A Model of the World Wool Market

By

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Abstract

This paper presents the theoretical and empirical structure of WOOLMOD – a model of the world wool market which treats raw wool and wool products as heterogeneous commodities. The model divides the world wool market into ten geographical regions and production in each region amongst eight major industrial sectors, each representing a different stage of the wool market. The industrial sectors cover the full spectrum of activities from raw wool production to retail garment production. The usefulness of WOOLMOD is demonstrated via an illustrative application: analysing the short-run effects of two to three years worth of total factor productivity growth in the Australian sheep industry – the world's largest single producer and exporter of raw wool.

JEL classification: F11, L70, Q13

Key words: raw wool; wool products; modelling the world wool market; wool processing.

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1 Introduction

The importance of the wool industry – as a share of production and employment – in the economies of the world's largest producers of wool has been declining since the advent of industrialisation (Bell 1970). Despite this trend, the traditional dominance in production and exporting of a few producers has not dissipated; in the year 2000 three countries alone – Australia, New Zealand and China – produced over half the world's volume of greasy wool, while two of these regions – Australia and New Zealand – accounted for nearly three-quarters of the world's volume of greasy wool exports (TWC 2001).[1] However, this regional pattern of output and exports at the primary end of the world wool market is not indicative of the pattern of production and exports at the different processing stages. Thus, at the spinning (or yarn production) and garment manufacturing stages the use of wool is concentrated in Western European countries (particularly Italy and the United Kingdom) and the Far East (particularly China) at 27 and 31 per cent, respectively. Whereas at the retail stage Germany, as well as Italy and the United Kingdom, is an important Western European consumer of wool, and Japan, as well as China, is an important Far East consumer of wool (TWC 2001). This diverse regional pattern of output and trade in wool and wool products suggests that a comprehensive framework is required to analyse changes in any part of the world wool market; comprehensive in terms of covering all the major producers and exporters of raw wool and wool products, and also in covering all major stages of production from raw wool through to retail garment production.

There exist a number of previous examples of wool models, see, for instance, Connolly (1992), Tulpule, Johnston and Foster (1992) and CIE (2002).[2] Taken individually, these studies detail either: (i) all the major raw wool and wool commodity producing and consuming regions of the world; (ii) all the major stages of production from the sheep farm through to retail garments; and (iii) international trade in raw wool and wool products. However, none of these studies combines all of these characteristics into a single analytical framework.[3] Further, all of these previous studies have treated wool as a homogeneous commodity. This assumption leads to some unrealistic results, e.g., treating different wool types as substitutes (Kopke, Stanton and Islam 2004). We address these shortcomings by developing WOOLMOD.

1 The data on exports is for 1999.

2 These studies have concentrated on modelling apparel wool markets, i.e., wool used in the production of wearing apparel, thus excluding wool used in the production of carpet. In this paper all discussion regarding wool refers to apparel wool.

3 Layman (1999) does combine these characteristics into a single framework; however it has been found not to be internally consistent (Kopke, Stanton and Islam 2004).

WOOLMOD divides the world wool market into ten geographical regions, representing all of the major raw wool and wool commodity producing and consuming regions of the world. This includes two regions of Australia given its unique status as both the largest single producer of greasy wool and the largest single exporter.[4] The model represents all the major stages of production from the sheep farm through to retail garments, and it does so by treating raw wool and wool commodities as heterogeneous. The *broad* regional sectors include a sheep industry, scouring industries (of which there are nine), carbonising industries (three), worsted top making industries (six), yarn or spinning industries (five), fabric or weaving industries (six), wholesale garment making industries (12) and retail garment making industries (14). In total, there are 56 *individual* industrial sectors producing 68 commodities. Thus, the model distinguishes around 560 separate industries and 680 separate commodities in total. Each region in WOOLMOD is linked via international trade in wool and wool commodities, which is depicted on a bilateral basis. Thus, one of the major contributions of the framework presented here is the combination of (i) all the major wool and wool products producing and consuming regions of the world; (ii) all the major stages of production from the sheep farm through to retail garments; and (iii) international trade in wool and wool commodities; into a single analytical framework. The second major contribution is the unprecedented degree of industry and commodity detail in representing the world wool market.

The model presented here is partial equilibrium with a particular industry focus – wool and wool commodity producing industries. However, unlike previous wool models noted above, it uses applied general equilibrium techniques to develop a differentiated treatment (in terms of regions, trade and commodities) of the wool industry. This approach is similar to that taken by Wittwer, Berger and Anderson (2003) in modelling global wine markets. Like Wittwer, Berger and Anderson (2003), the approach adopted here assumes that the non-wool economy in each region, and globally, is exogenous to the wool economy as represented by WOOLMOD. Further, the framework presented here provides industry analysts and policy makers a sophisticated tool for answering questions like (i) how would trade and growers' incomes be affected by major technical change that enhances productivity in wool production, (ii) what are the likely effects on the world wool market of the increased costs of synthetic fibres brought about by the recent increase world oil prices, and (iii) which regions would gain and lose the most from multilateral trade liberalisation in raw wool and wool products?

