Distribution of Research Gains in Multistage Production Systems: A General Equilibrium Analysis of Wool

By

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Abstract

The seminal work of Freebairn, Davis and Edwards (FDE, 1982) showed that in a multistage production system, research that reduces production costs at one stage provides benefits to producers at all stages and to consumers. This work assumed a partial equilibrium environment, while producers operate in general equilibrium. We apply a general equilibrium model to investigate the importance of the economic environment in the distribution of research gains in an extreme example of a multistage production system: wool. Our results do not support FDE's conclusions with regard to the distribution of benefits to producers across production stages – research in a multistage production system that reduces production costs at one stage will not necessarily provide benefits to producers at all stages.

Key words: economic surplus, general equilibrium, multistage production, research benefits, wool.

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1 Introduction: previous work on the distribution of research gains in multistage production systems

Analysis of research gains in multistage production systems was a neglected area of research when FDE (Freebairn, Davis and Edwards 1982) published their seminal paper on this topic. Their work is especially relevant to agricultural production systems where primary farm products pass through a number of production processes before being consumed by households. FDE postulate a two-stage theoretical model where farm output passes to a marketer who uses marketing goods and services, along with nonfarm inputs, to produce the retail good from whom it is purchased by households. They analyse the distribution of research gains between members of the production system and consumers, under competitive conditions but allow for both perfectly and less that perfectly elastic supply functions for farm, nonfarm and marketing output – see appendix A for FDE's simplified model. Under these conditions, FDE's key finding is "…that in a multistage production system, research-induced cost reductions in one part of the system provide benefits to consumers and all other members of the production system." (pp. 44-5). Further, they also find that "…the distribution of the research benefits is the same whether the cost reductions occur at either the nonfarm input, farm, or marketing sectors." (pp. 45). These results have important implications for the distribution of research funds (and any associated producer levies used to fund research) across multistage production systems – they suggest that, in principle, the distribution of research funds across production stages is unimportant as all members of the system will benefit.

FDE's work generated a response from A&S (Alston and Scobie 1983) where they raise the issue of the importance of the elasticity of substitution between inputs in farm and marketing production – FDE assume zero values for such elasticities.[1] A&S show that as input substitutability rises, farmers will obtain a greater proportion of total benefits from on-farm research versus off-farm research. They suggest that such elasticities are not, in general, zero. Thus, they conclude that "…farmers should not be indifferent about which stage of production pays a per unit levy to finance research." (pp. 356). Further theoretical work on the elasticities issue by Holloway (1989) derived necessary and sufficient conditions for farmers to gain from off-farm research under various assumptions regarding the types of technical change and production technologies. The conditions show the importance of the relative sizes of the elasticity of demand for the retail product and the intermediate products in determining whether the farmer gains or not.

[1] A&S's comment elicited a reply from FDE (1983).

Applied work estimating the distribution of research gains in multistage production systems includes two notable examples. MAW (Mullen, Alston and Wohlgenant 1989) apply an equilibrium displacement model of the world wool top industry to estimate the gains to Australian wool farmers from productivity improvements in farm production, top making and textile manufacturing. They demonstrate that (i) Australian wool producers gain more when research is assumed not to spread from Australia to other regions,[2] and (ii) Australian wool producers gain less from on-farm research, the less substitutable wool inputs are with nonwool inputs in processing stages. MAW's analytical framework does not explicitly model the textile manufacturer and household demand is not represented at all. Thus, it is not a true representation of the wool multistage production system, just a section of it. Like all previous work in this and related areas, MAW assume research induces parallel shifts in supply curves. Wohlgenant (1993) compares the benefits to the United States beef and pork industries of research and promotion. The main finding is that producers gain more from a research-induced downward shift in the supply curve compared with an equivalent upward shift of the retail demand curve. The results, however, are quite sensitive to the assumed substitutability between farm and nonfarm inputs in retail production.

In analysing the distribution of research gains in multistage production systems, all of the aforementioned studies suffer from various limitations. None of these studies assumes an explicit functional form for the production functions employed. As such, it is not possible to separately model factor and intermediate demands by producers. Thus, all discussion and analysis about the all-important issue of input substitutability at different production stages must, by necessity, be in broad or vague terms such as 'farm' and 'nonfarm' inputs. Separately capturing factor and intermediate demands allows the analysis to focus more on areas where substitution is and is not possible; for instance, it is likely that, in general, there are greater possibilities for substitution between broad factors of production (land, labour and capital) than between broad intermediate inputs (e.g., electricity and fertilisers). Another limitation of using implicit functional forms for representing production functions is the assumption that research induces parallel supply shifts. By using explicit functional forms for representing the production function, one can assume a less restrictive supply shift; for instance, one can assume a factor specific, an intermediate input specific, or input neutral productivity improvement.

Another limitation of previous studies is the assumption of a partial equilibrium environment, whereas producers operate in general equilibrium. This limitation is particularly acute when modelling primary products which are highly traded. In this case, research can induce substitution of the locally-produced good for the foreign-

[2] This result was first demonstrated for the wool industry by Edwards and Freebairn (1984).

produced good. Partial equilibrium analysis implicitly assumes fixed real exchange rates as it is not possible to impose a trade balance constraint in such a framework. Thus, research can lead regions to increase exports without also having to increase imports – due to the absence of a trade balance constraint – which in turn would drive up domestic prices and dampen the cost-reducing effects of research. This is particularly relevant where research occurs in an industry which is a dominant global exporter of the product in question. In this case, research-induced expansions in output can negatively impact on the world price received by the producer, can transfer costs and benefit to industries in other regions, and lead to a depreciation of the real exchange rate and an adverse movement in the terms of trade. Further, it is also possible that nonmembers of the production system may benefit by as much, or even more, than members. But the adoption of a partial equilibrium analytical framework implicitly dismisses this possibility from the outset.

We attempt to shed light on the importance of some of these limitations by employing a general equilibrium model of the world economy which includes a detailed representation of a multistage production system and an aggregated representation of the rest of the economy. We choose as our example an extreme form of multistage production system: wool. The model allows us to examine all of the issues analysed in previous studies without the limitations identified above.

2 A general equilibrium model of the world wool market: overview

This section provides a mainly descriptive representation of the model employed here. Complete technical documentation of the model is available upon request.

2.1 A linear equation system

Our general equilibrium model can be represented as

$$\boldsymbol{A}\boldsymbol{v} = 0, \qquad (0.1)$$

where $\boldsymbol{A}$ is an $m \times p$ matrix and $\boldsymbol{v}$ is a $p \times 1$ vector of *percentage* changes in all model variables. There are m equilibrium conditions in (0.1) and p variables, some of which (e) are exogenous. The e exogenous variables can be used to shock the model to project changes in endogenous variables. Writing the equation system like (0.1) allows us to avoid finding the explicit forms for the functions underlying (0.1), which are highly nonlinear, and we can therefore write percentage changes (or changes) in the endogenous variables as linear functions of the percentage changes (or changes) in the exogenous variables. To do this, we rearrange (0.1) as

$$\boldsymbol{A}_n \boldsymbol{n} + \boldsymbol{A}_x \boldsymbol{x} = 0, \tag{0.2}$$

where $\boldsymbol{n}$ and $\boldsymbol{x}$ are, respectively, vectors of percentage changes in endogenous and exogenous variables. $\boldsymbol{A}_n$ and $\boldsymbol{A}_x$ are matrices formed by selecting columns of $\boldsymbol{A}$ corresponding to $\boldsymbol{n}$ and $\boldsymbol{x}$. We can then compute percentage changes in the endogenous variables as

$$\boldsymbol{n} = -\boldsymbol{A}_n^{-1} \boldsymbol{A}_x \boldsymbol{x}. \tag{0.3}$$

The model is implemented and solved using the GEMPACK economic modelling software (Harrison and Pearson 1996).

