The Diffusion of Canola in Australian Broadacre Cropping (1975-2001)

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Canola was first grown in Australia in 1970, but its adoption remained stagnant until the early 1990s when the rate of adoption increased dramatically. This paper seeks to explain the late and rapid diffusion of canola into the Australian broadacre cropping rotation, and account for the observed interstate variation in canola diffusion patterns. Results from logistic diffusion models suggest that variation in the profitability of crops was less important than is commonly believed. The estimated diffusion models suggest that the causal determinants of canola's decade-long expansion were (1) the fall in the wool price, which initiated a transition from crop-pasture to continuous-cropping rotations and (2) the development of new canola varieties more suitable for various Australian conditions.

Key words: canola, diffusion, Australia.

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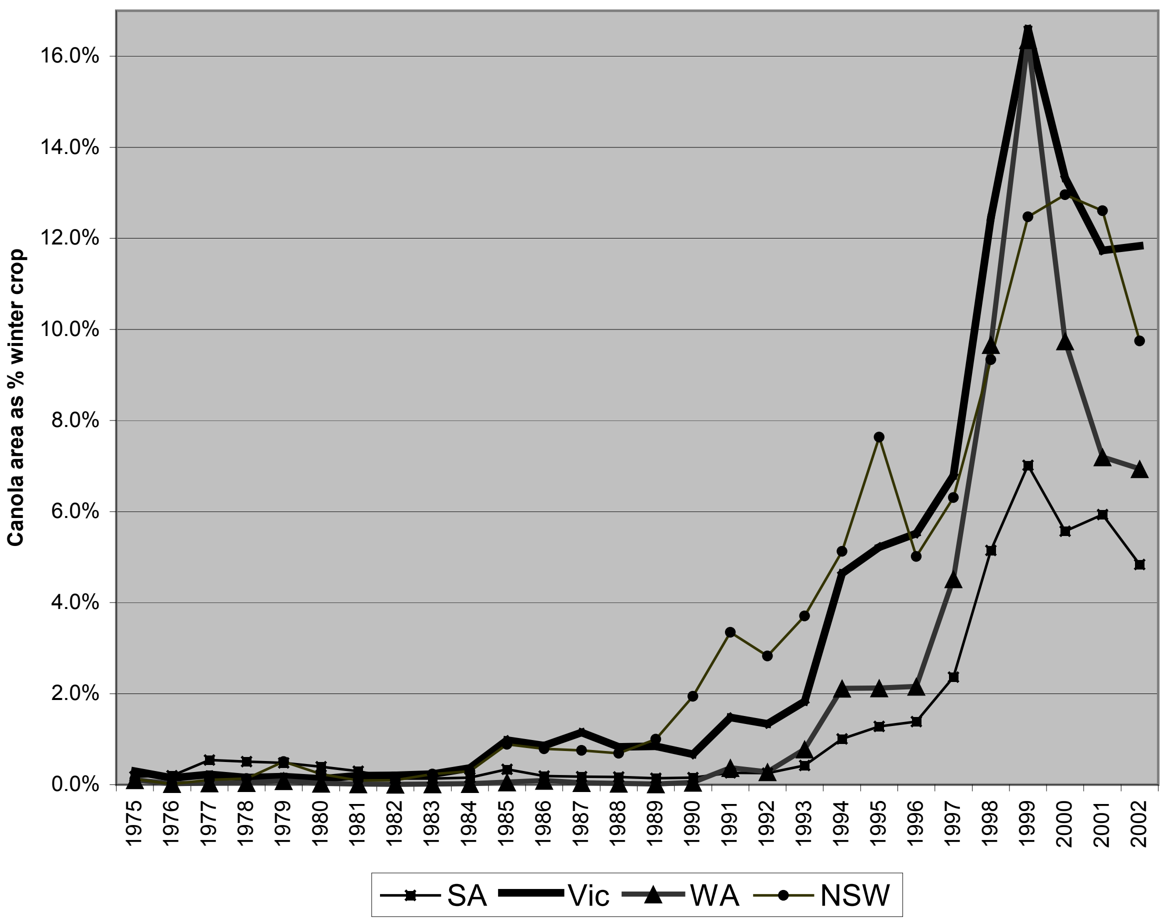
1. Background of Canola growing in Australia

