We then plot breeder profit against the end-point royalty and find, for a wide range of reasonable parameter values, a typical shape emerges for the breeder profit function; this is depicted in Figure C.1. Marked on the figure are the end-point royalties that maximises social welfare r^{SW} and breeder profit r^{PB}. The figure shows the end-point royalty that maximises breeder profit is above the welfare maximising level; hence, social welfare is lower under the monopolist breeder than the social planner case. This supports our conjecture that the monopolist breeder maximises profits by choosing

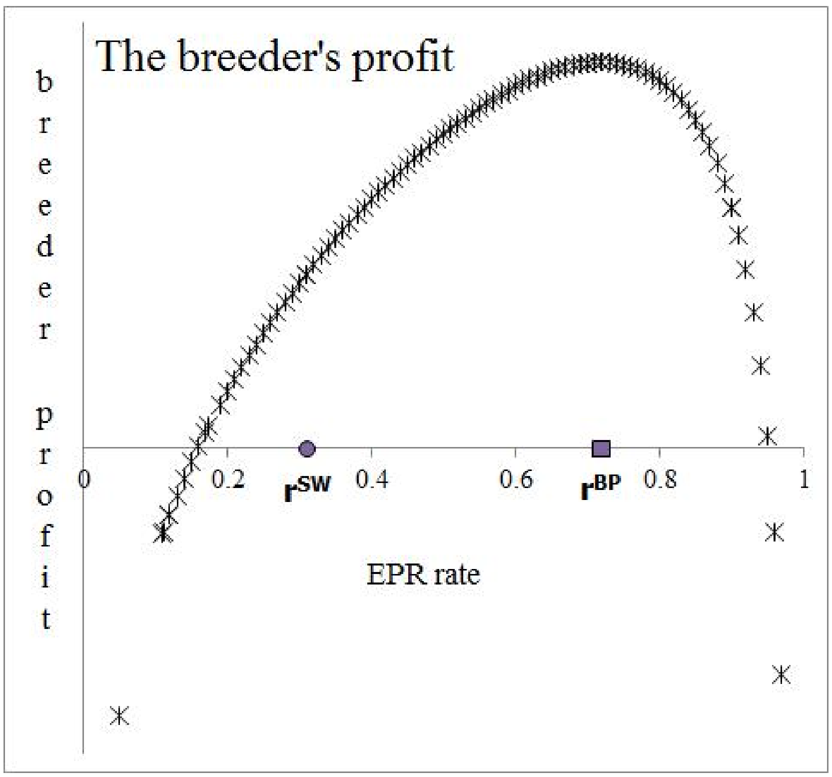

Figure C.1: The breeder’s profit for different EPRs.

an end-point royalty above the welfare-maximising level; this means total welfare is below the maximum but the monopolist breeder is able to extract a large enough share of this, via the end-point royalties, so that they are better off than with their share of the welfare-maximising surplus.

C.1.6 POS and EPR

With a point-of-sale and end-point royalty but no saved-seed royalty, we have $P_s = 0$. Then,

$$\begin{aligned}
\pi_f &= (1-r)q - (P_b + r)\psi b + r\psi - C, \\
q^{\dagger} &= \frac{\bar{q}}{\theta} - \frac{1}{\theta}\sqrt{\frac{(P_b + r)\psi(1-\theta)\bar{q}}{1-r}}, \\
b^{\dagger} &= 1 - \frac{1}{\theta} + \frac{1}{\theta}\sqrt{\frac{(1-r)(1-\theta)\bar{q}}{(P_b + r)\psi}}, \\
\pi_B &= rq + (P_b + r - g)\psi b - r\psi - K \\
\text{and } \; SW &= q - \psi g b - C - K.
\end{aligned}$$

Maximising social welfare gives the optimum seed quality as in Equation 3.16 of the main text. The social planner can implement this social welfare optimum by setting

$$\frac{P_b + r}{1-r} = g.$$

This condition also allows the monopolist breeder to implement the maximum level of social welfare, and both the benevolent social planner and the monopolist breeder can allocate the surplus by changing the royalties, whilst still fulfilling the required condition.

The monopolist will continue to do this until farmer profit reaches zero. Thus, the optimum royalties from the perspective of the breeder are royalties such that

$$\frac{P_b + r}{1 - r} = g \text{ and } \pi_f = 0.$$

C.1.7 EPR and SSP

With an end-point and saved-seed royalty but no point-of-sale royalty, we have $P_b = 0$ and

$$\begin{aligned} \pi_f &= (1-r)q - (P_s - r)\psi(1-b) - C, \\ \pi_B &= rq + (r - P_s - g)\psi b + (P_s - r)\psi - K \\ \text{and } SW &= q - g\psi b - C - K. \end{aligned}$$

There are two cases to consider, $P_s - r \geq 0$ and $P_s - r < 0$.

First, if the saved-seed royalty exceeds the end-point royalty so that $P_s - r \geq 0$, saved seed will be too expensive since its royalty exceeds the royalty on output sold but saved seed is never as productive as bought, new, seed. In this case, the farmer maximises by choosing b and q to be as high as possible, $b^{\dagger} = 1$ and $q^{\dagger} = \bar{q}$. Then

$$\begin{aligned}\pi_f =& (1-r)\bar{q} - C,\\ \pi_B =& r\bar{q} - g\psi - K\\ \text{and } SW =& SW^0 = \bar{q} - g\psi - C - K.\end{aligned}$$

Again, the social planner or the monopolist breeder could use the end-point royalty r to allocate the surplus. For the monopolist breeder we have the optimum end-point royalty is

$$1 - \frac{C}{\bar{q}}.$$

The second case is where the saved-seed royalty is less than the end-point royalty so that $P_s - r < 0$. The analysis continues in the same way as in other scenarios and shows

$$\begin{aligned}q^{\dagger} =& \frac{\bar{q}}{\theta} - \frac{1}{\theta}\sqrt{\frac{(r-P_s)\psi(1-\theta)\bar{q}}{1-r}}\\ b^{\dagger} =& 1 - \frac{1}{\theta} + \frac{1}{\theta}\sqrt{\frac{(1-r)(1-\theta)\bar{q}}{(r-P_s)\psi}}.\end{aligned}$$

Social welfare is given by $q - \psi g b - C - K$ and maximising this gives the optimum seed quality as in Equation 3.16 of the main text. Both the social planner and the monopolist breeder can implement this social welfare optimum by setting

$$\frac{r - P_s}{1 - r} = g$$

and both can allocate the surplus by changing the royalties, whilst still fulfilling the required condition.

The monopolist will continue to do this until farmer profit reaches zero. Thus, the optimum royalties from the perspective of the breeder are royalties such that

$$\frac{r - P_s}{1 - r} = g \text{ and } \pi_f = 0.$$

C.1.8 Discussion

The results for this alternative model in which the end-point royalty is payable on production net of saved seed are similar to those of the model in Chapter 3 in which the royalty is payable on all production. The differences are largely algebraic and occur because the end-point royalty acts differently on seed sold or saved in this new model, as explained in Section 3.4. Table C.1 summarises the scenarios and is analogous to Table 3.3. Again, the social planner results are in the top half of the table and the monopolist breeder results in the bottom half.