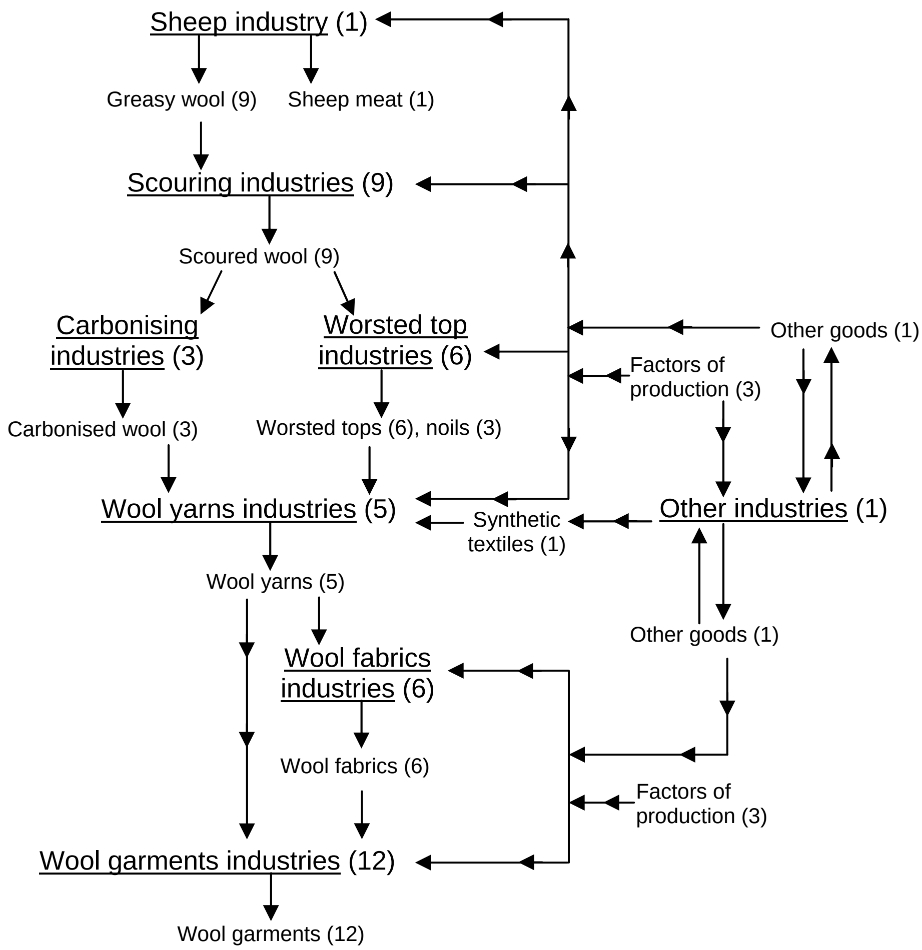
2.2 Industry and commodity structure

The focus of the model is its representation of the wool economy. Primary production of wool consists of nine qualities of greasy wool, distinguished by diameter and hauteur (length). These nine qualities are tracked through five successive processing stages, after which twelve different types of wool garments are (largely) consumed by a representative household. All of these activities are represented in nine regions of the world – France, Germany, Italy, the United Kingdom, the United States, Japan, China, Australia and a composite Rest of World region. Production, processing and household demand for raw wool (greasy wool, scoured wool, carbonised wool, worsted tops, and noils), wool textiles (yarns and fabrics) and wool garments vary significantly across regions of the world, so that significant trade occurs for all classes of products.

The model also contains a comprehensive representation of the nonwool economy, i.e., a representation of the economy as a complete system of interdependent components – industries, households, investors, governments, importers and exporters (Dixon et al. 1992). As such, it completes and complements the wool specific aspects described above, by linking the wool economy in each region with the nonwool economy through domestic factor markets, domestic and international markets for intermediate inputs, and domestic and international markets for household goods. Further, it constrains the behaviour of the wool economy in individual regions to assumptions about macroeconomic behaviour, such as a balance of trade constraint, and household and government consumption constraints. All of this is done at minimum cost, in terms of industry and commodity detail, by representing nonwool industries and commodities as a single composite industry and commodity, respectively.

Figure 1 summarises the industry and commodity structure of the model. It shows the dichotomous nature of the model: a detailed representation of the wool economy showing the processing stages through which greasy wool passes on its way to becoming wool garments; and a composite representation of the nonwool economy which is, nevertheless, fully linked to the wool economy through intermediate inputs and demands for factors. The wool economy is represented as having a linear hierarchy where outputs from downstream wool industries are not used as inputs by upstream wool industries. This conforms to the 'Austrian' view of production. In contrast, the nonwool economy is represented as having 'whirlpools' of production and general interdependence between all the industries it represents via direct or indirect intermediate input usage, so that the other industries composite is a net supplier of the other goods composite. This conforms to the 'Leontief' view of production (Blaug 1978, p. 544; Dorfman et al. 1987, p. 205).

Figure 1 **Industry and commodity structure of the model**



Note: Bracketed figures indicate the number of individual industries, commodities or factors of production in each region. Arrows indicate flows of inputs (commodities and factors of production) and outputs (commodities only) between industries.

2.3 Theoretical structure[3]

Firms are assumed to treat the three factors of production (land, labour and physical capital) as variable, so that they rent their land and physical capital. Factor prices are taken as given by each industry as they attempt to minimise costs. Demands for primary factors are modelled using nested production functions consisting of two levels: at the top level, all firms decide on their demand for the primary factor composite using Leontief production technology; at the second level, firms decide on their demand for individual factors of production. The underlying production technology applied in combining individual factors varies by type of industry; the sheep industry applies a CRESH (constant ratios of elasticities of substitution, homothetic) production function, whereas all other industries apply CES (constant elasticities of substitution) production functions – both these production functions exhibit constant returns to scale.

Firms are also assumed to able to vary their intermediate inputs which they use in production. Analogous to the factor markets they face, firms have no control over the prices of the intermediate inputs in their attempt to minimise costs. In combining intermediate inputs all firms are assumed to use three nested production functions. At level 1, all firms decide on their use of the intermediate input composite using Leontief production technology; at level 2, firms decide on their use of individual intermediate input composites using CES production technology; and at level 3, firms decide on their use of individual intermediate inputs from different sources (domestic and foreign) also using CES production technology.

All industries are modelled as multiproduct industries and are assumed to be price takers in the market for their outputs.[4] As price takers, all industries attempt to maximise revenue in determining their mix of outputs. However, the actual outputs producible by each industry are strictly limited by the initial data as we assume input-output separability in modelling industries and their outputs, so that industries never alter the set of commodities for which they are (net) suppliers. Input-output separability allows the zero pure profits condition to be expressed as equating revenues with costs by all firms.

The sheep industry is assumed to determine its outputs using a CRETH (constant ratios of elasticities of transformation, homothetic) production possibilities frontier, whereas all other industries determine their outputs using a CET (constant

[3] Here we describe only those aspects of the model theory which are essential in understanding the results discussed later. Complete documentation of the model equation system is available upon request.

[4] In fact, there are only three classes of multiproduct industries in each region: (i) the sheep industry; (ii) the six worsted top industries; and (iii) the other industries composite (see figure 1).

elasticities of transformation) production possibilities frontier. To determine the basic (or supply) price of each domestic commodity, a market-clearing condition is specified which relates the supplies and demands of domestic commodities to each other.

The representative household in each region determines demand for its inputs to utility maximisation via a four stage procedure. The first three stages employ Theil's (1980) differential approach to consumption theory. At the top level, households determine demand for four broad composite commodities – sheep meat (one good), wool garments (three subgroups), synthetic textiles (one good), and other goods (one good). At the second level, households determine demand for the three wool garments subgroups – men's wool garments (five goods), women's wool garments (five goods), and knitted wool garments (two goods). At level three, households determine demand for the individual composite goods which make up each of the three wool garments subgroups. At the final level, households determine demand for individual goods from different sources (domestic and foreign) using a CES utility function.

Exports are distinguished on a bilateral basis, and are demanded by firms, capital creators, households and governments. These demands relate to individual import composites; that is, firms, households and governments do not choose between individual imports from different sources. The decision on goods from different sources is made by a representative importer using a CES production function.