Canola is currently the third most valuable grain crop in Australia behind only wheat and barley. It is a winter break-crop that forms part of a cereal-oilseed-pulse-pasture rotation in temperate southern Australia. Between 1990 and 1999, national area allocation to canola rose from 72,900 ha to 1,917,000 ha. By many measures, the decade-long annualised rate of growth of 44% in canola acreage was the most dramatic sustained grain crop expansion in Australia's agricultural history. Figure 1.1 plots the canola area expansion since 1975:

FIGURE 1.1: CANOLA AREA AS A PROPORTION OF WINTER GRAIN CROP BY STATE, 1975 TO 2002



Source: ABARE, *Oilseed Statistics*

The early rapeseed varieties first grown in Australia in the 1970s were of Canadian origin but they were of poor quality by today's standards. Their oils had the undesirable properties of being high in erucic acid (up to 40%, compared to 0.5% now), and their meals were very high in glucosinolates (up to 120 moles/g, compared to less than 20 now). In order to take advantage of rapeseed's latent nutritional applications, Canadian industry developed varieties with improved edibility. The name "canola" - a creative merger of the words Canada and oil - first appeared in 1979 to denote varieties of rapeseed that have an erucic acid level below 2% and less than 40 moles/g of total glucosinolates (Salisbury & Potter 1999). Unfortunately, when grown in Australian conditions, the early "double low" Canadian canola[1] varieties exhibited extremely low yields as a result of inadequate rainfall and susceptibility to weeds and disease. Consequently, the early varieties were not popular with Australian farmers.

The desire to develop improved Australian varieties led to specific public and private breeding and trialling programs in Western Australia, New South Wales, Victoria and South Australia.[2] Since the first canola-quality Brassica Napus was released in Australia 1980, there has been a constant stream of innovations in varieties to counteract weeds, pests and disease. The improved yield reliability of new location-adapted canola varieties, along with consistent high relative prices, increased the profitability of canola for grain growers in the temperate wheat-growing areas of southern Australia. Canola fits easily into the existing broadacre production system because only limited additional capital expenditure is necessary to support canola production. Furthermore, in most regions, sowing and harvesting times of canola are earlier than for cereals, which spreads management time and use of existing machinery. While canola-specific fixed costs are relatively low, the variable costs involved with canola are significantly higher than for cereals or pulse break-crops. Reluctance to grow canola before

[1] Canola refers to varieties of rapeseed which are edible. That is, those varieties of rapeseed with levels of glucosinolates and erucic acid below a specified threshold level. Practically all rapeseed grown in Australia is canola-quality.

[2] These are the four key Australian canola-growing states. No other state has produced more than 10kT in any given year.

the 1990s is likely to have been caused in part by canola being viewed as a high-cost, high-risk cropping option.

Canola has two significant rotational benefits. First, as a broadleaf crop, canola is not a host for major soil-borne pathogens that affect cereal crops and thus serves as a "break". Second, it has been shown that decaying canola roots release biocidal compounds in a process which "biofumigates" fungal inoculum in the soil (Norton, 2003). The rotational benefit of canola on subsequent crops appears to be even greater than the rotational benefits provided by nitrogen-fixing legume break crops (Kirkegaard, 1994). To quantify the yield benefit of growing wheat after canola in comparison with alternative land uses, the following results were obtained from 226 observations in Western Victoria over a three year period.

TABLE 2.1 WHEAT YIELDS FOLLOWING VARIOUS ALTERNATIVE LAND USES

Previous Crop	Subsequent Wheat Yield (t/ha)
Wheat	2.5
Canola	**3.8**
Pasture	2.6
Pulse	3.0
Fallow	3.1

Source: Norton (1999)

Canola is the first grain crop to have a genetically modified (GM) variety approved for commercial production by the OGTR. Consequently, there has been a great deal of forecasting of the impact that GM may have on the canola industry in the context of predicted acreage (e.g. Foster 2002), trade (e.g. Phillips & Isaac, 1999) and plant research (e.g. Gray & Stavoula, 2001). As a (now) major crop in the Australian broadacre rotation, canola is subject to forecasting by the Australian Bureau of Agricultural and Resource Economics (ABARE). Short-term forecasts for canola planting and yield are provided in quarterly "Australian Crop Reports". Medium- and long-term forecasting for Australian canola production, price, consumption and trade is conducted using the OECD "Aglink" partial equilibrium model for world commodity trade (see Foster 2002). While forecasting canola indicators is a valuable undertaking, too little attention has been paid to how canola came to arrive in its position as an important part of the broadacre rotation and perhaps extant forecasting models ignore some causal determinants which led to the dramatic expansion of canola acreage. Since history is the economist's laboratory, understanding past determinants of canola adoption in Australia may help in understanding current and future influences on canola planting decisions. One of the main aims of this paper, therefore, is to provide an historical perspective of conventional canola adoption to complement forecasting models and the burgeoning literature being devoted to the economics of GM canola. In order to structure the economic history of canola in Australia, logistic diffusion models provide the conceptual framework within which the two key questions of this study are addressed: (1) what factors drove overall Australian canola adoption, and (2) what were the sources of interstate variation in observed canola diffusion paths.

