Economics in plant breeding: A case focusing on doubled haploid technology

Jo Pluske
The School of Agricultural and Resource Economics, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia

Abstract. With increasing choices in technologies, decision makers responsible for allocating resources in plant breeding programs can benefit from using bioeconomic models. This paper illustrates how such a model works when doubled haploid technology is incorporated into a hypothetical lupin breeding program. The results derived from the model are presented in terms of seed prices required to achieve an 8% return on research. Doubled haploid technology will be used in a breeding program providing the price for seed produced using this technology is less than the seed market price and the estimated price for seed produced using alternative technologies.

1. Introduction

Developments in plant breeding technologies have contributed to innovative new strategies for breeding programs. Dreher *et al.* (2000) detailed a marker-assisted selection program being conducted at the International Maize and Wheat Improvement Centre (CIMMYT), and assessed the cost effectiveness of using this technique over conventional methods. Investors in both the private and public plant breeding sectors will require similar studies if they are to effectively compete in, as Lindner (2002) emphasises, a 'plant breeding industry' driven by interactions between advances in scientific knowledge, changes in the legal framework for intellectual property rights, and competitive forces in the market.

This paper presents initial developments in modeling the costs and benefits of plant breeding programs. The example used to demonstrate this model is a hypothetical lupin breeding program, and was chosen to simplify the interpretation of the results. Moreover, data from actual breeding programs is generally confidential or confounded with issues that may be of a sensitive nature, and so is difficult to obtain. As the purpose of this paper is not to determine if a particular program is efficient but rather to demonstrate the workings of the model, the numerical example presented is applicable.

The two breeding techniques explored in the following example are conventional and doubled haploid. While doubled haploid technology has not yet been developed specifically for lupins, this work will provide an estimate of the benefits of furthering research into this technique. As explained by Davies and Howes (1999), in comparison to a conventional plant breeding program, doubled haploid technology speeds up the release of varieties by 3 to 5 years, improves efficiency of selection in breeding populations, and offers benefits in molecular marker-assisted selection. Conversely, the inclusion of doubled haploid technology in a program is likely to increase operating costs and, since the technology is new in terms of development, the probability that a successful variety will be produced on time may be lower initially and therefore indirectly increase costs. Even though a hypothetical example is explored in this paper by specifying lupins (narrow-leafed lupin, *Lupinus angustifolius*), realistic values for inputs and outputs can be used because it is a typical self-pollinating species, and so breeding methods are much the same as for wheat or barley.

Paper presented at the 47th Annual Conference of the Australian Agricultural and Resource Economics Society, Fremantle, Western Australia, 11-14 February 2003

Identifying the costs associated with a breeding program is relatively straight forward. Costs associated with operating, labour, capital, land and management can be identified and accounted for. However, the benefits arising from each program are numerous and may be realised, in part, by sectors in the value chain ranging from plant breeders to consumers. Estimating these benefits would require several detailed and difficult economic studies as emphasized by Pannell (1999) with regard to the estimation of on-farm benefits. Furthermore, as Kingwell (2001) notes grain is used on-farm as seed while according to Bertram (1998), Robertson (Chief Executive Office of the Western Australian Department of Agriculture) is reported to have said that there is a 'high level of *saved* seed on farms'. As farmers are able to save lupin seed and buy from sources other than registered seed suppliers, the acquisition of lupin seed can not be based on seed sales figures. It is therefore difficult to estimate returns to a breeding program.

A simple alternative to valuing all benefits is to work backwards by selecting an appropriate rate of return to research for each program. Alston *et al*. (2000) suggested that 8% is a fair rate of return to agricultural research, and this figure will be utilized in the example presented in this paper. The *estimated* price[1] of lupin seed required for all varieties produced in a program can then be determined from the model and compared to a *market* price[2].