Where all three royalties are allowed, the condition required to implement the maximum social welfare becomes

$$g = \frac{P_b + r - P_s}{1 - r}$$

	Royalty scheme				
	All three royalties, EPR & POS; POS & SSP; EPR & SSP ($P_s < r$)	POS only	EPR & SSP ($P_s \geq r$)	No royalties, SSP only	EPR only
Social planner outcome					
Condition	$\frac{P_b+r-P_s}{1-r} = g$ (***)	$P_b = g$	-	-	$r = \frac{g}{1+g}$
Social welfare	SW^{SW}	SW^{SW}	SW^0	SW^0	SW^{SW}
Bought seed	b^{SW}	b^{SW}	1	1	b^{SW}
Seed quality	q^{SW}	q^{SW}	$\bar{q}$	$\bar{q}$	q^{SW}
Allocation	determined by planner	negative breeder profit	determined by planner	negative breeder profit	not determined by planner
Monopolist breeder outcome					
Condition	$\frac{P_b+r-P_s}{1-r} = g$ (***) and $\pi_f = 0$	$g < P_b < \frac{\bar{q}}{\psi(1-\theta)}$	$r = 1 - \frac{C}{\bar{q}}$	-	$r > \frac{g}{1+g}$
Social welfare	SW^{SW}	$< SW^{SW}$	SW^0	$< SW^{SW}$	$< SW^{SW}$
Bought seed	b^{SW}	$\neq b^{SW}$	1	1	-
Seed quality	q^{SW}	$\neq q^{SW}$	$\bar{q}$	$\bar{q}$	-
Allocation	$\pi_f = 0$ and breeder can allocate	breeder can allocate	$\pi_f = 0$ and breeder can allocate	$\pi_B < 0$ and breeder cannot allocate	breeder can allocate

(***): Where a royalty is not allowed, the respective parameter takes the value 0.

Table C.1: Results of the alternative full-declaration model instead of

$$g = \frac{P_b - P_s}{1 - r}.$$

Where where no saved-seed royalty is allowed and we have only end-point and point-of-sale royalties, the condition becomes

$$g = \frac{P_b + r}{1 - r}$$

instead of

$$g = \frac{P_b}{1 - r}.$$

Where no point-of-sale royalty is allowed and we have only end-point and saved-seed royalties, the model in the main chapter showed there would be no saved seed, and a benevolent social planner or a monopolist breeder could not achieve the maximum level of social welfare but they could use royalties to allocate it. This result carries over to this new model if $P_s > r$ since (as in the model in the chapter) saved seed is then too expensive and none is used. However, if $P_s < r$, the condition required to implement the maximum social welfare is

$$g = \frac{r - P_s}{1 - r}$$

and the benevolent social planner and the monopolist breeder can both achieve the maximum level of social welfare and allocate it.

Finally, when there is an end-point royalty only, the results of the two models differ because the end-point royalty acts differently on sold or saved seed. Whereas previously the social planner could allocate but not maximise the surplus, now they can maximise but not allocate. We cannot obtain an analytic solution for the outcome for the monopolist breeder in this scheme and the conjecture is made, backed up by simulation and some analysis, that there is little difference between the nature of the monopolist breeder outcome in this model and the one used in the chapter—that is, the monopolist breeder will maximise their profit by choosing an end-point royalty above the one the social planner would choose.

Table C.2 is the analogue for this alternative model to Table 3.4 for the original model and summarises the outcomes whilst Table C.3 summarises the outcomes for both models, highlighting which royalty schemes differ between the two formulations.

		Level of social welfare achieved		
		SW^{SW}	$SW^0 < SW^{SW}$	
social planner	can determine allocation	All 3 royalties EPR & POS EPR & SSP ($P_s < r$) SSP & POS	EPR & SSP ($P_s \geq r$)	
	cannot determine allocation	POS only EPR only	No royalties SSP only	
		Level of breeder profit achieved		
		$\pi_B = SW^{SW}$	$\pi_B = SW^0 < SW^{SW}$	$\pi_B < SW^{SW}$
monopoly breeder	can determine allocation	All 3 royalties EPR & POS EPR & SSP ($P_s < r$) SSP & POS	EPR & SSP ($P_s \geq r$)	POS only EPR only
	cannot determine allocation			No royalties SSP only

Table C.2: Summary of the alternative full-declaration model

Case	Social planner outcome	Monopoly breeder outcome	Original model schemes	Alternative model schemes
I	SW^{SW} can determine allocation	SW^{SW} can extract	All three royalties, EPR and POS, POS and SSP	All three royalties, EPR and POS, POS and SSP, EPR and SSP ($P_s < r$)
II	SW^{SW} cannot determine allocation	less than SW^{SW} can extract	POS only	POS only EPR only
III	less than SW^{SW} can determine allocation	less than SW^{SW} can extract	EPR and SSP, EPR only	EPR and SSP ($P_s \geq r$)
IV	less than SW^{SW} cannot determine allocation	less than SW^{SW} cannot extract	SSP only, no royalties	SSP only, no royalties

Table C.3: Comparison of the two formulations of the full-declaration model

Appendix D

Appendix to Chapter 4: A game-theoretic model with less than full-declaration

D.1 The optimum declaration rates

In this section, we find the values of the declaration rates that maximise the farmer's profit. We start by substituting the expression for the breeder's enforcement costs ϕ from Equation 4.4 into the expression for farmer profit π_f from Equation 4.1 to give

$$\pi_f = (1-rd)q - P_b\psi b - P_s\psi m(1-b) - \frac{f^2\left\{r(1-d)q + P_s\psi(1-m)(1-b)\right\}^2}{2a} - C. \tag{D.1}$$

We take the first-order condition with respect to d

$$-rq + \frac{f^2}{a}(rq)\left\{r(1-d)q + P_s\psi(1-m)(1-b)\right\} = 0,$$

divide by rq and simplify, giving

$$r(1-d)q + P_s\psi(1-m)(1-b) = \frac{a}{f^2} \tag{D.2}$$

Next, we take the first-order condition with respect to m

$$-P_s\psi(1-b) + \frac{f^2}{a}(P_s\psi(1-b))\left\{r(1-d)q + P_s\psi(1-m)(1-b)\right\} = 0,$$

divide by $P_s\psi(1-b)$ and simplify. This gives rise to the same expression as in Equation D.2.

It is worth noting that this expression shows the two forms of cheating are substitutes: implicit differentiation of Equation D.2 gives

$$\frac{\partial d}{\partial m} = \frac{P_s\psi(1-b)}{-rq} < 0.$$

The second order derivatives are

$$\begin{aligned}
\frac{\partial^2 \pi_f}{\partial d^2} &= \frac{-f^2 r^2 q^2}{a}, \\
\frac{\partial^2 \pi_f}{\partial m^2} &= \frac{-f^2 P_s^2 \psi^2 (1-b)^2}{a} \\
\text{and } \frac{\partial^2 \pi_f}{\partial d \partial m} &= \frac{-f^2 P_s r\psi(1-b)q}{a}
\end{aligned}$$

which lead to a zero discriminant and standard optimisation is inconclusive. We use an alternative approach.

Take the expression for π_f in Equation D.1 and re-write as

$$\pi_f = q - P_b\psi b - (rdq + P_s\psi m(1-b)) - \frac{f^2}{2a}(rq - rdq - P_s\psi m(1-b) + P_s\psi(1-b))^2 - C.$$

Denote $rdq + P_s\psi m(1-b)$ by χ so the equation above becomes

$$\pi_f = q - P_b\psi b - C - \chi - \frac{f^2}{2a}(rq - \chi + P_s\psi(1-b))^2.$$

Note that d and m only appear in this Equation in the term χ so now maximise π_f with respect to χ. The first-order condition with respect to χ is

$$\begin{aligned} & -1 + \frac{f^2}{a}(rq - \chi + P_s\psi(1-b)) = 0 \\ \text{or} \quad & \chi = rq + P_s\psi(1-b) - \frac{a}{f^2} \\ \text{which is} \quad & rdq + P_s\psi m(1-b) = rq + P_s\psi(1-b) - \frac{a}{f^2}. \end{aligned} \tag{D.3}$$

This provides a maximum since the second derivative

$$\frac{\partial^2 \pi_f}{\partial \chi^2} = \frac{-f^2}{a} < 0.$$

Hence, π_f is maximised when the condition in Equation D.3 is met.