A number of explanations have been put forward to account for the dramatic expansion of canola area across Australia although, to the authors' knowledge, none have been statistically tested. There are three main hypotheses that will be assessed in this study. The first proposition is that farmers began to grow canola because it became profitable relative to traditional crops in the early 1990s. The second is that the fall in wool prices after 1991 induced a transition away from crop-pasture rotations towards continuous-cropping practices, and increased demand for non-cereal break crops. The third hypothesis is that the development and marketing of new varieties suitable for varying Australian conditions increased the reliability for farmers in growing canola.

In respect of explaining the observed interstate variation in canola diffusion patterns it is hypothesised that profitability considerations (broadly conceived) will be most significant, consistent with Griliches (1957) seminal findings on the diffusion of hybrid corn across the United States. The question in this case, however, is what are the most appropriate profitability indicators, and how do these vary in importance by state?

2. Measuring Canola Diffusion and its Determinants

Most previous diffusion studies have used as the dependent variable a cumulative measure of the percent of the potential adopting group (PAG) that have adopted a given innovation, where each individual observation is attributed with a binary score of either zero or one.[3] Given that there is no satisfactory data on the number of grain cropping farms or farmers that grow canola, an alternative measure of adoption was sought, namely the aggregate canola acreage.[4] Although area allocation is potentially a more volatile measure than the cumulative number of canola-growing farms, it may be argued that total area planted to canola better captures the aggregate intensity of adoption and, in this respect, may provide a more accurate reflection of the diffusion process than alternative binary measures. By itself, the absolute area planted to canola would be an inadequate measure of the adoption level as it would not reflect canola's relative standing in the overall crop portfolio (the analogue of the PAG in conventional studies). The choice of adoption metric is given by canola as a proportion of the total winter grain crop area allocation (winter cereals, canola and pulses):

$$(1.1) \qquad A_t = \frac{\textbf{Area Allocated to Canola in state "s" in year t}}{\textbf{Total Winter Grain Crop Area in state "s" in year t}}$$

[3] It should be noted that while the concepts of diffusion and adoption are often used interchangeably, they are conceptually distinct. Adoption refers to a *binary* decision at the unit or farm-level and in aggregate terms adoption is measured in *levels*, whereas diffusion is a rate of change in the level of adoption of the innovation across the potential adoption group (PAG). In the context of this paper, individual farmers adopt canola, and as they adopt - with varying levels of intensity - canola is diffused into the aggregate cropping portfolio.

[4] Production would be an inappropriate metric as it does not readily allow for comparison with other crops. Also, because of yield and seasonal variability, production does not adequately capture the allocation decision by the

Explanatory Variables

Relative Profitability

There have been a variety of profitability variables that have been used in empirical diffusion studies to explain inter-firm or inter-regional differences in adoption levels, although aggregating to the state-level does limit the types of variables available. The ideal profitability variable for a crop would be a time series measure of expected gross profit margins (revenue minus variable costs) of canola vis-à-vis alternative farming enterprises. In the absence of accessible data of this nature, output prices are used as proxies for the relative profitability of alternative broadacre enterprises.

Clearly, caution must be exercised when adopting relative output price as a proxy for profitability. Given canola's more demanding input requirements (e.g. windrowing, extra spraying and more expensive sowing seed) the price margin between canola and wheat, for example, as indicated by output price will be proportionately greater than the profit margin inclusive of input costs. The industry standard national indicator price for canola is the price per tonne of seed with 40% oil content. Time series (1975-2001) output prices for the major alternative farming enterprises have been obtained in order to gauge canola's relative profitability. Returns for wheat are measured in terms of the unit grade national average price. The barley price used is the price for malting barley as it is the quality to which most farmers aim, rather than lower-grade feed grain barley. A national indicator price for lupins is included because it is the dominant pulse in Victoria, Western Australia and South Australia. Time series data for the price per kilogram of lamb, beef, and greasy wool were also obtained for possible inclusion in the vector of profitability variables.