We assume perfect mobility of labour between industries in each region regardless of what is assumed about the behaviour of total employment in a region. For the rented factors of production, land and capital, we allow for interindustry mobility within regions in a long run environment. To accommodate this objective for land, we use the following allocation rule specified in percentage-change form, which was first applied in Peter et al. (1996):

$$ph_{ijr}^{F} - ph_{ir}^{F} = \rho\left(q_{ijr}^{F} - q_{ir}^{F}\right) + zph_{ijr}^{F},\ i = Land, \forall j, r. \qquad (0.4)$$

The left-hand side of (0.4) is the percentage change in the ratio of the rental price received by households for a unit of land in industry j in region r to the average land rental price received by households in region r. The bracketed term on the right-hand side (RHS) of (0.4) is the percentage change in the ratio of land used by industry j in region r to total land usage in region r. zph_{ijr}^{F} is a shift term. Letting (the parameter) ρ=1 and setting zph_{ijr}^{F} as exogenous, (0.4) enforces a one-to-one relationship between the price and quantity ratios, where fast-growing (slow-growing) industries pay a premium (receive a discount) on the land they rent. Taking the view that land is a very immobile factor and specific to certain uses, we set ρ=10; thus a small increase (decrease) in the use of land by an industry will lead to a significant increase (decrease) in the rental price paid by the industry, which, in turn, will discourage (encourage) a further increase (decrease) in the use of land by the industry.

To allow for interindustry capital mobility within regions we specify the following (percentage-change) allocation rule;

$$r_{jr} = r_r + zr_{jr}, \; \forall j, r. \tag{0.5}$$

That is, the post-tax rate of return on (a unit of) capital used by industry j in region r $\left(r_{jr}\right)$ is indexed to the region-wide post-tax rate of return on capital $\left(r_r\right)$ plus a shift variable $\left(zr_{jr}\right)$. With zr_{jr} set as exogenous, capital moves between industries within a region equalising the post-tax rate of return on capital. Thus, this allocation rule simulates a period of time long enough for all post-tax (risk-adjusted) rates of return to return to their initial relativities. This might be thought of as a period of 5 years or more.

2.4 Closing the model

The model contains more equations (*p)* than variables (*m*). Thus, to close the model $\left(p-m\right)$ variables must be set as exogenous, and most of these will have a value of zero. We specify two sets of exogenous variables, one for simulating a short-run environment and another for simulating a long-run environment.

Short run closure of the model proceeds as follows. Land and capital are assumed to be industry specific and fixed in the short run. All technical change variables are set as exogenous, as are all direct and indirect tax rates. The regional real wage rate is set as exogenous in all regions, which imposes the idea that total employment in each region can vary, implicitly through changes in regional unemployment rates. At the same time, industry employment is endogenous and labour moves between industries in a region so that relative industry prices of labour are maintained. Regional depreciation rates are also set as exogenous with zero change. To achieve macroeconomic closure in each region, we fix the average propensity to consume in all regions except ROW (the Rest of World region) so that a household consumption function operates in all regions via Walras's law. This fixes savings rates in all regions and allows the trade balance to be determined in the short run. The global CPI is also set as exogenous thus serving as the numeraire.

In altering the model closure for simulating the long run, we begin with our short run closure and move variables between the lists of exogenous and endogenous variables. In the long run, industry usage of all primary factors is endogenous. Land is allocated across industries using equation (0.4) by exogenising zph^{F}_{ijr}; capital is allocated using equation (0.5) by exogenising zr_{jr}. As the region-wide post-tax rates of return on capital, r_r, are already exogenous, this fixes the differences between industry post-tax rates of return on capital, r_{jr}, within each region and forces capital to move perfectly between industries within a region. We set the regional real wage rate as endogenous and fix regional labour usage; this assumes that the regional unemployment rate is invariant to the simulation and is a function of an imperfectly flexible national labour market. All income tax rates are endogenised and the ratio of the government deficit to GDP is fixed. Thus all income tax rates will adjust to ensure that the government savings position remains constant in the long run. We adjust the macroeconomic closure by endogenising the average propensity to consume in all regions except ROW; this turns off the household consumption function in all regions. At the same time we fix the ratio of the trade balance to GDP in all regions except ROW, so that all regions must return to their initial trading position with the rest of world (via Walras's law) once the new equilibrium is reached.

2.5 Data structure[5]

The model database is a heavily disaggregated version of the widely used and well-known database of the world economy, GTAP, which is specified in $US for 1997 (Dimaranan and McDougall 2002). This database is comprehensive in its representation of the world economy. By disaggregating the relevant commodities and industries, we create a highly disaggregated raw wool, wool textile and wool garment commodities and industries structure. In disaggregating we apply data from Layman (1999), adjusted for discrepancies, as supplied by DAWA (2003), on the structure of individual raw wool, wool textile and garment commodities and industries in each of the more aggregated GTAP commodities and industries. This is desirable as it retains the broad numerical structure of the original GTAP database while capturing the numerical structure of the detailed raw wool, wool textile and garment commodities and industries in Layman (1999).

To the disaggregated database we add two forms of tax data: import tariffs on raw wool, wool textiles and garments; and income tax rates. Import duties on raw wool, wool textiles and garments for 1997 are taken from TWC (2003). Income tax rates are taken from data applied in Verikios and Hanslow (1999), the calculation of

5 We refer to certain key parameter values in the next section; however, a complete description of all parameter values and a detailed description of the database construction are described in a separate document available upon request.

which is described in Hanslow et al. (1999), appendix E. These tax rates reflect labour and nonlabour income taxes for the mid-1990s.

3 General equilibrium research gains in a multistage production system

The model contains 56 individual industries (see figure 1) in each of nine regions. To keep the discussion of results manageable, we aggregate industry results to the broad production stages identified in figure 1 – these are (i) primary production by the sheep industry; (ii) wool scouring, (iii) carding/combing, comprising the wool carbonising, and worsted top industries; (iv) spinning, comprising the wool yarn industries; (v) weaving, comprising the wool fabric industries; and (v) garment making. Further, we simulate research gains in one region (Australia) and aggregate results for all other regions (AOR). We choose Australia as our focus as it applies significant levies on wool producers. These levies amount to two per cent of revenue from sales of greasy wool and they are used, amongst other things, to fund both on- and off-farm research (AWIL 2005). There are no equivalent levies in other wool-producing regions. We also assume that the nature of the research is specific to Australian conditions so that it is not adopted by foreign firms. For completeness, the productivity improvements are evaluated under both short-run and long-run scenarios.

We analyse the impact on producers and consumers of a one per cent improvement in the productivity of all inputs – intermediate and factors of production – at each production stage.[6,7] Thus, we are assuming that the cost of such an improvement is equivalent at each production stage. There are no strong *a priori* expectations for varying this simplifying assumption in favour of cheaper research at any particular production stage. Note that the type of productivity improvement we are considering here is one which increases output from a given quantity of inputs, or that allows output to be maintained with a reduction in total inputs. For the farmer, this includes improvements in land management, effectiveness of fertilisers, animal

[6] We apply input neutral technical change to avoid biasing the results in favour or against any particular set of inputs.

[7] An argument can be made for including the imposition of the levy when applying the productivity improvements. However, this would require judgements about the strength of the relationship between the value of the levy and the size of resulting productivity improvement at each production stage. This presents two problems: (i) such judgements would be arbitrary in the present case as there are no studies evaluating these relationships; and (ii) such judgements would cloud the results of our simulations by interacting with the effects of research, and we wish to focus on the issue of the relationship between the distribution of benefits to producer and consumers on the one hand, and research at different production stages on the other.

disease control, and other such improvements.[8] For the garment maker, this includes reorganising production processes to reduce input wastage or congestion in the factory space.

In evaluating the welfare of producers we choose real producer's surplus as our welfare measure, i.e., producer's surplus deflated by the general cost of living index (CPI). It has been shown that producer's surplus arises from fixed or specific factors of production (Mishan 1968). Applying this concept to the model, we are able to measure the change in real producer's surplus by direct reference to the change in rents to the fixed factors in the short run, as follows:

$$\Delta QPS_{jr} = VPS_{jr}\frac{qps_{jr}}{100}, \ \forall j,r, \tag{0.6}$$

where ΔQPS_{jr} is the change in real producer's surplus for the j-th industry in the r-th region; VPS_{jr} is the initial value of producer's surplus defined as rents to the fixed factors taken from the model database; and qps_{jr} is the percentage change in real producer's surplus defined as

$$qps_{jr} = \sum\nolimits_{i=1}^{2} SPS_{ijr}\left(qf_{ijr}^{F} + pf_{ijr}^{F}\right) - ph_r, \ \forall j,r; i = Land, Capital. \tag{0.7}$$

Equation (0.7) says that qps_{jr} is the share-weighted sum of the percentage change in the (pre-tax) value of land and capital rentals $\left[\sum\nolimits_{i=1}^{2} SPS_{ijr}\left(qf_{ijr}^{F} + pf_{ijr}^{F}\right)\right]$, deflated by the percentage change in the regional CPI $\left(ph_r\right)$.