4 In terms of quantities, in the year 2000 Australia produced 29 per cent and exported 53 per cent of the respective world aggregates (TWC 2001).

The paper proceeds as follows: section 2 describes the theoretical structure of the model and its closure, section 3 discusses the model data and parameters, section 4 proceeds through an application of the model and explains the results, while section 5 offers concluding comments.

2 Theoretical structure

The principal purpose in constructing WOOLMOD is to provide projections of changes in endogenous variables – such as wool growers' incomes, exports and imports – due to changes in exogenous variables – such as factor productivity and import protection. When a non-zero shock is applied to an exogenous variable in WOOLMOD, the resulting projections of changes in endogenous variables indicate the variation in these variables from the values they would have had in the absence of the change in the exogenous variable. Further, WOOLMOD only allows for the short-run effects of changes in exogenous variables, i.e., simulations can only be conducted within an environment where industry capital stocks are fixed and cannot change.

WOOLMOD can be represented as

$$F_i(X, N) = 0\,, \qquad (2.1)$$

where X and N are the vectors of exogenous and endogenous variables, respectively, which comprise p components in total. F_i, i = 1,…, m, are m differentiable functions. Equilibrium conditions, such as demands equal supplies and costs equal revenues, are imposed on equations (2.1); thus there are m such equilibrium conditions. As such, the values of all endogenous variables in equations (2.1) are equilibrium values, and any perturbation of the exogenous variables will lead to new *equilibrium* values for all endogenous variables.

The underlying economic behaviour in equations (2.1) is highly non-linear but we specify it in linear form. Linearisation of (2.1) is completed by totally differentiating each equation giving

$$\boldsymbol{A}v = 0, \qquad (2.2)$$

where $\boldsymbol{A}$ is an $m \times p$ matrix and v is the vector of *percentage* or *natural-logarithmic* changes in exogenous and endogenous variables. Using equations (2.2) allows us to avoid finding the explicit forms for the functions underlying the equations in (2.1), 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 (2.2) as

$$\boldsymbol{A}_n n + \boldsymbol{A}_x x = 0, \quad (2.3)$$

where n and x are, respectively, vectors of percentage changes in endogenous and exogenous variables. $\boldsymbol{A}_n$ are $\boldsymbol{A}_x$ are matrices formed by selecting columns of $\boldsymbol{A}$ corresponding to n and x. The log-differential forms of equations (2.1) are then obtained by computing

$$n = -\boldsymbol{A}_n^{-1} \boldsymbol{A}_x x. \quad (2.4)$$

In this way, the nonlinearities represented in equations (2.1) are avoided.

The following sections describe the equation system of WOOLMOD in linearised form.[5] This is done in thematic order. Note that we will follow the notational convention of using upper case letters to denote variable levels and corresponding lower case letters for their percentage changes.

2.1 Demands and supplies by firms

2.1.1 Primary factor demands

Firms in WOOLMOD are assumed to treat all factors of production (land, labour and physical capital) as variable, so that they rent their land and physical capital. Section 2.8 describes the short-run closure of WOOLMOD, which includes the assumption that land and physical capital are assumed fixed in each industry. Thus, there exists a rental market for the use of land and capital of each industry and the rental prices of land and capital are taken as given by each industry as they attempt to minimise costs. The rental prices act to ensure market clearing for the land and capital used by each industry, such that demand and supply of land and capital by each industry are equated.

The underlying production technology for the use of individual primary factors is a constant ratios of elasticities of substitution, homothetic (CRESH) (Hanoch 1971) by the sheep industry (SHP), and constant elasticity of substitution (CES) (Arrow et al. 1961) by the other (l – SHP) industries in WOOLMOD.[6] We assume each firm operates in a perfectly competitive environment and is efficient. Perfect competition means firms face given input (and output) prices; efficiency means that for any given activity level, firms choose each input so as to minimise total costs, and

[5] WOOLGEM is implemented using the GEMPACK economic modelling software (Harrison and Pearson 1996).

[6] Thus, there are l industries in WOOLMOD.

choose outputs so as to maximise revenues. Given these assumptions, the input demand functions for CRESH and CES production functions can be represented in linearised form as[7]

$$x^F_{fjr} = x^F_{jr} + a^F_{fjr} - \sigma shp^F_{fr}\left(p^F_{fjr} + a^F_{fjr} - pshp^F_{jr}\right), \qquad f = 1,\ldots,y;\ j = SHP;\ r = 1,\ldots,c\,, \quad (2.5)$$

$$x^F_{fjr} = x^F_{jr} + a^F_{fjr} - \sigma^F_{jr}\left(p^F_{fjr} + a^F_{fjr} - p^F_{jr}\right), \qquad f = 1,\ldots,y;\ j = 1,\ldots,l - SHP;\ r = 1,\ldots,c\,, \quad (2.6)$$