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farmer.

When price is used as the profitability proxy, what matters is not the price in the year of planting, but rather farmers' price expectations. In order to model the formation of price expectations (which are unobservable), a Nerlovian framework is adopted, in which the most important determinants of price expectations are a number of past seasons' prices. While this construction of expectations is elegant and simple, it should be acknowledged that past prices are not the only determinants of price expectations. This is particularly relevant in the case of canola where, due to aggressive marketing and information flows, farmers are made aware of the expanding range of applications for canola oil, which affects their perception of expected demand. As a result, price expectations for canola may be determined less by past prices than for alternative crops. Nevertheless, for the purpose of a proxy for profitability, past prices will suffice as the determinants of price expectations.

An important consideration when constructing price expectations is the specification of the lag. Among the class of distributed lag models, the polynomial distributed lag (PDL) was chosen on the basis of its relative ease of estimation and interpretation, and also because it provides for a flexible form for the lag distributions. The construction of price ratios is undertaken because it is assumed that farmers respond to movements in relative rather than absolute output prices. The use of price ratios has the added benefit of reducing by one the number of profitability coefficients to be estimated. Given the perception that canola was rapidly introduced due to depressed markets in traditional crops, inclusion of these relative price variables will be useful in assessing the validity of this view.

Export Orientation

It may be tempting to include some proxy measure for the export orientation of canola after 1993 since the majority of canola output was exported after this date. However, bulk handlers were long aware of canola's potential export market and there was no substantive change in the international market for canola that would have induced them to begin selling overseas.

The transition towards export was simply a result of the expansion of production which saturated domestic demand and crushing capacity and provided enough volume to justify the fixed costs of breaking into international markets.

Canola Varieties

It is hypothesised that one of the major stimuli for canola diffusion was the breeding, trialling and marketing of varieties that overcame pest, disease, and weed impediments, which enabled farmers to take advantage of persistently high canola price margins over traditional crops and canola's rotational benefits. The introduction of canola was not a once-and-for-all crop innovation that could be adopted all throughout Australia. In order to take advantage of canola's latent profitability, public and private breeding organisations undertook the costly process of developing region-specific canola varieties. With the assistance of state-based extension agencies, a data set was compiled cataloguing the properties of major Australian-bred canola varieties. (See Appendix Table A1). As with the question regarding which output prices were of economic significance, an assessment must be made with respect to which varietal characteristics were significant in the diffusion process. On the basis of preliminary regression analysis, the key variables appear to be measures for weed and disease management. These attributes were proxied respectively by a dummy variable for the introduction of conventionally-bred triazine tolerant varieties, and a scalar (0-10) variable measuring the degree of protection offered against blackleg (the primary Brassica disease). Other potential varietal indicators included time to maturity, and oil and protein content, however, none of these variables were statistically significant. It should be noted that this model treats the development of improved varieties as being exogenously determined.

Farm Portfolios

In order to capture the heterogeneity of available cropping land across states the composition of each state's farming portfolio is considered. Inclusion of relative enterprise intensities may serve as a proxy for the overall soil type, thereby helping control for one of the variables which aggregate crop analyses are often criticised for omitting. Enterprises included in the dynamic model are time series for wheat intensity (i.e. wheat as a proportion of total winter grain crop), barley intensity, pulse intensity, the size of the state sheep flock and the size of the state cattle herd.

Location

One of Griliches' (1957) key findings was that the slow diffusion of hybrid corn in the Southern US states was in fact *not* significantly caused by location, or what Blainey (1966) might call the Australian "tyranny of distance". Griliches' conclusion was in stark contrast to the view of rural sociologists of the day who argued that the tardiness of Southern farmers in adopting new varieties and technology was significantly caused by their distance from key infrastructure. Instinctively, the sociological view may appear credible in the case of Australian canola diffusion given the interstate variation in farmers' proximity to coastal harbour ports, crushing plants and bulk handling facilities. However, this view only bears economic scrutiny to the extent that transport costs involved with growing canola were greater than for existing crops. Since canola can be deposited at the same bulk handling facilities as for cereals and pulses, there is little reason to believe that distance *per se* is a cause of the late diffusion of canola.