We require $m^*, d^* \in [0, 1]$. Re-arranging Equation D.3 to give an expression for m^* which we then set between 0 and 1 gives

$$0 \leq \frac{rq + P_s\psi(1-b) - \frac{a}{f^2} - rd^*q}{P_s\psi(1-b)} \leq 1,$$
$$\text{or } 1 - \frac{a}{f^2 rq} \leq d^* \leq 1 + \frac{P_s\psi(1-b)}{rq} - \frac{a}{f^2 rq}.$$

Consider the lower value in this expression. If this lower value was above 1, d would exceed 1; so for an interior solution for d^*, we need $1 - \frac{a}{f^2 rq} \leq 1$. This will hold since $a, f, r, q > 0$ are assumed.

Similarly, consider the upper value in the expression above. If this upper value was negative, d would be negative; so for an interior solution for d^*, we need

$$1 + \frac{P_s\psi(1-b)}{rq} - \frac{a}{f^2 rq} \geq 0.$$

This is the required condition for an interior solution for m^* and d^* and can be rewritten as

$$P_s\psi(1-b) + rq \geq \frac{a}{f^2}.$$

The intuition is that if this condition holds, the royalty revenue to the breeder from the royalties on which the farmer can cheat is more than the expected fine (which depends on enforcement costs and the level of fines) so the breeder will exert effort to detecting mis-declaration and the farmer will declare at least some of their output and saved seed.

The interior solutions for d and m are then given by

$$d^* = \alpha \max(1 - \frac{a}{f^2 rq}, 0) + (1-\alpha)\min(1 + \frac{P_s\psi(1-b)}{rq} - \frac{a}{f^2 rq}, 1)$$

for $\alpha \in [0, 1]$, and

$$m^* = \frac{rq + P_s\psi(1-b) - \frac{a}{f^2} - rd^*q}{P_s\psi(1-b)}.$$

Finally, suppose the required condition for an interior solution for d and m does not hold so that

$$P_s\psi(1-b) + rq < \frac{a}{f^2}. \tag{D.4}$$

We show in this case $d^* = m^* = 0$.

First, take the partial derivative of π_f with respect to χ,

$$\frac{\partial \pi_f}{\partial \chi} = -1 + \frac{f^2}{a}(rq - \chi + P_s\psi(1-b)).$$

This is negative since from Equation D.4,

$$\frac{f^2}{a}\left\{P_s\psi(1-b) + rq\right\} < 1.$$

Now, recall that $\chi = rdq + P_s\psi m(1-b)$ and take the partial derivatives of π_f with respect to d and m:

$$\frac{\partial \pi_f}{\partial d} = \frac{\partial \pi_f}{\partial \chi}\frac{\partial \chi}{\partial d} = \frac{\partial \pi_f}{\partial \chi} rq < 0 \text{ and}$$
$$\frac{\partial \pi_f}{\partial m} = \frac{\partial \pi_f}{\partial \chi}\frac{\partial \chi}{\partial m} = \frac{\partial \pi_f}{\partial \chi} P_s\psi(1-b) < 0.$$

From this, we see both partial derivatives are always negative and they are positive multiples of each other; hence, π_f is maximum when d and m are at their minimum values and hence $d^* = m^* = 0$.

D.2 Farmer profits with the three royalties

In this section, we simplify the expression for farmer profit when the declaration rates are at their optimum values, d^* and m^*. We take Equation 4.1 and rewrite as

$$\begin{aligned}\pi_f =&(1-r)q + (1-d)rq - P_b\psi b + P_s\psi(1-m)(1-b) - P_s\psi(1-b)\\ &- \phi f\left\{(1-d)rq + P_s\psi(1-b)(1-m)\right\} - C\\ =&(1-r)q - P_b\psi b - P_s\psi(1-b) +\\ &(1-\phi f)\left\{(1-d)rq + P_s\psi(1-b)(1-m)\right\} - C.\end{aligned}$$

Now substitute from Equations 4.9 and 4.5 to give

$$\pi_f = (1-r)q - P_b\psi b - P_s\psi(1-b) + \frac{a}{2f^2} - C.$$

This is the same expression as in Chapter 3 except for the extra term involving fines and enforcement costs. Farmer profit will be maximised at the same level of b and q as in that Chapter, although realised farmer profit will be higher.

D.3 The comparative statics for declaration rates

In this section, we sign the comparative static results for m and d with respect to the royalties, the fine parameter and enforcement costs. We take the expression that jointly determines the declaration rates, Equation D.2 and re-write it as $X = 0$ where

$$X = rq - rdq + P_s\psi(1-m)(1-b) - \frac{a}{f^2},$$

with $q = q(\theta, \bar{q}, \psi, r, P_S, P_b)$ and $b = b(\theta, \bar{q}, \psi, r, P_S, P_b)$. Then

$$\frac{\partial X}{\partial m} = -P_s\psi(1-b) \text{ and } \frac{\partial X}{\partial d} = -rq$$

are both negative.

Hence, for any parameter z,

$$\frac{\partial m}{\partial z} = -\frac{\frac{\partial X}{\partial z}}{\frac{\partial X}{\partial m}} \text{ and } \frac{\partial d}{\partial z} = -\frac{\frac{\partial X}{\partial z}}{\frac{\partial X}{\partial d}}$$

take the same sign as $\frac{\partial X}{\partial z}$.

For the enforcement costs parameter a,

$$\frac{\partial X}{\partial a} = -\frac{1}{f^2} < 0$$

so both $\frac{\partial m}{\partial a}$ and $\frac{\partial d}{\partial a}$ are negative.

For the fine parameter f,

$$\frac{\partial X}{\partial f} = \frac{2a}{f^3} > 0$$

so both $\frac{\partial m}{\partial f}$ and $\frac{\partial d}{\partial f}$ are positive.

For the probability of detection ϕ, recall that $\phi = \frac{1}{2f}$ so

$$\frac{\partial X}{\partial \phi} = \frac{\partial X}{\partial f}\frac{\partial f}{\partial \phi} < 0$$

and both $\frac{\partial m}{\partial \phi}$ and $\frac{\partial d}{\partial \phi}$ are negative.

The partial derivatives with respect to the royalties are indeterminate. For example, consider the end-point royalty r.

$$\frac{\partial X}{\partial r} = (1-d)q + r(1-d)\frac{\partial q}{\partial r} - P_s\psi(1-m)\frac{\partial b}{\partial r}.$$

In this expression, the partial derivatives with respect to b and q take the same sign and the result is indeterminate. This shows that an increase in the end-point royalty increases the incentive to cheat to avoid the higher royalty, but also increases the fine, thus reducing the incentive to cheat, and the effect is indeterminate overall.

The same problem occurs with the derivatives with respect to P_b and P_s. Again, an increase in the saved-seed or point-of-sale royalty increases the incentive to cheat to avoid paying the higher royalty, but also increases the fine, thus reducing the incentive to cheat, and the effect is indeterminate overall.

D.4 Less than three royalties

In this section, we consider the schemes when not all royalties are available. First, we look at no royalties; then royalties one at a time; and finally, two at a time.

D.4.1 No royalties or a point-of-sale royalty only

If there are no royalties, or a point-of-sale royalty only, there can be no false declaration and the outcomes are the same as in Chapter 3.

D.4.2 A saved-seed royalty only

With only a saved-seed royalty, the farmer will never use saved seed because it is more expensive than new seed but no more productive. Hence, there is no saved seed, so no false declaration on saved seed and this model reverts to the one in Chapter 3.