In the long run all factors of production are variable (in the model), including land. Thus, producer's surplus does not arise. Here we revert to the use of real value added as our industry welfare measure; these are returns to all factors of production deflated by the CPI:[9]

$$\Delta QVA_{jr} = VVA_{jr}\frac{qva_{jr}}{100}, \ \forall j,r, \tag{0.8}$$

[8] As farm land has a tendency to become less productive with use, it is necessary for farmers to continually apply research which only maintains land productivity. The nature of the on-farm productivity improvement we are considering here is over and above such 'maintenance' research. We thank Ross Kingwell for bringing this to our attention.

[9] This concept is to be distinguished from the volume of factor inputs. The two concepts are, however, closely related.

where ΔQVA_{jr} is the change in real value added for the *j*-th industry in the *r*-th region; VVA_{jr} is the initial value of value added taken from the model database; and qva_{jr} is the percentage change in real value added defined as

$$qva_{jr} = \sum\nolimits_{i=1}^{3} SVA_{ijr}\left(qf_{ijr}^{F} + pf_{ijr}^{F}\right) - ph_{r}\,,\ \forall i, j, r\,. \tag{0.9}$$

Equation (0.9) says that qva_{jr} is the share-weighted sum of the percentage change in (pre-tax) value added $\left[\sum\nolimits_{i=1}^{3} SVA_{ijr}\left(qf_{ijr}^{F} + pf_{ijr}^{F}\right)\right]$, deflated by ph_{r}.

In evaluating the welfare of consumers we choose consumer's surplus as our welfare measure. We calculate the change in consumer's surplus for the *i*-th good in the *r*-th region $\left(\Delta CS_{ir}\right)$ using equation (1) of FDE (see equation (0.17) in appendix A), which is reproduced below:

$$\Delta CS_{ir} = 1/2\left(P1_{ir} - P2_{ir}\right)\left(Q1_{ir} + Q2_{ir}\right),\ \forall i, r\,, \tag{0.10}$$

where $P1_{ir}\left(P2_{ir}\right)$ is the initial (subsequent) equilibrium consumer price, and $Q1_{ir}\left(Q2_{ir}\right)$ is the initial (subsequent) equilibrium consumer quantity. $P1_{ir}$, $\forall i, r$, is set equal to 1. $P2_{ir}$, $\forall i, r$, is defined as follows:

$$P2_{ir} = P1_{ir}\left(1 + \frac{ph_{ir}}{100}\right),\ \forall i, r\,, \tag{0.11}$$

where ph_{ir} is the percentage change in the household price. $Q1_{ir}$ is calculated as $VH_{ir}/P1_{ir}$, where VH_{ir} is the value of consumer expenditure taken from the model database. Using $Q1_{ir}$ and the percentage change in household demand $\left(qh_{ir}\right)$, $Q2_{ir}$ is defined as

$$Q2_{ir} = Q1_{ir}\left(1 + \frac{qh_{ir}}{100}\right),\ \forall i, r\,. \tag{0.12}$$

3.1 Short-run research benefits

Table 1 summarises the short-run welfare effects on producers and consumers of research in each broad wool production stage. The first consistent pattern in the results is that consumers of sheep meat and wool garments in all regions benefit no matter which production stage experiences research (row 8). This result is consistent with the findings of FDE, MAW and Wohlgenant. It is obvious from the first bracketed term on the RHS of equation (0.10) that as long as the price paid by consumers falls, then consumers will benefit and vice versa. Research in any of the wool production stages always reduces the average price of sheep meat and wool garments so that consumers always gain in overall terms. The relative gains of consumers in Australia and AOR are reversed in moving from on-farm research to garment-making research. AOR consumers gain the most from research in production stages producing goods where Australian production is mainly exported – greasy wool (US$43 million), scoured wool (US$26 million) and carded/combed wool (US$15 million). The reverse is true for Australian consumers; they benefit most from research in production stages producing goods where Australian production is mainly consumed domestically – wool fabrics (US$2 million) and wool garments (US$9 million). In other words, consumers benefit more from research in production stages ‘closer’ to them. For foreign consumers, (Australian) on-farm research affects them more directly as they are the main users of Australian wool; for Australian consumers, (Australian) garment-making research affects them more directly as they are the main users of Australian wool garments.

The second consistent pattern is that real producer’s surplus for the other (nonwool) industries rises in all regions from research in each of the wool production stages (row 7). With producer’s surplus largely a function of rents to fixed factors, as long as the demand curve for fixed factors shifts out from its initial position, then rents to fixed factors will rise and the other (nonwool) industries will gain. With value added a Leontief function of gross output, as long as gross output expands then the demand curve for fixed factors will shift out from its initial position.

Table 1 **Short-run economic welfare changes from research at each stage of the Australian wool production system (US$ million)**

Change in economic welfare of:	Research in sheep industry		Research in scouring		Research in carding/combing	
	(1) All other regions	(2) Australia	(3) All other regions	(4) Australia	(5) All other regions	(6) Australia
1. Sheep industry	-68.041	-3.755	-20.846	-7.072	-9.954	-4.035
2. Scouring	-0.181	0.636	-1.834	2.272	-0.784	0.603
3. Carding/combing	1.021	0.202	-0.710	2.636	-2.857	3.070
4. Spinning	-2.763	-0.011	-2.362	0.000	2.750	0.030
5. Weaving	1.215	0.007	0.984	0.004	0.448	0.005
6. Garment making	5.784	0.018	4.127	0.011	2.413	0.015
6a. Wool inds total[a]	-62.966	-2.904	-20.640	-2.149	-7.985	-0.312
7. Other industries	105.649	7.687	51.962	1.282	29.545	1.215
8. Consumers[b]	42.996	0.475	25.600	0.239	14.887	0.167
	Research in spinning		Research in weaving		Research in garment making	
	All other regions	Australia	All other regions	Australia	All other regions	Australia
1. Sheep industry	-0.192	-0.033	-0.195	-0.006	-0.085	0.113
2. Scouring	-0.012	-0.004	-0.012	-0.005	-0.009	0.001
3. Carding/combing	-0.023	-0.005	-0.024	-0.010	-0.018	0.000
4. Spinning	-0.230	0.062	-0.087	-0.136	-0.082	-0.051
5. Weaving	0.022	0.023	-0.019	-0.906	-0.094	-0.438
6. Garment making	0.036	0.078	-0.067	0.406	-0.532	-1.148
6a. Wool inds total[a]	-0.399	0.121	-0.404	-0.657	-0.822	-1.523
7. Other industries	0.805	0.619	1.150	2.960	3.219	12.206
8. Consumers[b]	0.466	0.352	0.473	2.124	0.963	8.967

[a] Refers to producers in wool production system only, i.e., sum of previous six rows. [b] Refers to consumers of sheep meat and wool garments only.