Extension Activity

While the new canola varieties are assumed to be exogenously created in this model, it may nevertheless be desirable to attempt to include a variable to capture the relative intensity of the research effort in each state. The optimal measure would be dollar expenditure in each state on canola-specific research and trialling, relative to spending on other crop variety research. Obtaining such data is an undertaking beyond the scope of this study, so research intensity was proxied by the timing of the introduction of new varieties developed by each state. Unfortunately, however, since there is no way to weight each variety as a proportion of canola grown in each state, or otherwise measure each new variety's relative importance as an innovation, inclusion of a binary variable for the timing of new varieties from each state did not yield reliable results.

3. Logistic Diffusion Models

The seminal study by Griliches (1957) on the diffusion of hybrid corn popularised the use of a logistic function to formally describe the technology diffusion process. Griliches' study provides evidence that the diffusion pattern of a new crop variety is linked to economic variables, specifically relative profitability. That is, the fraction of acreage ultimately planted to a new variety depends on expectations of profits to be realised from the change. The rate of change in canola area allocation is a function of the current adoption level (A_t – the area of canola as a proportion of total winter grain crop area), the ultimate equilibrium level of canola allocation (K), and time (t):

$$\frac{dA_t}{dt} = f(A_t, K, t) \qquad (3.1)$$

The logistic diffusion model assumes that the rate of diffusion (i.e. the rate of change in canola area) is directly proportional to the difference between the ceiling (K) and the current adoption level (A_t), where g is the coefficient of diffusion and captures the degree of internal influence or "contagion" among canola adopters (Mahajan & Peterson 1985):

$$\frac{dA_t}{dt} = gA_t\left[K - A_t\right] \qquad (3.2)$$

It is convenient to define C_t to be the adoption rate as a proportion of the ceiling ($C_t = A_t /K$) and to re-scale the constant, b = g K, to obtain

(3.3) $$\frac{dC_t}{dt} = bC_t\left[1-C_t\right]$$

Integrating this differential equation yields a standard logistic function:

(3.4) $$C_t = \frac{1}{(1+e^{(-a-bt)})}$$

where *a* is the constant of integration. This model is rendered amenable to data analysis by having *a* be a stochastic function of time-variant explanatory variables X_i rather than a constant:

(3.5) $$a = \beta_0 + \beta_1 X_1 + \ldots + \beta_n X_n + \varepsilon$$

A logit transformation yields an equation that can be estimated linearly. This model is estimated for each canola-growing state and the results are presented in Table 4.1.

(3.6) $$\text{logit}(C_t) = \ln\left[\frac{C_t}{1-C_t}\right] = bt + \beta_0 + \beta_1 X_1 + \ldots + \beta_n X_n + \varepsilon_t$$

To compute C_t, we must determine the ceiling K for each state. Since canola will never make up 100% of the winter crop area, it is not possible to assign a unitary ceiling for canola allocation. The Pearl-Read method of estimating a non-unitary numerator on a symmetrical logistic function was therefore applied (Pardey 1978).

TABLE 3.1 PEARL-READ ESTIMATED CEILING PARAMETERS FOR EACH AUSTRALIAN CANOLA-GROWING STATE AS A PROPORTION OF TOTAL WINTER GRAIN CROP

SA	Vic	WA	NSW
13	20	21	16

4. Results

TABLE 4.1 STATE LEVEL LOGISTIC DIFFUSION MODELS
(p values in italics)

	SA		Vic		WA		NSW	
Time Trend	0.250	*0.08*	0.560	*0.01*	0.306	*0.01*	0.648	*0.01*
C	-0.120	*0.61*	0.896	*0.01*	-0.279	*0.03*	1.396	*0.01*
Triazine Tolerance	0.078	*0.08*	0.033	*0.01*	0.034	*0.01*	0.020	0.68
Blackleg Rating	0.049	*0.03*	0.010	*0.14*	-0.012	*0.11*	-0.120	*0.01*
Sheep Flock	-0.006	*0.01*	-0.005	*0.01*	-0.005	*0.42*	-0.003	0.25
Wheat Intensity	-0.697	*0.01*	0.003	*0.79*	0.308	*0.01*	-1.731	*0.01*
Barley Intensity	-1.047	*0.03*	-0.237	*0.01*	0.263	*0.14*	-2.391	0.03
Pulse Intensity	0.951	*0.32*	0.449	*0.01*	1.429	*0.01*	-1.520	0.06
Pwheat/Pcanola	0.352	*0.14*	-0.001	*0.03*	0.044	*0.25*	-0.032	0.35
Pwool/Pcanola	-0.059	*0.08*	-0.025	*0.01*	-0.026	*0.01*	-0.076	0.25
AR(1) coefficient	-0.905	*0.01*	-0.886	*0.01*	0.308	*0.01*	-0.933	*0.01*
Adjusted R^2	0.98		0.95		0.98		0.91	

The apparent conformability of the data as evidenced by the R^2 values, is largely due to the logistic transformation which has the effect of smoothing the fluctuations in the absolute values of the dependent variable (canola area as proportion of winter grain crop area). Due to different scaling of the explanatory variables, what is important for interpretation is not the magnitude of the coefficient estimates, but rather their signs and significance.