D.4.3 An end-point royalty only

With no saved-seed or point-of-sale royalty, we have

$$\pi_f = (1 - rd)q - \phi fr(1 - d)q - C,$$

$$\pi_B = rdq + \phi fr(1 - d)q - gb\psi - a\phi^2 - K$$

and by inspection from the expression for π_B,

$$\phi^* = \frac{fr(1 - d)q}{2a}.$$

Substituting ϕ^* into the expression for farmer profit, we get

$$\pi_f = (1 - rd)q - \frac{f^2 r^2 (1 - d)^2 q^2}{2a} - C,$$

with first-order condition with respect to d given by

$$-rq + \frac{f^2 r^2 (1 - d^*) q^2}{a} = 0 \ \text{ or } \ 1 - d^* = \frac{a}{f^2 rq}.$$

Then,

$$\phi^* = \frac{1}{2f}.$$

We saw in Chapter 3 the farmer will use no saved seed and only new seed in this case since saved seed is not more productive than new seed and both attract end-point royalties at the same rate. The same is true here so we have $b^* = 1$ and $q^* = \bar{q}$. Hence,

$$\begin{aligned}
\pi_f &= (1-r)\bar{q} + r(1-d)\bar{q} - \phi f r(1-d)\bar{q} - C \\
&= (1-r)\bar{q} + r(1-d)\bar{q} - \frac{r(1-d)\bar{q}}{2} - C \\
&= (1-r)\bar{q} + \frac{ar\bar{q}}{2f^2 r\bar{q}} - C \\
&= (1-r)\bar{q} + \frac{a}{2f^2} - C, \\
\pi_B &= r\bar{q}(1 - \frac{a}{f^2 r\bar{q}}) + \frac{r\bar{q}a}{2f^2 r\bar{q}} - g\psi - \frac{a}{4f^2} - K \\
&= r\bar{q} - \frac{a}{f^2} + \frac{a}{2f^2} - \frac{a}{4f^2} - g\psi - K \\
&= r\bar{q} - \frac{3a}{4f^2} - g\psi - K \\
\text{and } \; SW &= \bar{q} - g\psi - \frac{a}{4f^2} - C - K.
\end{aligned}$$

We denote this level of social welfare as $\tilde{SW}^0$; the tilde indicates this value is from the model with less than full-declaration whilst the superscript ^{0} shows this level of social welfare is analogous to SW^0 in Chapter 3 and is below the maximum level of social welfare, $\tilde{SW}^{SW}$.

D.4.4 An end-point and a saved-seed royalty

With a saved-seed royalty but no point-of-sale royalty, the farmer will not save seed because saved seed is now more expensive than new seed but no more productive. Thus, $b = 1$ and $q = \bar{q}$ so the declaration rate of saved seed m is irrelevant and this case reduces to the end-point royalty only case which was analysed in the previous section.

D.4.5 A saved-seed and a point-of-sale royalty

With saved-seed and point-of-sale royalties, we have

$$\begin{aligned}\pi_f =& q - P_b b\psi - P_s\psi m(1-b) - \phi f P_s \psi(1-m)(1-b) - C,\\ \pi_B =& P_b b\psi + P_s\psi m(1-b) + \phi f P_s\psi(1-m)(1-b) - g\psi b - a\phi^2 - K\end{aligned}$$

and by inspection from the expression for π_B,

$$\phi^* = \frac{fP_s\psi(1-m)(1-b)}{2a}.$$

Substituting ϕ^* into the expression for farmer profit, we get

$$\pi_f = q - P_b\psi b - P_s\psi m(1-b) - \frac{f^2 P_s^2 \psi^2 (1-m)^2(1-b)^2}{2a} - C,$$

and the first-order condition with respect to m is

$$P_s\psi(1-b) = \frac{f^2 P_s^2 \psi^2 (1-m^*)(1-b)^2}{a} = 0 \text{ or } 1-m^* = \frac{a}{f^2 P_s \psi(1-b)}.$$

As in the main text, $\phi^* = \frac{1}{2f}$ and use this to simplify π_f, giving

$$\begin{aligned}\pi_f =& q - P_b b\psi - P_s\psi(1-b) + P_s\psi(1-m)(1-b) \\ & - \phi f P_s \psi(1-m)(1-b) - C, \\ =& q - P_b\psi b - P_s\psi(1-b) + \frac{a}{2f^2} - C.\end{aligned}$$

Similarly,

$$\begin{aligned}\pi_B =& P_b\psi b + P_s\psi(1-b) - P_s\psi(1-b)(1-m) + \phi f P_s\psi(1-b)(1-m) \\ & - a\phi^2 - g\psi b - K \\ =& P_b\psi b + P_s\psi(1-b) - \frac{a}{f^2} + \frac{a}{2f^2} - \frac{a}{4f^2} - g\psi b - K \\ =& P_b\psi b + P_s\psi(1-b) - \frac{3a}{4f^2} - g\psi b - K\end{aligned}$$

and $SW = q - g\psi b - \dfrac{a}{4f^2} - C - K.$

This level of social welfare is denoted $S\tilde{W}^{SW}$ and is

$$SW^{SW} - \frac{a}{4f^2}.$$

It is the maximum level of social welfare attainable in this model with less than full-declaration. These equations are the same as the corresponding ones for farmer and breeder profit in Chapter 3, with the extra term involving a and f.

D.4.6 A point-of-sale and an end-point royalty

With no saved-seed royalty we have

$$\pi_f = (1 - rd)q - P_b\psi b - \phi fr(1 - d)q - C,$$

$$\pi_B = rdq + P_b\psi b + \phi fr(1 - d)q - g\psi b - a\phi^2 - K$$

and by inspection from the expression for π_B,

$$\phi^* = \frac{fr(1 - d)q}{2a}.$$

Substituting ϕ^* into the expression for farmer profit, we get

$$\pi_f = (1 - rd)q - P_b\psi b - \frac{f^2r^2(1 - d)^2q^2}{2a} - C,$$

with first-order condition with respect to d given by

$$-rq + \frac{f^2r^2(1 - d^*)q^2}{a} = 0 \text{ or } 1 - d^* = \frac{a}{f^2rq}.$$

Then,

$$\phi^* = \frac{1}{2f}.$$

Substituting back into farmer and breeder profit gives

$$\begin{aligned}
\pi_f &= (1-r)q - P_b\psi b + r(1-d)q - \frac{r(1-d)q}{2} - C \\
&= (1-r)q - P_b\psi b + \frac{arq}{2f^2rq} - C \\
&= (1-r)q - P_b\psi b + \frac{a}{2f^2} - C. \\
\pi_B &= rq + P_b\psi b - \frac{a}{2f^2} - \frac{a}{4f^2} - g\psi b - K \\
&= rq + P_b\psi b - \frac{3a}{4f^2} - g\psi b - K. \\
SW &= q - g\psi b - \frac{a}{4f^2} - C - K = \tilde{SW}^{SW}.
\end{aligned}$$

These expressions for farmer and breeder profit and social welfare are analogous to the corresponding ones in the previous chapter and are maximised at the same values of b and q although realised values are different. We get $b = b^{SW}$, $q = q^{SW}$.

D.4.7 The breeder's perspective

The analysis above assumed a benevolent social planner maximising social welfare. If, instead, we consider a monopolist breeder maximising their own profit, the difference is in the allocation of the surplus. For schemes where the social planner could re-allocate the surplus, the monopolist breeder could also do so and by forcing the farmer down to zero profits, the monopolist breeder can extract the surplus and maximise their profits. The condition the monopolist breeder uses to maximise their profit follows from the corresponding model in Chapter 3. For the end-point royalty only case, reducing farmer profit to zero gives

$$\begin{aligned} \pi_f &= (1-r)\bar{q} + \frac{a}{2f^2} - C = 0 \\ \text{or } \; r^* &= 1 + \frac{a}{2f^2\bar{q}} - \frac{C}{\bar{q}}. \end{aligned}$$

For other schemes, the analysis is essentially the same as for the model in Chapter 3 where declaration was complete, apart from a re-distribution from breeder to farmer, caused by the enforcement costs; our model assumed breeders incurred these costs. Alternative assumptions here would change the distribution between farmer and breeder but not the overall reduction in the surplus caused by the costs.