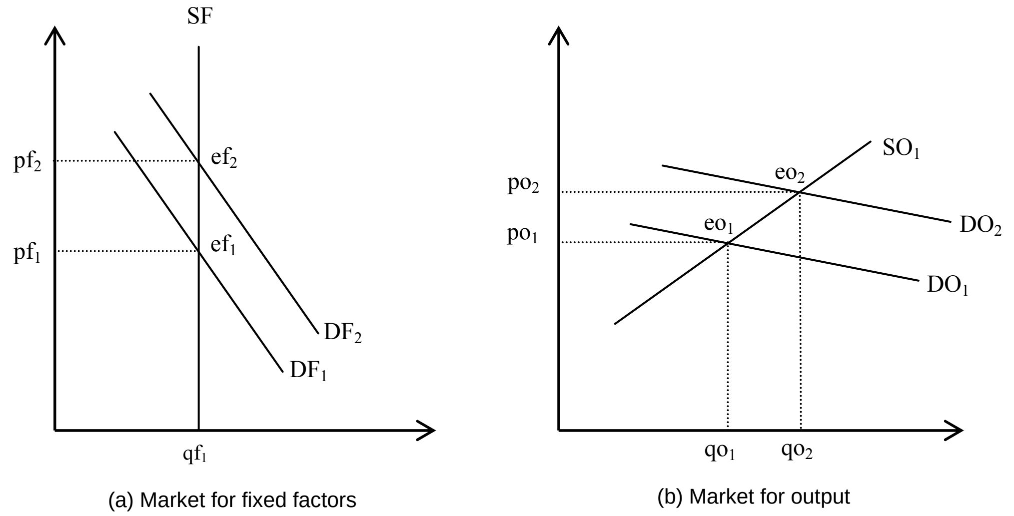
The exegesis is reflected graphically in figure 2, which maps demand and supply curves in price/quantity space. With the initial equilibrium in the market for fixed factors [panel (a)] at point ef_1, the area below the price pf_1 and to the left of the supply curve SF is roughly equivalent to the levels form of equation (0.7) – real producer's surplus. The initial equilibrium in the market for output [panel (b)] is at point eo_1. An improvement in the productivity of any of the Australian wool industries leads to rising real incomes in all regions.[10] With income elasticities for other (nonwool) goods being greater than one in all regions, a rise in real incomes leads to an even greater rise in demand for other goods despite no initial change in the cost of producing these goods.[11] At the post-simulation equilibrium we observe

10 Australia gains from the improvement in the productivity of factors; AOR gain from an improvement in the terms of trade.

11 Income elasticities for sheep meat, synthetic textiles and wool garments are less than one in all regions and sourced from econometric estimates in Dimaranan and McDougall (2002) sourced from FAO (1993) and Theil, Chung and Seale (1989). Income elasticities for the other goods

that the relative price of other (nonwool) goods has risen from research in the wool production system, and the relative prices of wool garments have fallen.[12] Demand for both classes of goods has risen but for different reasons; demand for wool garments rise due to research-induced lower production costs, whereas demand for other (nonwool) goods rise due to rising real incomes and income elasticities of greater than one.

Figure 2 **Short-run effects upon the nonwool industries of a productivity improvement in the wool industries**



The increased demand for other (nonwool) goods requires an expansion in gross output of the other (nonwool) industries. When demand for other (nonwool) goods increases, the demand curve for output shifts out from DO_1 to DO_2, raising the quantity from qo_1 to qo_2. To accommodate the increase in output, the other (nonwool) industries increase their demand for all inputs, including fixed factors. The demand curve for fixed factors in panel (a) will shift out from DF_1 to DF_2, increasing the price from pf_1 to pf_2 which raises rents to the producer.

Estimating benefits to producers in the rest of the economy is unique to this work, as none of the previously-mentioned studies modelled these producers. This aspect of the model should not be underestimated as the size of the gains to the other industries exceed (usually far exceed) the effects on the wool industries in aggregate (row 6a). And this is the case for all regions regardless of the stage in which the research occurs. Consequently, the typical partial equilibrium assumption of taking the rest of the economy as given and assuming that it is unaffected by research in a

composite are determined by applying Engel's aggregation so that the normalised sum (i.e., the budget share-weighted sum) of all income elasticities equal unity in each region.

12 Thus we observe research in the wool production system generating an adverse movement in the terms of trade of members and a favourable movement for nonmembers.

small section of the economy is inappropriate in this case; such an assumption would ignore large benefits to the rest of the economy from research in the wool production system.

The third pattern we can identify in the results is the inconsistency in the sign of the welfare effects across Australian wool industries when research is undertaken in a given production stage. This contrasts with FDE's key finding that research-induced cost reductions in one part of a multistage production system provide benefits to all other members of the production system. Our results indicate that this is not the case for the Australian wool production system. This result is also inconsistent with MAW and Wohlgenant; however, both A&S and Holloway have shown how such a result is possible for farmers. We find that an industry may gain from research in its own production stage (e.g., scouring, US$2.3 million; carding/combing, US$3 million; spinning, US$0.06 million) or it may lose (e.g., sheep farming, US$3.8 million; weaving, US$0.9 million; garment making, US$1.1 million). Further, an industry may gain or lose from research in other production stages; in fact, only garment makers consistently receive a gain from research in other production stages, even though they lose from own-stage research.

The short-run effects on an industry's welfare from own-stage research can be explained using a combination of model algebra and graphs. With land and capital fixed in the short run (i.e., $qf_{ijr}^{F} = 0$, $i = Land, Capital$), the RHS of (0.7) becomes $qps_{jr} = \sum_{i=1}^{2} SPS_{ijr}\, pf_{ijr}^{F} - ph_r$, $i = Land, Capital$, i.e., the average price of fixed factors deflated by the CPI. Given that each of the wool industries is a small share of net output in all regions, we can assume the CPI effect will also be small. Thus, we can largely explain qps_{jr} by reference to the average price of fixed factors: $\sum_{i=1}^{2} SPS_{ijr}\, pf_{ijr}^{F}$, $i = Land, Capital$. In the model's short-run environment, the factor demand equations [equations (0.24)–(0.25) in appendix B] determine the percentage change in the price of fixed factors. Thus equations (0.24)–(0.25) will determine $\sum_{i=1}^{2} SPS_{ijr}\, pf_{ijr}^{F}$, $i = Land, Capital$; so we can use these equations to derive an expression for $\sum_{i=1}^{2} SPS_{ijr}\, pf_{ijr}^{F}$, $i = Land, Capital$, in terms of other model variables and parameters [see appendix B, equation (0.29)];

$$\sum_{i=1}^{2} SPS_{ijr}\, pf_{ijr}^{F} = \frac{qf_{jr}}{\sigma f_{jr}^{F}} + \frac{af_{jr}^{F}}{\sigma f_{jr}^{F}} + pf_{jr}^{F}, \ \forall j, r; i = Land, Capital, \qquad (0.13)$$

where qf_{jr} and af_{jr}^{F} are industry activity levels and Hicks-neutral technical change, respectively. Equation (0.13) explains the percentage change in producer's surplus as a positive function of three terms: the expansion effect, $qf_{jr} \big/ \sigma f_{jr}^{F}$; the productivity effect, $af_{jr}^{F} \big/ \sigma f_{jr}^{F}$; and the general factor price effect, pf_{jr}^{F} .

3.1.1 The productivity effect and the general factor price effect

For an industry experiencing a one per cent improvement in the productivity of all inputs, $af_{jr}^{F} = -1$; ignoring for the moment the other two effects on the RHS of (0.13) gives $\sum_{i=1}^{2} SPS_{ijr} pf_{ijr}^{F} = af_{jr}^{F} \big/ \sigma f_{jr}^{F}$, i.e., producer surplus will fall and this effect will be greater the smaller the elasticity of factor substitution (the more inelastic the factor demand curve) – this is the productivity effect.[13] At the same time, setting $af_{jr}^{F} = -1$ will also cause the price of variable factors to fall. Letting the change in the prices of all factors feed through to the index of factor costs $\left(pf_{jr}^{F}\right)$ in (0.13), the subsequent effect on producer's surplus will be $\sum_{i=1}^{2} SPS_{ijr} pf_{ijr}^{F} = pf_{jr}^{F}$ – this is the general factor price effect. The general factor price effect will reinforce the first, as we expect $pf_{jr}^{F} < 0$ for an industry experiencing research.[14]

The productivity effect and the general factor price effect are partially captured graphically in figure 3, which maps demand and supply curves in price/quantity space. With the initial equilibrium in the market for fixed factors [panel (a)] at point e_1, the area below the price pf_1 and to the left of the supply curve SF is roughly equivalent to real producer's surplus. An improvement in the productivity of all inputs will initially cause demand for all inputs to fall at existing input prices; the demand curve for fixed factors in panel (a) will shift inward from DF_1 to DF_2, dropping the price from pf_1 to pf_2 and reducing rents to the primary producer – the productivity effect. There will also be a reduction in the price of variable (factor and intermediate) inputs but this will not be as great as with fixed inputs, as the supply curve for variable inputs will not be vertical – the general factor price effect. Both of these effects lower the costs of producing the initial output level [qo_1 in panel (b)], so that the output supply curve SO_1 shifts down to SO_2.