If the *estimated* price is **less** than the *market* price of seed, it may be argued that it is economically effective to run the program. The lower the *estimated* price, the more efficient the program. If the *estimated* seed price is **greater** than the *market* price, decision makers would require a more complex economic analysis to decide if this difference can be justified in terms of public and private benefits obtained off-farm, or in terms of a contra for levies and taxes already paid by producers.

In the following sections, the methodology is outlined with a description of the economic model and associated parameters. Application of the model is then explained and the results and conclusions are presented and discussed in the final section of the paper.

2. Methodology

To estimate the benefits derived from a breeding program, an adoption measure for a variety needs to be established along with some estimation for the probability of producing an expected variety. Having determined the maximum regional tonnage applicable for the new variety, total tonnes of the variety required by farmers can be established. Revenue can then be calculated by multiplying total tonnes of the variety required by the net price for seed of that variety.

[1] For simplicity, in this numerical example all varieties within a program are assumed to realise the same price.

[2] Kingwell (2001) discussed four alternative charging mechanisms and expects that profit-based royalties would be the preferred charging mechanism. While it is acknowledged that in the case of lupins there is significant use of farmer-saved seed and hence this charging method may be appropriate if it is feasible, the purpose of this paper is not to determine how best to capture returns to research and development of seed, but rather to establish whether the seed is valued at a price that would ensure a required return on research and be acceptable to buyers.

2.1 Adoption of varieties

For the purpose of this paper, adoption of lupin varieties was derived from a method used by Gray *et al*. (2000). An initial adoption measure (M_{it}) for each lupin variety (*i*), for each year was found by dividing the area (ha) sown of each variety each year (H_{it}) by the maximum area (ha) sown of that variety during the adoption period (H_i^m).

$$M_{it} = \frac{H_{it}}{H_i^m} \tag{1}$$

This measure was then weighted (W_{it}) by dividing each initial adoption measure by the sum of all initial adoption measures for each variety over the period that variety was in use.

$$W_{it} = \frac{M_{it}}{\sum_{t=1}^{n} M_{it}} \tag{2}$$

The sum of the weighted initial adoption measures for all varieties in each year of use was calculated and then averaged to determine the average weighted adoption measure for lupins in each year of use ($\overline{W_t}$).

$$\overline{W}_t = \frac{\sum_{t=1}^{n} W_{it}}{n} \tag{3}$$

The average time period for a lupin variety to be in use was found to be eight years. Therefore the average weighted adoption measures were found using the same formula for each year up to the eighth year of use.

Finally the average weighted adoption measure was normalized so that $\sum_{t=1}^{n} \overline{W}_t = 1$ to give the adoption measure (A_t) needed to calculate how much seed would be required by farmers each year.

This adoption measure for any one year varied from 0.05 to 0.21 (Figure 1). Effectively the adoption model described above shows the proportion of area cropped each year to lupins and would account for farmers' attitudes towards risk and prices, their production decisions associated with climatic changes, crop rotations and other production factors as well as competition between varieties in use at the time. While it is acknowledged that farmers would have a different set of choices today than they did in 1983, as rates for individual varieties are relative to each other this factor is not an issue.

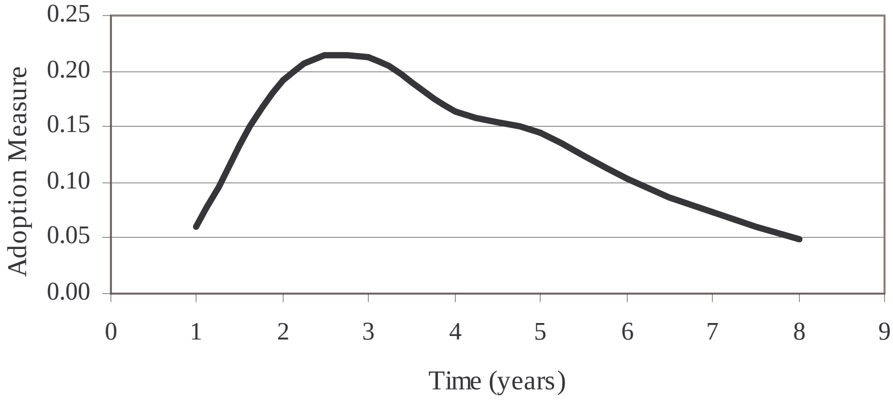

Figure 1. The adoption measure for a generic variety of lupins grown in Western Australia
(Figures were derived from data provided by Wallace Cowling & Ian Wilkinson, pers. comm.)