National Canola Diffusion

In aggregate terms, the strength of various hypotheses for the determinants Australian canola diffusion can be explained with reference to a number of key explanatory variables. The first hypothesis - that farmers began to grow canola because it became profitable relative to traditional crops in the early 1990s – does not appear to bear close scrutiny. On the basis of observable relative price movements, and the insigificant and inconsistently signed coefficients on the relative wheat price variable, it may be concluded that the explanation for canola's decade-long expansion is not necessarily to be found in movements of relative crop profitability. That is not to say that canola's consistent margin over wheat and other winter crops was unimportant, because it was that margin which provided the underlying incentive for farmers to consider adopting canola. However, it was not necessarily the *change* in this margin relative to other crops that drove the diffusion process. On the basis of results from the pooled logistic diffusion model, more likely candidates for causal determinants of Australian canola diffusion are the fall in the wool price in the first half of the 1990s and the development of improved canola varieties.

The estimated national coefficients on the relative wool price and size of the state sheep flock provide support for the hypothesis that the dramatic fall in the price of wool after 1991 initiated a net transition from crop-pasture to continuous-cropping rotations by broadacre farmers.[5] This transition could be interpreted as a movement away from diversification between enterprises (crops and livestock) to an effort to diversify within an enterprise (cropping only). With the rise of continuous-cropping, increasing numbers of farmers began to demand an alternative cereal break to pasture, and so conditions were ripe for a non-cereal crop that could deliver a high margin, yet fit easily into existing cropping practices.

However, the fall in wool price is only part of the national canola diffusion story because, in spite of its persistent margin advantage over traditional crops, and increase in returns relative to pasture-fed livestock, canola was still seen an unreliable crop due to severe weed and disease impediments. Therefore, the development of new canola varieties that could address these agronomic problems was crucial in canola being considered for inclusion in the national winter crop rotation. These new varieties are thus interpreted as the catalysts for canola being viewed as a more reliable cropping option. The timing of the introduction of blackleg resistance and triazine tolerance characteristics, along with the dynamic learning process

[5] The transition from crop-pasture to continuous cropping is evidenced by the 21% reduction in the national sheep flock since 1990.

implicit in the specification of the epidemic logistic diffusion model, provide indirect measures for the unobservable temporal adjustment in farmers' subjective expectations of crop reliability.

Since conditions were ripe for non-cereal crops to emerge in the early 1990s, why was it overwhelmingly canola that was able to launch itself from obscurity to being a central fixture of the crop rotation in southern Australia? Why not a pulse crop, many of which farmers viewed as being more agronomically reliable at the beginning of the 1990s? Intuitively, it may be thought that the reason no single pulse crop emerged was because there were many pulse crops from which farmers could choose, whereas canola is effectively the only oilseed that can be grown in the winter crop rotation in southern Australia. However, this view would ignore the fact that canola's value of production in Australia over the period 1998-2000 was greater than that of all pulse crops combined. A major part of the explanation of the unique expansion of canola would appear to stem from its superior rotational benefits (not just a break, but also biofumigation) and larger gross margin relative to the various potential pulse break crops such as lupins and chick peas.

State Variation in Canola Diffusion

From Table 4.1, it can be seen that the signs of the parameter estimates for the wheat/canola price ratios, which served as measures for relative crop profitability, are not always significant or consistent in sign. The inconsistency of price variables may be explained in two ways. Firstly, as pointed out above, variation in crop prices was likely an unimportant determinant of canola diffusion, in particular during the early adopting stages. It is worth noting though that, as canola approaches its long-run saturation level (the ceiling, K), fluctuation in prices of alternative crops will likely bear a stronger influence on canola allocation decisions and estimation of price elasticity of canola supply will be more reliable. (diffusion less important;

supply response models better.