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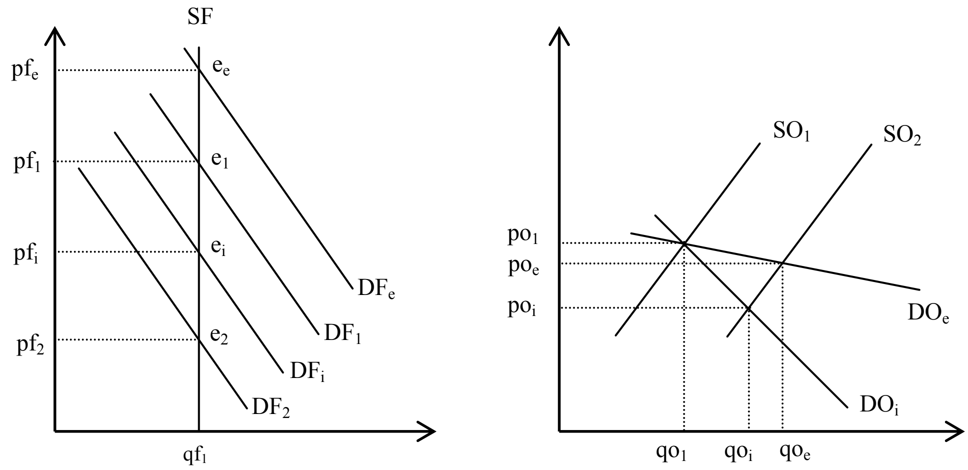
[13] Note that σf_{jr}^{F} is positive for all industries. Note also that for an industry not experiencing research the productivity effect will be zero.

[14] For an industry not experiencing research, the second effect will depend on whether output expands or contracts – if output expands, this effect will be positive; if output contracts, this effect will be negative.

Figure 3 **Short-run effects of a productivity improvement in a wool industry**



(a) Market for fixed factors (b) Market for output

3.1.2 The expansion effect

If now allow output to change, i.e., $qf_{jr} \neq 0$, we observe the expansion effect on producer's surplus, $\sum_{i=1}^{2} SPS_{ijr} pf_{ijr}^{F} = qf_{jr} \big/ \sigma f_{jr}^{F}$, which will be larger the greater is the expansion in output and the more inelastic the factor demand curve. For an industry experiencing research, the expansion effect will determine whether producer's surplus rises or falls, as the first two effects are both negative whereas the expansion effect is positive.[15] The expansion effect is demonstrated graphically as the producer moving down the output demand curve in figure 3: if demand is relatively elastic (DO_e) then output expands by more than if it is relatively inelastic (DO_i). In the former case (DO_e), the demand curve for fixed factors may shift out to DF_e from DF_2; here rents from fixed factors have increased. In the latter case (DO_i), the demand curve for fixed factors may only shift out to DF_i, so that rents from fixed factors fall. In order for the producer to benefit from research, the expansion effect of research must be strong enough to shift the demand curve for fixed factors to the right of its initial position (DF_1), that is, total revenue must rise for producers to benefit. For this to occur with a static demand curve, the producer must face elastic demand in the neighbourhood of the initial equilibrium for its output.

[15] This is true so long as the industry supply curve is not vertical. If the supply curve is vertical then output will remain unchanged and the expansion effect will be zero.

There is also another effect on producer's surplus which is not separately captured in (0.13) or drawn in figure 3; the traded nature of the good and its substitutability with other sources of supply – the substitution effect. If the productivity improvement is only experienced by the local producer (as we are assuming here), then the local price of the good will fall relative to foreign production – foreign and domestic users will substitute local production for foreign production.[16] The output demand curve (either DO_e or DO_i) will shift outwards making it more likely that the local producer will gain. Further, if the local producer is a major exporter of the good then the output demand curve is more likely to be less elastic, indicating market power – the market power effect. A less elastic output demand curve makes it more likely that the producer will lose from the productivity improvement as increases in output will strongly depress the world price of the good. Both the substitution effect and the market power effect affect the expansion effect identified above, $qf_{jr} / \sigma f_{jr}^F$.

For industries which lose from own-stage research (e.g., sheep farming, weaving and garment-making), the (negative) productivity and general factor price effects of research on producer's surplus are greater than the (positive) expansion effect of research on producer's surplus. The size of the expansion effect is determined by (i) the elasticity of factor substitution $\left(\sigma f_{jr}^F\right)$, (ii) the elasticity of substitution of wool inputs with other inputs in the production process: this is zero for all wool inputs except wool tops which are substitutable with synthetic textiles in spinning, and (iii) the elasticity of substitution of wool garments (and sheep meat for the sheep industry) with other commodities in final demand.[17]

Higher factor substitution possibilities cause both the productivity effect $\left(af_{jr}^F / \sigma f_{jr}^F\right)$ and the expansion effect $\left(qf_{jr} / \sigma f_{jr}^F\right)$ to be smaller, because as the value of σf_{jr}^F rises both of these effects become smaller. But the total negative effect in (0.13) falls more quickly than the positive effect as σf_{jr}^F rises, because as $\left(af_{jr}^F / \sigma f_{jr}^F\right)$ falls so does the general reduction in factor prices, pf_{jr}^F . The smaller negative effects reflect an increased ability for the producer to substitute fixed for variable factors, as the productivity improvement reduces the relative price of fixed

16 The demand curves in figure 3, panel (b) are drawn holding the price of substitutes constant.

17 It is possible to derive a short-run industry supply function which would explain the change in industry output in terms of the elasticities of input substitution, the industry's prices of output and variable inputs, as well as various input shares (see, for example, Dixon et al. (1982), p. 309, equation 45.19). This would not, however, be very illuminating in explaining the response of industry output in this case; because we are moving down the output demand curve, the response of industry output will be determined by the elasticity of demand for output in the neighbourhood of the initial equilibrium, rather than the elasticity of supply of output.

factors and raises the relative price of variable factors. Consequently, as σf_{jr}^{F} rises production costs fall by more which will cause output to also expand by more. In terms of figure 3, the smaller the initial reduction in the price of fixed factors (from pf_1 to pf_2 in figure 3) due to a more elastic factor demand curve, the greater will be the subsequent shift down in the producer's supply curve due to lower costs (from SO_1 to SO_2 in figure 3) and expansion in output. In the model, the CRESH elasticities of factor substitution used for Australian sheep producers range from 0.1 to 0.6; the CES elasticities of factor substitution used for all other wool industries range from 0.3 to 0.6. In both cases the absolute value of the average elasticity is much less than one. This also suggests that the expansion effect of research in any of the wool industries is likely to be small, making it more likely that wool industries will lose from own-stage research.

The CES elasticities of substitution for wool tops in the model range from 1 to 1.9; for synthetic textiles the elasticity is set at 0.5. For industries at the carding/combing stages (which produce wool tops), this makes it more likely that they will gain from own-stage research. In fact, they are the largest beneficiary amongst all of the Australian wool industries from own-stage research. The spinning industry, which uses wool tops and synthetics as inputs to production, also gains from own-stage research. The substitutability between intermediate inputs (wool tops and synthetics) for this industry, allows it to substitute into cheaper wool inputs and shift its output supply curve down by more than other industries from a given improvement in productivity.

The (own-price) elasticities of (final) demand for sheep meat range from -0.08 to -0.56 across regions; for wool garments they range from -0.35 to -0.45 across regions. Thus the average elasticity for the final product is around -0.5 or less for the sheep industry. Thus, the sheep industry faces relatively inelastic demand for its output – like DO_i in figure 3. Further, the Australian sheep industry is a dominant exporter of greasy wool which causes its demand curve to be more inelastic than would otherwise be the case. As such, the expansion effect of research in this industry is likely to be small, which is confirmed in the results where the sheep industry is the biggest loser from own-stage research. For the garment-making industries who export almost none of their output, the demand curve is only slightly more elastic than for the sheep industry so that they also lose from own-stage research.

When research is conducted in the production stages of other members of the production system, equation (0.13) becomes

$$\sum_{i=1}^{2} pf_{ijr}^{F} = \frac{qf_{jr}}{\sigma f_{jr}^{F}} + pf_{jr}^{F} \text{ , } \forall j, r; i = Land, Capital \text{ .} \qquad (0.14)$$

Here, there is only a general factor price effect, pf_{jr}^{F}, and an expansion effect, $\left(qf_{jr} / \sigma f_{jr}^{F}\right)$; there is no productivity effect. In this case both the general factor price effect and the expansion effect will have the same sign, because if qf_{jr} rises then pf_{jr}^{F} will also rise. Almost all industries gain from research in upstream production stages.[18] Research in an upstream production stage leads to cheaper wool inputs which shifts the output supply curve to the right for downstream industries, reducing the price of the downstream industries' outputs. Thus, downstream industries move down their output demand curves; the rise in output increases their demand for fixed (and other) factors, thus increasing rents from fixed factors.