Appendix E

Appendix to Chapter 5: A Principal–Agent model without enforcement costs

E.1 Unconstrained maximization

This Appendix derives the unconstrained maximum of the breeder's expected profit which was given in Equation 5.15 as

$$E\pi_B = \frac{(v - rv - p)(v + rv + p - 2g)}{2(c + \gamma(1-r)^2\sigma^2)} - K.$$

The first-order condition with respect to p has the numerator

$$(v - rv - p) - (v + rv + p - 2g) = 0 \text{ or } rv + p = g. \tag{E.1}$$

The first-order condition with respect to r has the numerator

$$\begin{aligned}&[c + \gamma(1-r)^2\sigma^2]\{v(v - rv - p) - v(v + rv + p - 2g)\} \\ &+ (v - rv - p)(v + rv + p - 2g)2\gamma(1-r)\sigma^2 = 0.\end{aligned}$$

Substituting the first of these into the second gives

$$2\gamma(1-r)(v-g)^2\sigma^2 = 0.$$

The optimal solution to this unconstrained problem is $r = 1$; and substituting this value of r into Equation E.1 gives $p_1 = g - v$, which is negative. In this case, the optimal quantity of seed from Equation 5.14 becomes

$$b_1 = \frac{v - rv - p}{c + \gamma(1-r)^2\sigma^2} = \frac{v-g}{c}$$

which is the same as first-best solution previously obtained.

For this unconstrained optimization, the second-order conditions are difficult and are not pursued because the outcome obtained is the same as the first-best, which is a maximum.

E.2 Kuhn Tucker maximization

This Appendix derives the constrained maximum of the expected profit of the breeder in Equation 5.15 with respect to r and p and subject to $0 \leq r \leq 1$ and $p \geq 0$. The Lagrangian is

$$\mathscr{L} = \frac{(v - rv - p)(v + rv + p - 2g)}{2(c + \gamma(1 - r)^2\sigma^2)} - K + \lambda(1 - r).$$

The Kuhn Tucker conditions are:

1) $\frac{\partial \mathscr{L}}{\partial p} \leq 0$ or $\frac{-2rv-2p+2g}{2(c+\gamma(1-r)^2\sigma^2)} \leq 0$ which gives $rv + p \geq g$

2) $p \geq 0$

3) $p(g - rv - p) = 0$

4) $\frac{\partial \mathscr{L}}{\partial r} \leq 0$ or $-\lambda + \frac{v(g-rv-p)}{c+\gamma(1-r)^2\sigma^2} + \frac{(v-rv-p)(v+rv+p-2g)(1-r)\gamma\sigma^2}{(c+\gamma(1-r)^2\sigma^2)^2} \leq 0$

5) $r \geq 0$

6) $r\frac{\partial \mathscr{L}}{\partial r} = 0$

7) $\frac{\partial \mathscr{L}}{\partial \lambda} \geq 0$ or $1 - r \geq 0$

8) $\lambda \geq 0$

9) $\lambda(1 - r) = 0$

E.2.0.0.1 Suppose $r = 0$. By 9), if $r = 0$ then $\lambda = 0$.

By 3), with $r = 0$, either $p = 0$ or $p = g$.

(a) Suppose $p = 0$. With $r = 0, \lambda = 0$ and $p = 0$, 1) fails, because $g > 0$ was assumed.

(b) Suppose $p = g$. With $r = 0, \lambda = 0$ and $p = g$, the left hand side of 4) becomes

$$\frac{(v-g)^2\gamma\sigma^2}{(c+\gamma\sigma^2)^2}$$

which is positive and 4) fails.

Hence r cannot be 0.

E.2.0.0.2 Suppose $r = 1$. If $r = 1$ then conditions 5), 7) and 9) hold.

By 1), 2) and 3): either $p = 0$ or $p = g - v$.

(a) Suppose $p = 0$. With $r = 1$ and $p = 0$, 6) becomes

$$\frac{v(g-v)}{c} = \lambda,$$

and this cannot hold since $g < v$, $g - v < 0$ but $\lambda \geq 0$ so 6) fails.

(b) Suppose $p = g - v$. Then condition 2) fails since since $g < v$.

Hence r cannot be 1, and so $0 < r < 1$.

E.2.0.0.3 Suppose $0 < r < 1$. Condition 5) holds.

By 7), 8) and 9), $\lambda = 0$.

By 1), 2) and 3), either $p = 0$ or $p = g - rv$.

(a) Suppose $p = g - rv$. Since $0 < r < 1$, then 6) becomes

$$\lambda = 0 + \frac{\gamma(1-r)(v-g)^2\sigma^2}{(c+\gamma(1-r)^2\sigma^2)^2}$$

but since $\lambda = 0$, this requires $\gamma(1-r)(v-g)^2\sigma^2 = 0$ or $v = g$ but this does not hold so 6) is contradicted.

(b) Suppose $p = 0$. Then with $0 < r < 1$, $p = 0$ and $\lambda = 0$, 6) requires

$$0 = \lambda = \frac{v(g-rv)}{c+\gamma(1-r)^2\sigma^2} + \frac{(v-rv)(v+rv-2g)(1-r)\gamma\sigma^2}{(c+\gamma(1-r)^2\sigma^2)^2}$$
$$\text{or} \;\; g - rv + \frac{\gamma(1-r)^2(v+rv-2g)\sigma^2}{c+\gamma(1-r)^2\sigma^2} = 0. \tag{E.2}$$

This is the only possibility for a solution, and is solved below.

Rearranging and simplifying Equation E.2 gives

$$\gamma(1-r)^2(v-g)\sigma^2 + (g-rv)c = 0. \tag{E.3}$$

This is manipulated to

$$\gamma(1-r)^2(v-g)\sigma^2 + (1-r)vc - (v-g)c = 0, \tag{E.4}$$

which is a quadratic in $(1-r)$ with solution, for $0 < r < 1$:

$$(1-r_1) = \frac{-vc + \sqrt{v^2c^2 + 4\gamma(v-g)^2c\sigma^2}}{2\gamma(v-g)\sigma^2}$$

and

$$r_1 = 1 + \frac{vc - \sqrt{v^2c^2 + 4\gamma(v-g)^2c\sigma^2}}{2\gamma(v-g)\sigma^2}. \tag{E.5}$$

For this constrained optimization, the second-order conditions is checked using the bordered Hessian which is

$$\begin{vmatrix} 0 & -1 & 0 \\ -1 & \mathscr{L}_{rr} & \mathscr{L}_{rp} \\ 0 & \mathscr{L}_{rp} & \mathscr{L}_{pp} \end{vmatrix}$$

$$= -\mathscr{L}_{pp}.$$

This second-order partial derivative $\mathscr{L}_{pp}$ is obtained by differentiating the Kuhn Tucker condition $\frac{\partial \mathscr{L}}{\partial p}$ with respect to p giving

$$\frac{-1}{c + \gamma(1-r)^2\sigma^2}$$

and hence the bordered Hessian determinant is strictly positive as required for a maximum.