While it is acknowledged that as more varieties become available to producers the adoption rate is likely to be reduced and the time period for which a variety is in circulation is also likely to drop, the average rates as presented in Figure 1 will be used in the example presented in this paper. Also for additional simplicity, the adoption rate is assumed to be the same for all varieties and is constant over the 20 year period.

2.2 Probability of producing an expected variety

The probability (α) that a program will produce a variety that contains the desired traits within an expected time frame is contingent to a large degree upon the technology used, the level of testing conducted, and other decisions made in the breeding program. The technology used to breed a specific variety will in some incidences have a bearing on success. For example, with the use of doubled haploid technology the probability that a variety will contain a specified trait is likely to be greater than if the variety had been bred using only conventional technology. While many plant breeders claim to have a sixth sense in predicting the success of their programs, little theoretical work has been completed in this area with regard to lupins. It is beyond the scope of this paper to estimate these figures. Nevertheless, the parameter in the model is still important so should not be omitted. For the example presented in this paper ‘guesstimates’ will be used.

2.3 Total seed requirement

To determine the revenue generated from selling seed from a commercial variety produced from the breeding program, the total tonnes of seed (from that variety) required in the specified region in a particular year (S_i) must first be found by multiplying the adoption measure (A_t) by the maximum regional tonnage (T_i) by the probability of producing an expected variety (α).

$$S_i = A_t T_i \alpha \qquad (4)$$

The maximum regional tonnage refers to the seed required to crop the entire lupin growing area in that region for which a variety has been specifically developed. The maximum regional tonnage may well be different for different varieties as not all new varieties will be suitable for all geographical regions.

2.4 Revenue

2.4.1 Revenue per year

Revenue generated from selling seed from a particular variety in any one year (R_i) would then be the total seed requirement multiplied by the difference between the price at which the seed is sold (Ps_i) and the seed handling costs (Cs_i).

$$R_i = S_i\left(Ps_i - Cs_i\right) \tag{5}$$

2.4.2 Time to variety release

The number of varieties commercially produced in any one year will depend on the technology used. For example, the use of haploidy speeds up variety development because complete homozygocity can be obtained by converting haploids to doubled haploids within a few years (Anon., 2001) Normally, using conventional breeding techniques, many generations (five or more) of selfing are required to reach the same level of homozygocity (Anon, 2001). Barley and canola breeders using the pedigree method can take about 7 years to bring a cultivar to market, and using haploids reduces this time by two years (Anon, 2001).

For the purpose of this paper, in the conventional breeding program, time for the first variety to be released will be seven years with a variety released every second year thereafter. In the conventional plus doubled haploid program, time to release will be five years with a variety released every year thereafter

2.4.3 Total revenue

Total revenue (TR_i) for the breeding program for a particular year will be the sum of revenue generated from all varieties commercially available in that year.

$$TR_i = \sum R_i \tag{6}$$

2.4 Costs

Total cost for a particular year in the breeding program will be the sum of the total variable costs and the total testing costs associated with the particular technology or technologies, and the cost of releasing a new cultivar in each applicable year.