Research in a downstream industry may or may not benefit upstream industries. Later-stage processors (spinning and weaving industries) always lose from downstream research. For these industries, downstream research has two effects: (i) at the initial output level, it reduces demand for their outputs by downstream industries due to the productivity improvement experienced by the downstream industry, and (ii) it subsequently increases demand for their outputs by downstream industries as downstream industries move down their output demand curves and expand output. With inelastic demand for wool garments, the second effect is not large enough to offset the first for these industries. Early-stage processors (scouring and carding/combing industries) sometimes gain and sometimes lose from downstream research. The sheep industry loses from all downstream research except in garment making. It should also be noted that the welfare effects are strongest on industries which are 'close' to production stage experiencing research.

Another consistent pattern in the results is the loss to the wool industries in aggregate, from research in all production stages besides spinning. The combination of low substitution possibilities between factors of production, and between the wool industries' outputs and other goods in final demand, explains the fall in total wool industry welfare in all regions when research occurs in most of the wool production stages.

3.1 Long-run research benefits

In both the short run and the long run, benefits to consumers are measured using changes in consumer's surplus [equation (0.10)]. As in the short run, consumers of sheep meat and wool garments in all regions benefit no matter which production stage experiences research in the long run (table 2, row 8), but the gains are

[18] The only exception is the spinning industry which loses from on-farm research.

generally smaller. With all factors of production variable in the long run, research induces smaller (negative) price effects and larger (positive) quantity effects. From the first bracketed term on the RHS of equation (0.10) (reproduced below) we see that consumers benefit only if the price falls, and they benefit more, the more that the price falls; from the second bracketed term in equation (0.10) we see that consumers benefit more, the more that quantity increases:

$$\Delta CS_{ir} = 1/2\left(P1_{ir} - P2_{ir}\right)\left(Q1_{ir} + Q2_{ir}\right),\ \forall i,r\,. \qquad (0.15)$$

The nature of (0.15) is such, however, that the size of the price fall determines the size of the consumer benefits. Consequently, with a smaller price fall in the long run there are smaller benefits to consumers. Also consistent with the short-run results are the relative gains of consumers in Australia and AOR in moving from on-farm research to garment-making research. AOR consumers still gain the most from research in production stages producing goods where Australian production is mostly exported; Australian consumers still benefit most from research in production stages producing goods where Australian production is mostly consumed domestically.

In contrast to the short run, producer welfare in the long run is measured using the change in valued added deflated by the CPI – equation (0.8) – which is driven by the percentage change in real value added – equation (0.9) (reproduced below):

$$qva_{jr} = \sum\nolimits_{i=1}^{3} SVA_{ijr}\left(qf_{ijr}^{F} + pf_{ijr}^{F}\right) - ph_{r}\,,\ \forall i,j,r\,. \qquad (0.16)$$

Producer welfare is now a function of the price $\left(pf_{ijr}^{F}\right)$ *and* quantity $\left(qf_{ijr}^{F}\right)$ of primary factors. In the long run all factors are variable; labour and capital can move easily between industries within a region whereas land is only slightly mobile between industries within a region. Therefore, the prices of labour and capital are common for all industries, while land prices vary between industries. Land rentals are, however, a small share of value added in all regions; around one-third or less for the sheep industry and around seven per cent or less the other industries composite. Thus, the main determinants of the price of value added for these industries will be the prices of labour and capital which are common to all industries. In this situation an industry's real value added can increase even if output contracts, so long as the common prices of labour and capital increase by more than any fall in factor usage. A productivity improvement anywhere in the wool production system will expand economy-wide output, driving up demand and prices for the easily mobile factors of production – labour and capital – for all industries.

Table 2 **Long-run economic welfare changes from research at each stage of the Australian wool production system (US$ million)**

Change in economic welfare of:	Research in sheep industry		Research in scouring		Research in carding/combing	
	(1) All other regions	(2) Australia	(3) All other regions	(4) Australia	(5) All other regions	(6) Australia
1. Sheep industry	-40.060	4.806	-20.936	3.151	-14.561	4.022
2. Scouring	-0.350	0.606	-3.769	5.896	-2.060	3.141
3. Carding/combing	0.127	0.074	-1.371	2.369	-2.263	3.173
4. Spinning	-3.358	-0.009	-3.303	0.022	-0.243	0.038
5. Weaving	-0.258	0.000	-2.565	0.002	-3.676	0.005
6. Garment making	2.418	0.013	3.419	0.028	3.467	0.043
6a. Wool inds total[a]	-41.480	5.490	-28.525	11.469	-19.336	10.422
7. Other industries	76.014	25.178	74.442	0.996	71.296	0.608
8. Consumers[b]	36.967	0.437	35.344	0.332	28.572	0.296
	Research in spinning		Research in weaving		Research in garment making	
	All other regions	Australia	All other regions	Australia	All other regions	Australia
1. Sheep industry	-0.118	-0.025	-0.097	-0.013	-0.008	-0.006
2. Scouring	-0.007	0.000	-0.006	-0.008	-0.003	-0.003
3. Carding/combing	-0.006	0.002	-0.005	-0.005	-0.003	-0.001
4. Spinning	-0.186	0.088	-0.025	-0.094	-0.097	0.032
5. Weaving	-0.012	0.024	-0.069	-0.325	-0.194	-0.017
6. Garment making	-0.118	0.228	-0.218	0.586	-1.166	-0.400
6a. Wool inds total[a]	-0.447	0.317	-0.419	0.140	-1.471	-0.396
7. Other industries	0.000	1.021	0.000	2.394	-0.524	12.589
8. Consumers[b]	0.150	0.486	0.166	1.515	0.196	7.375

[a] Refers to producers in wool production system only, i.e., sum of previous six rows. [b] Refers to consumers of sheep meat and wool garments only.

The long-run pattern of results for the other (nonwool) industries is similar to the short-run pattern; welfare for this industry increases in all regions from research in almost all wool production stages (table 2, row 7). In contrast to the short run, however, the other (nonwool) industries sometimes expand and sometimes contract when research occurs anywhere in the wool production system in the long run. The increase in the common prices of labour and capital forces production costs for the other industries to rise by more in the long run, causing output to expand by less or to fall by more compared to the short run. The increase in the prices of labour and capital, however, offset any contractions in output so that the other (nonwool) industries still gain, in terms of real value added, from research in almost all parts of the wool production system. Consistent with the short-run results, the size of the gains to the other industries usually exceed the effects on the wool industries in aggregate (row 6a).

For a wool industry experiencing research in the long run, the welfare effects are more favourable than in the short run – some industries experience greater gains (scouring, carding/combing and spinning), some experience smaller losses (weaving and garment-making), and the sheep industry experiences a gain instead of a loss. In the long run, all wool industries can now vary their inputs of capital (and land), as well as labour and intermediate inputs, so as to exploit lower relative factor prices when they experience research. Thus, all wool industries experiencing research expand output by more in the long run. The more that output expands, the greater the increase or the smaller the reduction in real value added and thus welfare.

Similar to the short run, research in a downstream or upstream industry may or may not benefit upstream industries in the long run and vice versa. The difference in the long run is that, in general, the gains are larger or the losses are smaller. When all factors are variable, upstream and downstream industries can more easily exploit lower prices from research in other parts of the wool production system. In general, upstream and downstream industries expand output by more or reduce output by less than in the short run when research occurs in the wool production system. This general difference is highlighted by the gain in the aggregate welfare of the Australian wool industries when research is conducted in all production stages except garment making; this contrasts with the short-run loss in the aggregate welfare of the Australian wool industries when research is conducted in all production stages except spinning.