E.3 Checking the implementability constraint

This Appendix checks the implementability constraint which is given in Equation 5.7 as

$$(1-r)vb - \frac{cb^2}{2} - \frac{\gamma(1-r)^2\sigma^2 b^2}{2} > 0.$$

With $p = 0$, Equation 5.17 gave the optimum level of b which we substitute into the implementability constraint, so the left-hand side is

$$\frac{(1-r)^2v^2}{c+\gamma(1-r)^2\sigma^2}-\frac{c(1-r)^2v^2}{2(c+\gamma(1-r)^2\sigma^2)^2}-\frac{-\gamma(1-r)^2\sigma^2(1-r)^2v^2}{2(c+\gamma(1-r)^2\sigma^2)^2}=\frac{(1-r)^2v^2}{2(c+\gamma(1-r)^2\sigma^2)}$$

which is clearly positive as required since $r < 1$.

E.4 Derivation of comparative statics results

This Appendix derives comparative static results for the partial-insurance case of the Principal–Agent model. For simplicity, we omit the subscripts. However, these results are for the comparative static results at the optimum. Two results will be useful here. Re-arranging Equation E.3 gives

$$\gamma(1-r)^2\sigma^2 = \frac{c(rv-g)}{v-g}. \tag{E.6}$$

Hence, firstly,

$$c+\gamma(1-r)^2\sigma^2 = \frac{c(v+rv-2g)}{v-g} \tag{E.7}$$

which is positive; and second

$$c-\gamma(1-r)^2\sigma^2 = \frac{(1-r)vc}{v-g} \tag{E.8}$$

which is also positive.

It is also useful to note here that both

$$\begin{aligned} &rv > g \\ \text{and} \;\; &v + rv - 2g > 0. \end{aligned} \tag{E.9}$$

We now find the comparative statics for the end-point royalty, the quantity of seed, the expected profit of the breeder and then the license fee.

E.4.1 The end-point royalty rate

The expression for r is complex; hence, to find its comparative statics, we use implicit differentiation of the solution equation, Equation E.3. We expand this equation to

$$cg - rvc - \gamma(1-r)^2 g\sigma^2 + \gamma(1-r)^2 v\sigma^2 = 0.$$

For ease of notation, denote the left hand side of the expression by X so we have $X = 0$. The partial derivative of r with respect to, say, x, is found by implicit differentiation,

$$\frac{\partial r}{\partial x} = \frac{-\frac{\partial X}{\partial x}}{\frac{\partial X}{\partial r}}$$

which has the same sign as $\frac{\partial X}{\partial x}$ since (recalling that $v > g$ is assumed)

$$\frac{\partial X}{\partial r} = -vc - 2(v-g)\gamma(1-r)\sigma^2 < 0.$$

This is simplified, using Equation E.6, to

$$\frac{-c(v+rv-2g)}{1-r} \tag{E.10}$$

This result is useful later.

Then, $\frac{\partial r}{\partial v}$ has the same sign as

$$\frac{\partial X}{\partial v} = \gamma(1-r)^2\sigma^2 - rc.$$

By Equation E.6, this is

$$\frac{-(1-r)cg}{v-g},$$

which is negative, and therefore so is $\frac{\partial r}{\partial v}$. In fact,

$$\frac{\partial r}{\partial v} = \frac{-(1-r)^2 g}{(v-g)(v+rv-2g)}$$

and this expression will be useful later.

Next $\frac{\partial r}{\partial c}$ has the same sign as $\frac{\partial X}{\partial c}$ which is $g - rv$. From Equation E.6, this is non-positive. In fact, using Equation E.10,

$$\frac{\partial r}{\partial c} = \frac{-\frac{\partial X}{\partial c}}{\frac{\partial X}{\partial r}} = \frac{-(1-r)(rv-g)}{c(v+rv-2g)}.$$

This expression for $\frac{\partial r}{\partial c}$ will be useful later.

Now $\frac{\partial r}{\partial g}$ has the same sign as $\frac{\partial X}{\partial g}$ which is $c - \gamma(1-r)^2\sigma^2$ and is positive from Equation E.8. In fact,

$$\frac{\partial r}{\partial g} = \frac{-(c - \gamma(1-r)^2\sigma^2)(1-r)}{-c(v + rv - 2g)} = \frac{(1-r)^2 v}{(v + rv - 2g)(v - g)}$$

and this expression will be useful later.

Finally, consider $\frac{\partial r}{\partial \gamma}$, which has the same sign as $\frac{\partial X}{\partial \gamma} = (v-g)(1-r)^2\sigma^2$ which is positive. The partial derivative with respect to σ^2 is analogous.

E.4.2 The quantity of seed

Equation 5.17 gives

$$b = \frac{(1-r)v}{c + \gamma(1-r)^2\sigma^2}.$$

To find $\frac{\partial b}{\partial x}$, use

$$\frac{\mathrm{d}b}{\mathrm{d}x} + \frac{\partial b}{\partial r}\frac{\partial r}{\partial x}.$$

Here

$$\frac{\partial b}{\partial r} = \frac{-v\left(c + \gamma(1-r)^2\sigma^2\right) + 2v(1-r)^2\gamma\sigma^2}{\left(c + \gamma(1-r)^2\sigma^2\right)^2} = \frac{-v\left(c - \gamma(1-r)^2\sigma^2\right)}{\left(c + \gamma(1-r)^2\sigma^2\right)^2}.$$

This is simplified using Equations E.8 and E.7,

$$\frac{\partial b}{\partial r} = \frac{-(1-r)v^2(v-g)}{c(v + rv - 2g)^2} \tag{E.11}$$

and is negative. The partial derivatives $\frac{\partial r}{\partial x}$ were calculated in the previous section and used here.

Now, consider the comparative static results with respect to v,

$$\frac{\partial b}{\partial v} = \frac{\mathrm{d}b}{\mathrm{d}v} + \frac{\partial b}{\partial r}\frac{\partial r}{\partial v}.$$

$\frac{\mathrm{d}b}{\mathrm{d}v} = \frac{1-r}{c+\gamma(1-r)^2\sigma^2}$ is positive; we just showed $\frac{\partial b}{\partial r}$ is negative and $\frac{\partial r}{\partial v}$ was shown to be negative in the previous section. Hence, $\frac{\partial b}{\partial v}$ is positive.

Next consider the comparative statics with respect to c.

$$\frac{\partial b}{\partial c} = \frac{\mathrm{d}b}{\mathrm{d}c} + \frac{\partial b}{\partial r}\frac{\partial r}{\partial c}.$$

$$\frac{\mathrm{d}b}{\mathrm{d}c} = \frac{-(1-r)v}{\left(c+\gamma(1-r)^2\sigma^2\right)^2} = \frac{-(1-r)v(v-g)^2}{c^2(v+rv-2g)^2}.$$

From the previous section,

$$\frac{\partial r}{\partial c} = \frac{-(1-r)(rv-g)}{c(v+rv-2g)}$$

and we have $\frac{\partial b}{\partial r}$ from above. Putting these together gives

$$\frac{\partial b}{\partial c} = \frac{-(1-r)v(v-g)^2}{c^2(v+rv-2g)^2} + \frac{(1-r)^2v^2(v-g)(rv-g)}{c^2(v+rv-2g)^3}$$

$$= \frac{(1-r)v(v-g)}{c^2(v+rv-2g)^3}B$$

where $B = -(v-g)(v+rv-2g) + v(1-r)(rv-g)$

$$= 2gv + 2rvg - 2g^2 - v^2 - r^2v^2 = -(v-g)^2 - (rv-g)^2 < 0.$$

Hence, $\frac{\partial b}{\partial c}$ is negative.

Similarly,

$$\frac{\partial b}{\partial g} = \frac{\mathrm{d}b}{\mathrm{d}g} + \frac{\partial b}{\partial r}\frac{\partial r}{\partial g} = 0 + \frac{\partial b}{\partial r}\frac{\partial r}{\partial g}$$

is negative since $\frac{\partial b}{\partial r} < 0$ from above and $\frac{\partial r}{\partial g} > 0$ from the previous section.