In any one year, variable costs associated with plant breeding (C_v) include items such as operating costs (field expenses and laboratory and greenhouse costs) (C_o), labour and associated costs (C_l), capital costs that are spread over an appropriate period of time (C_c) and management and other such costs (C_m). These costs will be program specific and will depend on management activities.

$$C_v = C_o + C_l + C_c + C_m \tag{7}$$

While Brennan *et al.* (1998) detailed parameters required for estimating the costs of testing a cultivar, in this model those costs are included in the variable costs (as explained above). However, there are additional testing procedures that may be done in certain years depending on the traits that are anticipated in a cultivar, and may include testing for seed quality, disease and pest resistance, herbicide tolerance and yield and agronomic characteristics.

$$C_t = C_s s + C_d d + C_h h + C_y y \tag{8}$$

where:

C_s, C_d, C_h, C_y	= test costs for seed quality, disease and pest resistance, herbicide tolerance and yield and agronomic characteristics respectively
s, d, h, y	= number of tests for seed quality, disease and pest resistance, herbicide tolerance, and for yield and agronomic characteristics respectively

The cost of releasing a new cultivar (C_r) is likely to be specific to each cultivar as there are numerous options available in both the private and public sectors for producing commercial seed. For simplicity, the cost of releasing a new variety in the examples presented in this paper is based on a figure of $60, 000 as used by Brennan *et al.* (1998) and will be incurred in the year before release.

Total costs (TC) for any one year of the breeding program will be the variable costs plus the testing costs plus the cost of releasing a new cultivar if that cost is incurred in that year.

$$TC = C_v + C_t + C_r \tag{9}$$

2.5 Price of Seed

The net present value over a specified number of years is calculated by subtracting the total costs for the breeding program in any one year from the total revenue generated in that same year for each and every year within the specified period and dividing by an appropriate discount rate (r).

$$NPV_n = \sum_{t=1}^{n} \frac{(TR - TC)_t}{(1+r)^t} \tag{10}$$

By setting the discount rate to 8% and simply assuming that the price of seed for all varieties is the same, the parameter in the model for seed price can be adjusted until the NPV is just greater than zero. Alternatively, as the model has the facility to allow each variety to have its own price, specific prices for specific varieties can be put into the model and then similarly adjusted until the NPV just exceeds zero. This means that a mix of ‘expensive’ and ‘cheap’ varieties can be produced in a program in a proportion that keeps the breeding program earning a suitable return.

3. Application of the model to a hypothetical breeding program

3.1 Scenarios

The model can be adapted to put in any number of scenarios but for illustration purposes, five scenarios are presented (Table 1). In the first scenario, the probability that all four varieties will be released as expected from a conventional program is set at 60% with the potential maximum regional tonnage including the whole lupin growing region in Western Australia[3]. It is assumed in scenario 2 that the varieties produced from that program will be suitable for only half the lupin growing region in Western Australia. In scenario 3, with the inclusion of doubled haploid technology, the probability of successfully producing a variety is reduced to 50% for the first four varieties while the researchers familiarise themselves with the new technology. Again, the potential maximum regional tonnage of each variety is reduced because it is assumed that DH technology is used to produce region-specific varieties that may not be suitable for all lupin producing regions. In the fourth scenario there is no adjustment to the probability of producing an expected variety as the full benefits of the technology are realised immediately. In the final scenario it is assumed that varieties produced will be for very specific uses so reducing the potential maximum regional tonnage is reduced to only 1/8 of the State's lupin growing area.

Table 1. The probability of a program successfully producing a variety and the potential maximum regional tonnage for each variety given that the technology is either conventional only or a mix with DH technology.

Scenario	Probability of producing varieties 1-4 (%)	Probability of producing varieties 5-8 (%)	Potential maximum regional tonnage (t)
1 (conventional)	60	na	80,000
2 (conventional)	60	na	40,000
3 (convent. & DH)	50	60	40,000
4 (convent. & DH)	60	60	40,000
5 (convent. & DH)	60	60	10,000

3.2 Breeding program

A breeding program for a specified time period was constructed so that a realistic economic model could be developed and sensible costs and benefits could be identified. The hypothetical lupin breeding program will run over a 20 year period. In the conventional breeding program, it is anticipated that one new variety would be released in each of years 10, 12, 15 and 17. If DH technology was incorporated into this program a new variety would be released in each of years 5, 7, 9, 11, 13, 15, 17 and 19.