These differences in the short- and long-run pattern of benefits and losses are especially stark when noting that there are two instances in the long run when research leads to benefits for all members of the Australian wool production system; research in scouring, and research in carding/combing. In another two instances, a small loss accrues to only one member of the production system; on-farm and spinning research. Thus, it is in a long-run environment that we observe some support for FDE’s key finding that all members of a multistage production system will benefit from research at any production stage. However, it is important to note that an environment where all factors of production vary does not guarantee that an industry will gain from own-stage research, nor will it ensure that a downstream or upstream industry will also gain from such research; the results in later-stage processing (weaving and garment making) confirm this. The main difference between later-stage processing and the other stages is the tradability of the goods produced by the production stage experiencing research. Australian wool fabrics and garments are largely consumed by the domestic market and these have low own-price elasticities of demand (less than one). In contrast, raw wool (greasy, scoured and carbonised wool, worsted tops and noils) are largely traded and the elasticities of substitution between different sources of these goods is quite high (20). Thus, when local wool industries experience a productivity improvement, the price responsiveness faced by raw wool producers is much greater than that faced by weavers and garment makers, which makes it more likely that the raw wool producers will gain from research in their own production stages when all inputs are variable.

4 Concluding remarks

Our key finding is that research in a multistage production system that reduces production costs at one stage will not necessarily provide benefits to producers at all stages – this result contradicts previous theoretical and applied work in this area. For the wool multistage production system, we have demonstrated that research in any part of the system may not only reduce welfare for other members of the system, but may also reduce welfare for the member experiencing research – this also contradicts previous theoretical and applied work in this area. Losses, for all members of the system, are more likely in a short-run environment while gains are more likely in a long-run environment. Another important factor is the traded nature of the good produced in the stage experiencing research. Where research is localised in a production stage which produces highly traded goods which are highly substitutable with foreign production, the member of this production stage, and members of stages close to this production stage, are more likely to gain. For consumers we find support for previous work; consumers always gain from research as it will generally lead to lower prices and therefore higher economic surplus.

By employing a global general equilibrium model in our analysis, we are also able to estimate the effects of research on nonmembers of the wool multistage production system, both locally and in other regions. We find that, in general, research will generate benefits to industries which are not members of the wool multistage production system. These benefits usually far exceed the aggregate welfare effects experienced by the members of the wool production system. This finding is unique to this work and cannot be generated within a partial equilibrium framework as is typically employed in work of this kind. Consequently, the typical partial equilibrium assumption of taking the rest of the economy as given and assuming that it is unaffected by research in a small section of the economy is inappropriate in this case; such an assumption would ignore large benefits to the rest of the economy from research in the wool production system. Further, these results suggest a large external effect (benefit) to wool research, one that far exceeds the effects internal to the wool production system. This suggests that, in this case, it would be inappropriate for members of the wool production system only to contribute to the funding of this wool research, and that some public funding of this research is justified.

Appendix A

Here we outline FDE's simplified model pp. 40-1. FDE postulate a two-stage theoretical model where farm output passes to a marketer who uses marketing goods and services, along with nonfarm inputs, to produce the retail good from whom it is purchased by households. Household or retail demand is D_r, there is a constant per unit cost M of providing marketing services, and (derived) demand for the farm product is $D_f = D_r - M$. A constant rate of transformation between the farm and the retail product is assumed. A w per unit reduction in the costs of providing marketing services is assumed. The algebraic representations for the gain from technological change in marketing for consumers, $G_c(m)$, for farmers, $G_f(m)$, and the aggregate gain, $G(m)$, are

$$G_c(m) = 1/2(P_r - P_r')(Q + Q'), \tag{0.17}$$

$$G_f(m) = 1/2(P_f' - P_f)(Q + Q'), \tag{0.18}$$

$$G(m) = 1/2\, w(Q + Q'). \tag{0.19}$$

In (0.17)–(0.19), $P_r(P_r')$ is the initial (subsequent) retail equilibrium price, $P_f(P_f')$ is the initial (subsequent) farm equilibrium price, $Q(Q')$ is the initial (subsequent) equilibrium quantity.

Now assume a v per unit output reduction in farm production costs. The algebraic representations for the gain from reduced farm production costs for consumers, $G_c(f)$, for farmers, $G_f(f)$, and the aggregate gain, $G(f)$, are

$$G_c(f) = 1/2(P_r - P_r')(Q + Q'), \tag{0.20}$$

$$G_f(f) = 1/2\left[v - (P_f - P_f')\right](Q + Q'), \tag{0.21}$$

$$G(f) = 1/2\, v(Q + Q'). \tag{0.22}$$

Appendix B

This appendix outlines a number of equations relating to firms' demands for factors in the model. Demands for primary factors are modelled using nested production functions consisting of two levels: at the top level, all firms decide on their demand for the primary factor composite using Leontief production technology. The linearised form of the demand function for the primary factor composite is:

$$qf_{jr}^{F} = qf_{jr} + af_{jr}^{F}, \ \forall j, r. \tag{0.23}$$

Equations (0.23) say that (the percentage change in) demand for the *effective* primary factor composite by the *j*-th industry in the *r*-th region, qf_{jr}^{F}, is a positive (linear) function of (the percentage change in) the (j,r)-th industry's activity level, qf_{jr}, and Hicks neutral technical change, af_{jr}^{F}.

At the second level, firms decide on their demand for individual factors of production. The underlying production technology applied in combining individual factors varies by type of industry; the sheep industry applies a CRESH production function, whereas all other industries apply CES production functions:

$$qf_{ijr}^{F} = qf_{jr}^{F} + af_{ijr}^{F} - \sigma crsh_{ir}^{F}\left(pf_{ijr}^{F} + af_{ijr}^{F} - pcrsh_{jr}^{F}\right), \ \forall i, r; j = Sheep, \tag{0.24}$$

$$qf_{ijr}^{F} = qf_{jr}^{F} + af_{ijr}^{F} - \sigma f_{jr}^{F}\left(pf_{ijr}^{F} + af_{ijr}^{F} - pf_{jr}^{F}\right), \ \forall i, r; j = Nonsheep. \tag{0.25}$$

Equations (0.24) and (0.25) are the (percentage change) demand functions for individual factors by the *Sheep* industry and *Nonsheep* industries, respectively. Thus demand for factor *i* by industry *j* in region *r*, is a function of (i) demand for the primary factor composite $\left(qf_{jr}^{F}\right)$, (ii) factor specific technical change $\left(af_{ijr}^{F}\right)$, and (iii) and the *effective* relative price $\left(pf_{ijr}^{F} + af_{ijr}^{F} - pcrsh_{jr}^{F}\right)$, or $\left(pf_{ijr}^{F} + af_{ijr}^{F} - pf_{jr}^{F}\right)$, adjusted by the relevant elasticity of substitution, $\sigma crsh_{ir}^{F}$ or σ_{ir}^{F}.

To derive equation (0.13), we start with equation (0.25) and initially drop the exogenous variables set to zero in the short-run simulations, i.e., qf_{ijr}^{F} and af_{ijr}^{F}, giving

$$0 = qf_{jr}^{F} - \sigma f_{jr}^{F}\left(pf_{ijr}^{F} - pf_{jr}^{F}\right), \ \forall i, r; j = Nonsheep. \tag{0.26}$$

We then use (0.23) to replace qf_{jr}^{F} in (0.26) giving

$$0 = qf_{jr} + af_{jr}^{F} - \sigma f_{jr}^{F}\left(pf_{ijr}^{F} - pf_{jr}^{F}\right), \ \forall i, r; j = Nonsheep. \tag{0.27}$$

Last, we rearrange (0.27) to give

$$pf_{ijr}^{F} = \frac{qf_{jr}}{\sigma f_{jr}^{F}} + \frac{af_{jr}^{F}}{\sigma f_{jr}^{F}} + pf_{jr}^{F}, \ \forall i, r; j = Nonsheep. \tag{0.28}$$

Summing both sides of (0.28) over the fixed factors using the shares in (0.7), gives an expression for the percentage change in producer's surplus;

$$\sum_{i=1}^{2} SPS_{ijr} pf_{ijr}^{F} = \frac{qf_{jr}}{\sigma f_{jr}^{F}} + \frac{af_{jr}^{F}}{\sigma f_{jr}^{F}} + pf_{jr}^{F}, \; i = Land, Capital. \tag{0.29}$$

While (0.29) has been derived from the factor demand equations for the nonsheep industries, a similar expression results when starting from the factor demand equations for the sheep industry. Thus, (0.29) is also useful for explaining the percentage change in producer's surplus for the sheep industry as well as for all other industries.

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