Also,

$$\frac{\partial b}{\partial \gamma} = \frac{\mathrm{d}b}{\mathrm{d}\gamma} + \frac{\partial b}{\partial r}\frac{\partial r}{\partial \gamma} = \frac{-(1-r)^3 v\sigma^2}{\left(c + \gamma(1-r)^2\sigma^2\right)^2} + \frac{\partial b}{\partial r}\frac{\partial r}{\partial \gamma}$$

is negative since $\frac{\partial b}{\partial r} < 0$ from above and $\frac{\partial r}{\partial \gamma} > 0$ from the previous section. The partial derivative with respect to σ^2 is analogous.

E.4.3 The expected profit of the breeder

In the partial-insurance model, following Equation 5.15 with $p = 0$, the expected profit to the breeder is

$$E\pi_B = \frac{(1-r)v(v + rv - 2g)}{2(c + \gamma(1-r)^2\sigma^2)} - K. \tag{E.12}$$

Substituting Equation E.7 into Equation E.12 gives

$$E\pi_{B1} = \frac{(1-r)v(v-g)}{2c} - K. \tag{E.13}$$

Note that the partial derivative $\frac{\partial E\pi_{B1}}{\partial r} = \frac{-v(v-g)}{2c}$ is negative and the partial derivative with respect to K is clearly negative.

The partial derivative with respect to v,

$$\frac{\partial E\pi_B}{\partial v} = \frac{\mathrm{d}E\pi_B}{\mathrm{d}v} + \frac{\partial E\pi_B}{\partial r}\frac{\partial r}{\partial v} = \frac{(1-r)(2v-g)}{2c} + \frac{\partial E\pi_B}{\partial r}\frac{\partial r}{\partial v}$$

is positive since $v > g$, $\frac{\partial E\pi_B}{\partial r} < 0$ from above and $\frac{\partial r}{\partial v} < 0$ from Section E.4.1.

Next, for g:

$$\frac{\partial E\pi_B}{\partial g} = \frac{\mathrm{d}E\pi_B}{\mathrm{d}g} + \frac{\partial E\pi_B}{\partial r}\frac{\partial r}{\partial g} = \frac{(1-r)(-v)}{2c} + \frac{\partial E\pi_B}{\partial r}\frac{\partial r}{\partial g}$$

is negative since $\frac{\partial E\pi_B}{\partial r} < 0$ from above and $\frac{\partial r}{\partial g} > 0$ from Section E.4.1.

Then, for c:

$$\frac{\partial E\pi_B}{\partial c} = \frac{\mathrm{d}E\pi_B}{\mathrm{d}c} + \frac{\partial E\pi_B}{\partial r}\frac{\partial r}{\partial c}$$

where

$$\frac{\mathrm{d}E\pi_B}{\mathrm{d}c} = \frac{-(1-r)v(v+rv-2g)}{2(c+\gamma(1-r)^2\sigma^2)^2}.$$

We use $\frac{\partial r}{\partial c}$ from Section E.4.1 and $\frac{\partial E\pi_B}{\partial r}$ from above. Hence,

$$\frac{\partial E\pi_B}{\partial c} = \frac{-(1-r)v(v+rv-2g)}{2(c+\gamma(1-r)^2\sigma^2)^2} + \frac{(1-r)(v-g)v(rv-g)}{2c^2(v+rv-2g)}$$

and we simplify this by using Equation E.7.

$$\begin{aligned}\frac{\partial E\pi_B}{\partial c} &= \frac{-(1-r)v(v-g)^2}{2c^2(v+rv-2g)} + \frac{(1-r)(v-g)v(rv-g)}{2c^2(v+rv-2g)} \\ &= \frac{-(1-r)^2(v-g)v^2}{2c^2(v+rv-2g)}.\end{aligned}$$

This is negative since $v > g$.

Finally,

$$\frac{\partial E\pi_B}{\partial \gamma} = \frac{\mathrm{d}E\Pi_B}{\mathrm{d}\gamma} + \frac{\partial E\pi_B}{\partial r}\frac{\partial r}{\partial \gamma}$$

is negative since $\frac{\partial E\pi_B}{\partial r} < 0$ from above, $\frac{\partial r}{\partial \gamma} > 0$ by Section E.4.1 and

$$\frac{\mathrm{d}E\Pi_B}{\mathrm{d}\gamma} = \frac{-(1-r)^3 v(v+rv-2g)\sigma^2}{2(c+\gamma(1-r)^2\sigma^2)^2} < 0.$$

The derivative with respect to σ^2 is analogous.

E.4.4 The license fee

Substituting from Equation E.7 into the expression for the optimal license fee which was given in Eqution 5.18 as

$$l = \frac{(1-r)^2 v^2}{2(c+\gamma(1-r)^2\sigma^2)}$$

gives

$$l = \frac{(1-r)^2 v^2 (v-g)}{2c(v+rv-2g)}.$$

First, we find $\frac{\partial l}{\partial r}$

$$\begin{aligned}\frac{\partial l}{\partial r} =& \frac{v^2(v-g)\left[-2(1-r)(v+rv-2g)-(1-r)^2 v\right]}{2c(v+rv-2g)^2} \\ & \frac{-(1-r)v^2(v-g)(3v+rv-4g)}{2c(v+rv-2g)^2.}\end{aligned}$$

We have $v > g$ and using Equation E.9, we have $rv > g$. Hence,

$$3v + rv - 4g = 3(v - g) + rv - g$$

is positive and thus $\frac{\partial l}{\partial r}$ is negative.

We now derive the comparative static results for l.

First, consider c.

$$\frac{\partial l}{\partial c} = \frac{\mathrm{d}l}{\mathrm{d}c} + \frac{\partial l}{\partial r}\frac{\partial r}{\partial c}.$$

In this expression,

$$\frac{\mathrm{d}l}{\mathrm{d}c} = \frac{-(1-r)^2 v^2 (v-g)}{2c^2(v + rv - 2g)}.$$

$\frac{\partial r}{\partial c}$ was found in Section E.4.1 and is negative, $\frac{\partial l}{\partial r}$ is negative; signing $\frac{\partial l}{\partial c}$ requires multiplying out and simplifying the expressions, giving

$$\begin{aligned}
\frac{\partial l}{\partial c} =& \frac{-(1-r)^2 v^2 (v-g)}{2c^2(v + rv - 2g)} + \frac{(rv-g)(1-r)^2 v^2 (v-g)(3v + rv - 4g)}{2c^2(v + rv - 2g)^3} \\
=& \frac{(1-r)^2 v^2 (v-g)}{2c^2(v + rv - 2g)^3}\left[-(v + rv - 2g)^2 + (rv - g)(3v + rv - 4g)\right] \\
=& \frac{(1-r)^2 v^2 (v-g)}{2c^2(v + rv - 2g)^3}\left[-v(v-g)(1-r)\right].
\end{aligned}$$

Hence, the partial derivative of l_1 with respect to c is negative.