The second potential cause of insignificant coefficients on the price variables may simply be multicollinearity. By including enterprise intensity variables it is likely that a degree of measured explanatory power is usurped from the price variables and consequently both variables may appear less signficant than if only one price or intensity variable for each enterprise were included in the estimated equations. However, omitting either price or enterprise intensity variables did not greatly improve parameter significance. An interpretation of each canola growing state's diffusion pattern is now considered.

Western Australia

Given Western Australia's high wheat intensity (and overall volume), it was long believed that WA had most to gain from incorporating a Brassica in crop rotations. Indeed, early efforts in the 1970s to grow rapeseed in Australia were focused on WA for that very reason. Unfortunately, however, weed problems long proved insurmountable, and canola could not be grown in WA without some breakthrough in Brassica weed control. The econometric evidence in the individual diffusion model supports the view that what was important in WA was the introduction of varieties that could deal with these agronomic problems. The parameter estimates on the dummy variable for the launch of triazine-tolerant (TT) varieties were positive and significant. This result is consistent with observed rates of adoption of TT varieties which, by 2000, accounted for nearly 90% of canola varieties in WA, whereas TT canola varieties made up only 40% of canola plantings in Victoria and NSW, and 35% in South Australia (Norton 2003). It would appear that where weed problems mattered relatively less, adoption began either earlier (NSW), or adoption was not as significantly affected by the introduction of weed control varieties (SA).

New South Wales

The parameter estimates for the NSW canola adoption are less reliable than the other states, which may be a result of its relatively "lumpy" diffusion path. Given that canola is predominantly grown in southern NSW, but aggregate state-level variables also include northern NSW, which possesses a considerably different crop portfolio, changes in explanatory variables, in particular crop intensity, do not have a consistent effect across the state. The effect of a "lumpy" diffusion path led to some perverse parameter signs, such as a negatively significant coefficient on blackleg resistance.

Victoria

Victoria's diffusion path appears to be the most robust, and all signs conformed to *a priori* expectations. One surprising feature of the individual Victorian diffusion model was the result that pulse intensity appears to have had a positive and significant effect on canola area.[6] Although pulses and canola are clear substitutes in the crop rotation, there is likely a problem with contemporaneous correlation when including the pulse intensity variable. Since cropping farmers were increasingly diversifying their rotations, pulse area was expanding at the same time as canola area. Rather than viewing the pulse intensity variable as a substitute, it may alternatively be conceived as a crude measure of the extent of diversification in broadacre crop rotations. On this interpretation, the more area is allocated to pulse crops, the more farmers are seeking alternative break crops, which, from a farmer's decision-making perspective, may also include canola since it is the only oilseed that can be profitably grown in southern Australia.

South Australia

It is likely that canola's relatively late and slow diffusion in South Australia at the aggregate state-level is significantly caused by its relatively high barley intensity, due principally to Eyre

[6] Pulse intensity was also positively significant in WA largely due to the introduction of lupins and chickpeas.

and Yorke Peninsula growing regions. In the mid 1990s, barley prices rose relative to alternative crops, including canola and wheat. The increased incentive to grow barley - a crop that was already relatively reliable – in this key period for canola adoption is likely have provided a weaker incentive for SA farmers to take the risk of adopting potentially risky canola crops.

In SA and WA, wheat price exhibited a positive relationship with canola area over the period, which may appear counter-intuitive. However, this may suggest strong complementarity between canola and wheat as a result of the rotational benefits for wheat from being preceded by a crop of canola. In the face of diminished returns to wool, an increase in the relative price of wheat during the mid to late 1990s may have actually increased the incentive to grow canola because of yield-augmentation and the transition towards continuous cropping.

5. Conclusions

A number of explanations have been put forward to account for the dramatic expansion of canola area allocation across Australia although, to the authors' knowledge, none have been statistically tested. One of the most common suggestions - that farmers grew canola because it became profitable relative to traditional crops - does not bear close scrutiny. Irrespective of which formulation of the diffusion model one chooses, *variations* in crop prices were not statistically significant. To the extent that crop prices mattered, it was via the persistent gross margin canola enjoyed over traditional crops, not the change of that margin. Hence, relative crop output prices may have provided the underlying incentive for farmers to consider growing canola, but variation in these prices did not trigger the expansion in canola area.