[3] The total requirement for Western Australian lupin production is conservatively approximated to be 80,000 t for Scenario 1. Production in WA in 1999-2000 was 1.1 m ha (ABS, 2001) but has been as low as 700,000 ha during the last 10 years.

3.3 The market price for lupin seed

The *market* price of lupin seed can be estimated by considering all of the sources from which farmers can obtain seed. So while the *certified* lupin seed price varies between $350 to $650/t (Farm Budget Guide, 2002), farmers have only to buy this seed once as they can use their own source of seed for future crops. Alternatively, farmers can purchase seed from other farmers who have already grown the seed previously. In both cases the cost of 'saved' seed will be equivalent to at least the opportunity cost of selling the lupins in the commodity markets. Assuming that the majority of farmers use bulked-up seed rather than certified seed and given a net price for commercial lupin seed of between $180 and $200/t,[4] a reasonable *market* price for lupin seed is assumed to be $200/t.

3.4 Costs

The total variable costs pertaining to each program are based on reasonable estimates for operating labour, capital, management and testing costs associated with maintaining each program. To grasp an idea of the difference in potential investment between the two strategies, the total cost of the conventional program is estimated to be $5.92 million while adding doubled haploid technology would increase the total cost to $10.12 million (Table 2).

Table 2. The costs of various activities including the total costs for the conventional and conventional plus doubled haploid breeding programs.

Costs	*Conventional ($ million)*	*Conventional + DH ($ million)*
Operating	0.50	0.70
DH Laboratory	0.00	0.40
Labour	3.16	5.08
Capital	0.34	0.60
Management	0.50	0.50
Testing	1.42	2.84
Total	5.92	10.12

4. Results and Discussion

Table 3 shows the results derived from the model given the various scenarios as explained in Table 1. Results for Scenarios 1 to 4 all indicate that farmers would be willing to pay the *estimated* prices for lupin seed as all are below the *market* seed price. This finding suggests that programs based on each of these scenarios would be economically justified.

[4] These costs are based on a pool price of between $190 and $210/t, rail/road freight at between $5 and $20/t (Farm Budget Guide 2002), and a nominal amount for farm to receival-point freight.

.

Furthermore, in basing their decision criteria solely on results from this simple model, decision makers would favour using conventional technology to produce varieties suitable for the entire lupin growing region in Western Australia (scenario 1) over varieties produced by a mix of conventional and DH technologies that were developed for specific regions (scenarios 3&4) (Table 3). However, if the aim of a program was to produce region-specific varieties, the option of introducing doubled haploid technology into the program (Scenarios 2 & 3) could be justified if a conventional technology program (Scenario 2) was the alternative option.

As is predictable, if the probability of producing a variety as expected is reduced (Scenario 3) then returns will be smaller when compared to a program with the probability of producing an expected variety unadjusted (Scenario 4).

If the aim of introducing doubled haploid technology was to develop a program that produced only very specialized varieties for small, specific regions in WA then, based on the assumptions for scenario 5, the price that producers would have to be willing to pay ($320/t) would be significantly greater than the assumed *market* price ($200/t). Hence decision makers would have to consider off-farm benefits to justify such a breeding program or have some assurance that the varieties had characteristics that would warrant this higher value and hence farmers would be willing to pay for it.

Table 3. The *estimated* price of lupin seed that would be required to realise an 8% return on research given the assumptions specified in each of the five scenarios.

Scenario	Estimated seed price* ($/t)
1	75
2	150
3	90
4	80
5	320

* Allowing for handling costs - 20% of seed price/t

5. Conclusion and Further Work

While this model is able to quickly generate results that provide some indication as to the values that farmers would have to be willing to pay or at least value seed generated from a breeding program, there has been no research known to this author on how producers actually value seed. Further work proposed in this area aimed at finding farmers' values of seed and how they adopt varieties according to traits would not only enable verification of the results generated from this model, but would mean these values could be directly placed into the model. This in turn would mean that returns to research could then be generated for specific programs. Even so, care is still needed that so that benefits such as those extended from knowledge and use of doubled haploid technology to other programs that use for example molecular marker technology are accounted for.