Next, consider g.

$$\frac{\partial l}{\partial g} = \frac{\mathrm{d}l}{\mathrm{d}g} + \frac{\partial l}{\partial r}\frac{\partial r}{\partial g}.$$

In this expression,

$$\frac{\mathrm{d}l}{\mathrm{d}g} = \frac{(1-r)^2 v^2 (-v - rv + 2g + 2(v-g))}{2c(v + rv - 2g)^2}$$
$$= \frac{(1-r)^3 v^3}{2c(v + rv - 2g)^2} > 0.$$

$\frac{\partial r}{\partial g} > 0$ was found in Section E.4.1 and $\frac{\partial l}{\partial r} < 0$ was found above. Signing $\frac{\partial l}{\partial g}$ requires multiplying out and simplifying the expressions, giving

$$\frac{\partial l}{\partial g} = \frac{(1-r)^3 v^3}{2c(v + rv - 2g)^2} - \frac{(1-r)^3 v^3 (3v + rv - 4g)}{2c(v + rv - 2g)^3}$$
$$= \frac{(1-r)^3 v^3}{2c(v + rv - 2g)^3} [v + rv - 2g - 3v + 4g - rv]$$
$$= \frac{-(1-r)^3 v^3 (v-g)}{c(v + rv - 2g)^3}.$$

Hence, the partial derivative of l_1 with respect to g is negative.

Now we consider v.

$$\frac{\partial l}{\partial v} = \frac{\mathrm{d}l}{\mathrm{d}v} + \frac{\partial l}{\partial r}\frac{\partial r}{\partial v}.$$

In this expression,

$$\frac{\mathrm{d}l}{\mathrm{d}v} = \frac{(1-r)^2 \left[(3v^2 - 2vg)(v + rv - 2g) - (1+r)(v^3 - v^2 g)\right]}{2c(v + rv - 2g)^2}$$

$\frac{\partial r}{\partial v} < 0$ was found in Section E.4.1 and $\frac{\partial l}{\partial r} < 0$ was found above. Signing $\frac{\partial l}{\partial v}$ requires multiplying out and simplifying the expressions, giving

$$\frac{\partial l}{\partial v} = \frac{(1-r)^2 v}{2c(v+rv-2g)^2} B$$

where

$$\begin{aligned} B =& (3v-2g)(v+rv-2g) - (v^2-vg)(1+r) + \frac{v(1-r)g(3v+rv-4g)}{v+rv-2g} \\ =& 2rv^2 - 7gv + 4g^2 + 2v^2 - grv + \frac{4g^2rv - 4g^2v - gr^2v^2 - 2grv^2 + 3gv^2}{v+rv-2g} \\ =& \frac{-8g^3 - 2gr^2v^2 - 14grv^2 - 8gv^2 + 10g^2rv + 14g^2v + 2r^2v^3 + 4rv^3 + 2v^3}{v+rv-2g}. \end{aligned}$$

This expression is complex and we cannot sign it or the partial derivative of l_1 with respect to v. However, with a range of illustrative values, this derivative is positive which leads us to conjecture that it will most likely be positive. We have not proved this however; and indeed have found parameter values that lead to a negative derivative. These negative values are more likely to occur when the end-point royalty is much higher than they are currently in Australia or are likely to be in practice.

Finally,

$$\frac{\partial l}{\partial \gamma} = \frac{\mathrm{d}l}{\mathrm{d}\gamma} + \frac{\partial l}{\partial r}\frac{\partial r}{\partial \gamma}$$

is negative since $\frac{\partial l}{\partial r} < 0$ from above, $\frac{\partial r}{\partial \gamma} > 0$ by Section E.4.1 and

$$\frac{\partial l}{\partial \gamma} = \frac{-(1-r)^4 v^2 \sigma^4}{2(c + \gamma(1-r)^2\sigma^2)^2} < 0.$$

The derivative with respect to σ^2 is analogous.

E.5 Derivations of inequalities for Table 5.2

In this Section, we derive the inequalities between the results of the first-best and the partial-insurance model, given in Table 5.2. The superscript $*$ denotes a first-best outcome and the subscript 1 denotes the optimum in the partial-insurance model.

E.5.0.0.4 Row 1. By inspection $r_1 < 1$.

Now we show $r_1 > \frac{g}{v}$. The constrained optimisation in Section E.2 has solution $p_1 = 0$. Substituting this into condition 1), $g - rv - p \leq 0$, gives $r_1 \geq \frac{g}{v}$. If $r_1 = g/v$, then $\lambda = 0$ by condition 9), but condition 6) of the Kuhn Tucker optimisation then requires $\frac{\partial \mathscr{L}}{\partial r} = 0$, which in turn implies

$$\frac{\gamma(v-g)^2(1-r_1)\sigma^2}{(c + \gamma(1-r_1)^2\sigma^2)^2} = 0.$$

This fails and hence $r_1 v - g > 0$ or $r_1 > \frac{g}{v}$.

E.5.0.0.5 Row 3. The first-best quantity of seed b^* is given by Equation 5.10, and the partial-insurance quantity b_1 is given by setting $p_1 = 0$ in Equation 5.14. So,

$$b^* = \frac{v-g}{c} \text{ and } b_1 = \frac{(1-r_1)v}{c+\gamma(1-r_1)^2\sigma^2},$$

and the difference between them is

$$b^* - b_1 = \frac{v-g}{c} - \frac{v(1-r_1)}{c+\gamma(1-r_1)^2\sigma^2} = \frac{(v-g)c+\gamma(1-r_1)^2(v-g)\sigma^2-(1-r_1)vc}{c(c+\gamma(1-r_1)^2\sigma^2)}$$

The numerator of this expression is

$$(r_1v-g)c+\gamma(1-r_1)^2(v-g)\sigma^2$$

which is positive since $r_1v - g > 0$ from the discussion in Row 1. The denominator is also positive, so $b^* > b_1$: the optimal quantity of seed in the first-best model exceeds that of the partial-insurance model.

E.5.0.0.6 Row 4. The first-best license fee l^* and the optimal partial-insurance license fee l_1 are given by Equations 5.11 and 5.18 respectively with

$$l^* = \frac{-(v-g)^2}{2c} < 0, \; l_1 = \frac{(1-r_1)^2v^2}{2(c+\gamma(1-r_1)^2\sigma^2)} > 0 \text{ and } l^* < 0 < l_1.$$

E.5.0.0.7 Row 5. $Z = 0$ in both models by construction.

E.5.0.0.8 Row 6. The first-best royalty revenue RR^* is given in Equation 5.12, and the optimal partial-insurance model royalty revenue RR_1 is given by Equation 5.19. So

$$RR^* = \frac{v^2 - g^2}{2c} \text{ and } RR_1 = \frac{(1 - r_1^2)v^2}{2(c + \gamma(1 - r_1)^2\sigma^2)}$$

and the difference between them is

$$RR^* - RR_1 = \frac{v^2 - g^2}{2c} - \frac{(1 - r_1^2)v^2}{2(c + \gamma(1 - r_1)^2\sigma^2)}.$$

Simplifying, the numerator of this expression becomes

$$\begin{aligned}&(v^2 - g^2)(c + \gamma(1 - r_1)^2)\sigma^2 - (1 - r_1^2)v^2 c\\ =&\gamma(1 - r_1)^2(v^2 - g^2)\sigma^2 + c(r_1 v + g)(r_1 v - g).\end{aligned}$$

This is positive since $r_1 v - g > 0$. The denominator is also positive, so $RR^* - RR_1 > 0$: the optimal royalty revenue in the first-best model exceeds that of the partial-insurance model.

E.5.0.0.9 Row 7. Since this was the objective function of the optimization, the unconstrained maximum expected profit to the breeder (the first-best) must exceed the constrained optimum (the partial-insurance model). This can also be shown algebraically. The expected profit to the breeder in the first-best model was given in Equation 5.13, and in the partial-insurance model by Equation E.13. These are

$$E\pi_B^* = \frac{(v-g)^2}{2c} - K \ \text{ and } \ E\pi_{B1} = \frac{(1-r_1)v(v-g)}{2c} - K.$$

Hence,

$$E\pi_{B1} - E\pi_B^* = \frac{(v-g)(r_1 v - g)}{2c}$$

is positive since $r_1 v > g$: the expected profit to the breeder from the first-best case exceeds that in the partial-insurance case.

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