Two alternative hypotheses did, however, withstand statistical examination. The first was that the fall in wool prices in the early 1990s induced a transition away from crop-pasture rotations towards continuous-cropping practices. With the rise of continuous-cropping rotations, increasing numbers of farmers began to demand an alternative cereal break to pasture, and so conditions were ripe for a non-cereal crop that could deliver a high margin, yet fit easily into existing cropping practices. Canola - an oilseed that could augment wheat yield - was an obvious candidate. However, in spite of its high relative price and rotational benefits, canola was still seen as an unreliable crop due to severe weed and disease impediments.

Therefore, the second key determinant of canola's decade-long expansion was the development and marketing of new varieties suitable for varying Australian conditions that overcame these weed and disease problems. This second hypothesis suggests that the introduction of triazine-tolerant (TT) cultivars and varieties that offered increased protection against Brassica diseases (in particular Blackleg) were the crucial innovations which contributed to canola's agronomic reliability and, in combination with the fall in wool prices, were the causative factors that led to canola becoming a regular fixture in Australian farmers' cropping portfolios.

The observed interstate variation in canola diffusion patterns can be explained by broadly conceived profitability considerations. While there was a significant amount of interstate co-operation, especially in trialling new varieties, the differences between the four canola-growing states are noticeable. Comparative analysis indicates that New South Wales and Victoria were the early leaders in part because they were home to the vast majority of canola research. Victoria overtook New South Wales in terms of proportional canola adoption because the north of New South Wales had a greater availability of alternative oilseeds (e.g. sunflower, cottonseed) and also had the option of summer grain cropping due to its latitude. In South Australia, which has a lower than average wheat intensity, and a significantly higher barley intensity, canola's diffusion appears to have been delayed. This is likely the result of resurgent barley prices in the mid-1990s, which diminished the incentive to grow large amounts of canola. For Western Australia, results indicate that the principal driver of canola's late but rapid diffusion was the introduction of varieties that could combat weed and disease problems.

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Appendix

TABLE A1: MAJOR AUSTRALIAN CANOLA VARIETIES (1979-2001)

Year of release	Variety	Type	Maturity	Blackleg rating	Oil	Protein	State developed
1979	Wesway	Conventional	Mid	4.5	1	1	WA
1980	Wesbell	Conventional	Late	4.4	1	1	WA
1980	Wesroona	Conventional	Mid	4.5	1	1	WA
1981	Marnoo	Conventional	Mid	3.5	1	1	Vic
1986	Tatyoon	Conventional	Mid	5	1	1	Vic
1988	Maluka	Conventional	Mid	6	1	1	NSW
1988	Shiralee	Conventional	Mid	5.5	2	1	NSW
1988	Nindoo	Conventional	Mid	5	1	1	Vic
1988	Taparoo	Conventional	Early	5.5	1	1	Vic
1988	Hyola 30	Conventional	Early	6.5	1	1	NSW
1988	Hyola 40	Conventional	Early	6.5	1	1	NSW
1990	Barossa	Conventional	Mid	5	1	1	NSW
1990	Yickadee	Conventional	Mid	5.5	2	1	NSW
1990	Hyola 41	Conventional	Early	6.5	1	1	NSW
1991	Narendra	Conventional	Early	5	1	1	WA
1991	Hyola 42	Conventional	Early	6.5	1	1	NSW
1992	Oscar	Conventional	Mid	6	1	1	NSW
1993	Rainbow	Conventional	Mid	6.5	1	1	Vic
1993	Dunkeld	Conventional	Mid-late	6	2	2	Vic
1993	Siren	TT	Mid	5	1	1	Vic
1996	Karoo	TT	Early-mid	3.5	1	1	Vic
1997	Pinnacle	TT	Mid-late	6	1	2	Vic
1998	Charlton	Conventional	Mid-late	6	3	2	Vic
1998	Mystic	Conventional	Early-mid	6	1	1	Vic
1999	Surpass 400	Conventional	Early	9	2	3	NSW
1999	Ag-Emblem	Conventional	Early-mid	7.5	1	1	NSW
2001	ATR-Grace	TT	Mid-late	6.5	2	2	WA
2001	ATR-Hyden	TT	Mid	6.5	1	1	WA
2001	Surpass 501TT	TT	Early-mid	8.5	2	1	NSW
2001	Hyola 60	Hybrid	Mid	9	2	3	NSW
2001	Surpass 603CL	Clearfield	Mid	8	3	3	NSW

1 = moderate
2 = high
3 = very high
TT = triazine tolerant

Source: Trent Potter (SARDI) and Neil Warren (WA Canola Breeders Association).