It is also acknowledged that this model incorporates biological, adoption and economic information that must be specific to a particular program for it to generate any reasonable indications as to net value of that program to decision makers and or society. Understanding the biology and interpreting it sufficiently well to enable it to be quantified is also an avenue for further research. In the case of this model, this is especially relevant to the parameter 'probability of producing an expected variety'.

Plant breeders must produce varieties that will be adopted by producers, meet the requirements of processors and satisfy end-users. In so doing, even public breeding programs are now being faced with the prospect of having to achieve cost-recovery within a competitive environment. The model presented in this paper provides a tool to help these plant breeders and decision makers achieve this goal.

Acknowledgements

Initial development of the model referred to in this paper was funded by the Council of Grain Grower Organisations Ltd. The author thanks Wallace Cowling for his help on earlier development of this topic and Ben White for useful comments.

References

ABS (2001). Agricultural commodities 2000, Australian Bureau of Statistics 7121.0. Retrieved 26 May 2002, from the World Wide Web:http://www.abs.gov.au.

Alston, J.M., Marra, M.C., Pardey, P.G., Wyatt, T.J., (2000). Research returns redux: a meta-analysis of the returns to agricultural R&D. *Australian Journal of Agricultural and Resource Economics* **44**, 185-215.

Anon., (2001). 'Haploids'. University of Guelph, retrieved 6 June, 2001, from http://www.oac.uoguelph.ca/CRSC/biotech/haploid/haploids.htm

Bertram, L. (1998). Crop improvement royalties for grain. Retrieved 11 October 2002 from the World Wide Web:http: //www.agric.wa.gov.au.

Brennan, J.P., Kingwell, R.S., Thomson, F.M. and Cullis, B.R. (1998). Optimal strategies for regional cultivar testing. *Australian Journal of Agricultural and Resource Economics* **42**, 209-226.

Davies, P., Howes, N. (1999). Doubled haploids in Australian crop breeding: current use and potential developments, In P Langridge, A Barr, G Auricht, G Collins, A Granger, D Handford, J. Paull (eds.) *Proceedings of the 11th Australian Plant Breeding Conference,* Volume 2. The CRC for Molecular Plant Breeding: Adelaide pp. 81-82.

Dreher, K., Morris, M., Khairallah, M., Ribaut, J-M., Pandey, S. and Srinivasan, G. (2000). Is Marker-assisted selection cost-effective compared to conventional plant breeding methods? The case of quality protein maize. Paper presented at the 4th Annual Conference of the International Consortium on agricultural Biotechnology Research (ICABR), Revello, 24-28 August.

Farm Budget Guide (2002) Cropping. Farm Weekly. Retrieved 26 May 2002 from the World Wide Web: http://budget.farmonline.com.au

Gray, R.S., Malla, S. and Phillips, P. (2000). Gains to yield increasing research in the evolving Canadian canola research industry. In W. Lesser (ed.) *Transitions in Agbiotech: Economics of Strategy and Policy*. Food Marketing Policy Centre, University of Connecticut pp501-519.

Kingwell, R. (2001). Charging for the use of plant varieties. *The Australian Journal of Agricultural and Resource Economics* **45**: 291-305.

Lindner, B. (2002). Access by plant breeders to collectively funded research and other services in an increasingly privatized world. In J.A. McComb (ed.), *Plant Breeding for the 11th Millennium, Proceedings of the12th Australian Plant Breeding Conference,* Perth, September. pp 604-608.

Pannell, DJ (1999). On the estimation of on-farm benefits of agricultural research. *Agricultural Systems* **61**: 123-143.