where the superscript *F* refers to primary factors in general, and the subscript *f* refers to individual primary factors, subscript *j* refers to industries, and *r* to regions. Equation (2.5) represents the primary factor demand functions for the sheep industry, whereas equation (2.6) represents the primary factor demand functions for the other (*l* – SHP) industries. x^F_{fjr} and x^F_{jr} are the *effective* inputs of individual and composite primary factors, respectively; a^F_{fjr} is factor-specific technology or input-output coefficients; σshp^F_{fr} and σ^F_{jr} are CRESH and CES elasticities of substitution for the sheep industry and all other industries, respectively; p^F_{fjr} is the price of individual primary factors; and $pshp^F_r$ and p^F_{jr} are CRESH and Divisia prices of the effective primary factor composite used by the sheep industry and all other industries, respectively.

Equations (2.5) – (2.6) state that the demand for any factor *f* is a function of an expansion effect and a substitution effect. If we set the change in relative effective prices, $\left[p^F_{fjr} + a^F_{fjr} - p^F_{jr}\right]$, to zero, then demand for factor *f* will move exactly with the firm's primary factor composite, x^F_{jr}; i.e., the expansion effect. This reflects the constant nature of returns to scale in the underlying production function. Alternatively, if we set the change in the firm's primary factor composite, x^F_{jr}, to zero, then demand for factor *f* will be a function of the change in price of factor *f* relative to the change in the price of composite inputs, and the size of the elasticity of substitution between any pair of inputs, σ. So that if the price of factor *f* rises relative to the price of the primary factor composite, demand for factor *f* will fall relative to the firm's primary factor composite, i.e., the substitution effect. The size of the substitution effect is determined by the size of σ.[8]

[7] See Dixon et al. (1992), chapter 3, section C for the derivation of the percentage-change forms of the input demand functions from CRESH and CES production functions.

[8] Note that even though equations (2.6) are written for *f* = 1,…,*y*, only the sheep industry uses land as a factor of production, whereas all industries use both labour and capital as a factor of production.

In contrast to the technology used to combine individual primary factors, Leontief technology is assumed to determine demand for the primary factor composite by all industries,

$$x_{jr}^{F} = z_{jr} + a_{jr}^{F}, \qquad j = 1,...,l; r = 1,...,c, \tag{2.7}$$

where a_{jr}^{F} is the Hicks-neutral technology coefficient. With z_{jr} representing the firm's activity level, equation (2.7) implies that primary factor inputs are non-specific to outputs and only provide a general capacity to produce.

2.1.2 Intermediate input demands

Firms use a double CES nested production function in combining *k* intermediate inputs. The upper CES nest determines the use of composite intermediate inputs $\left(xc_{ijr}^{I}\right)$ which, solving for the cost minimum, is represented as

$$xc_{ijr}^{I} = x_{jr}^{I} - \sigma c_{ir}^{I}\left(pc_{ijr}^{I} - p_{jr}^{I}\right), \qquad i = 1,...,k; j = 1,...,l; r = 1,...,c. \tag{2.8}$$

Variables in equations (2.8) superscripted with *I* refer to intermediate-input usage by firms. The *i* subscript denotes the *k* goods used as intermediate inputs. Thus, x_{jr}^{I} is total intermediate input usage by the firm, pc_{ijr}^{I} and p_{jr}^{I} are the Divisia price indexes of composite intermediate input *i* from all sources and total intermediate input usage, respectively, and σc_{ir}^{I} is the CES elasticity of substitution between composite intermediate inputs. The upper nest allows differing assumptions to be made about substitution between intermediate inputs, particularly in the use of synthetics versus non-synthetics by the yarns or weaving industries.

In the lower CES nest firms choose from two sources of each intermediate input; domestic production (*xd*) and composite imports (*xm*). In distinguishing between two possible sources of good *i* we follow Armington (1969, 1970). This allows for the possibility that imported goods are not perfectly substitutable for domestic production. The percentage-change form of the input demand functions for individual intermediate goods are

$$xd_{ijr}^{I} = xc_{ijr}^{I} - \sigma dm_{ir}^{I}\left(pd_{ijr}^{I} - pc_{ijr}^{I}\right), \qquad i = 1,...,k; j = 1,...,l; r = 1,...,c, \tag{2.9}$$

$$xm_{ijr}^{I} = xc_{ijr}^{I} - \sigma dm_{ir}^{I}\left(pm_{ijr}^{I} - pc_{ijr}^{I}\right), \qquad i = 1,...,k; j = 1,...,l; r = 1,...,c, \tag{2.10}$$

where xd_{ijr}^{I}, xm_{ijr}^{I} and pd_{ijr}^{I}, pm_{ijr}^{I} denote demands and prices for domestic and imported goods used as intermediate inputs, respectively; and σdm_{ir}^{I} is the CES elasticity of substitution between domestic and imported intermediate inputs. Note that equations (2.9) – (2.10) are also subject to expansion and substitution effects.

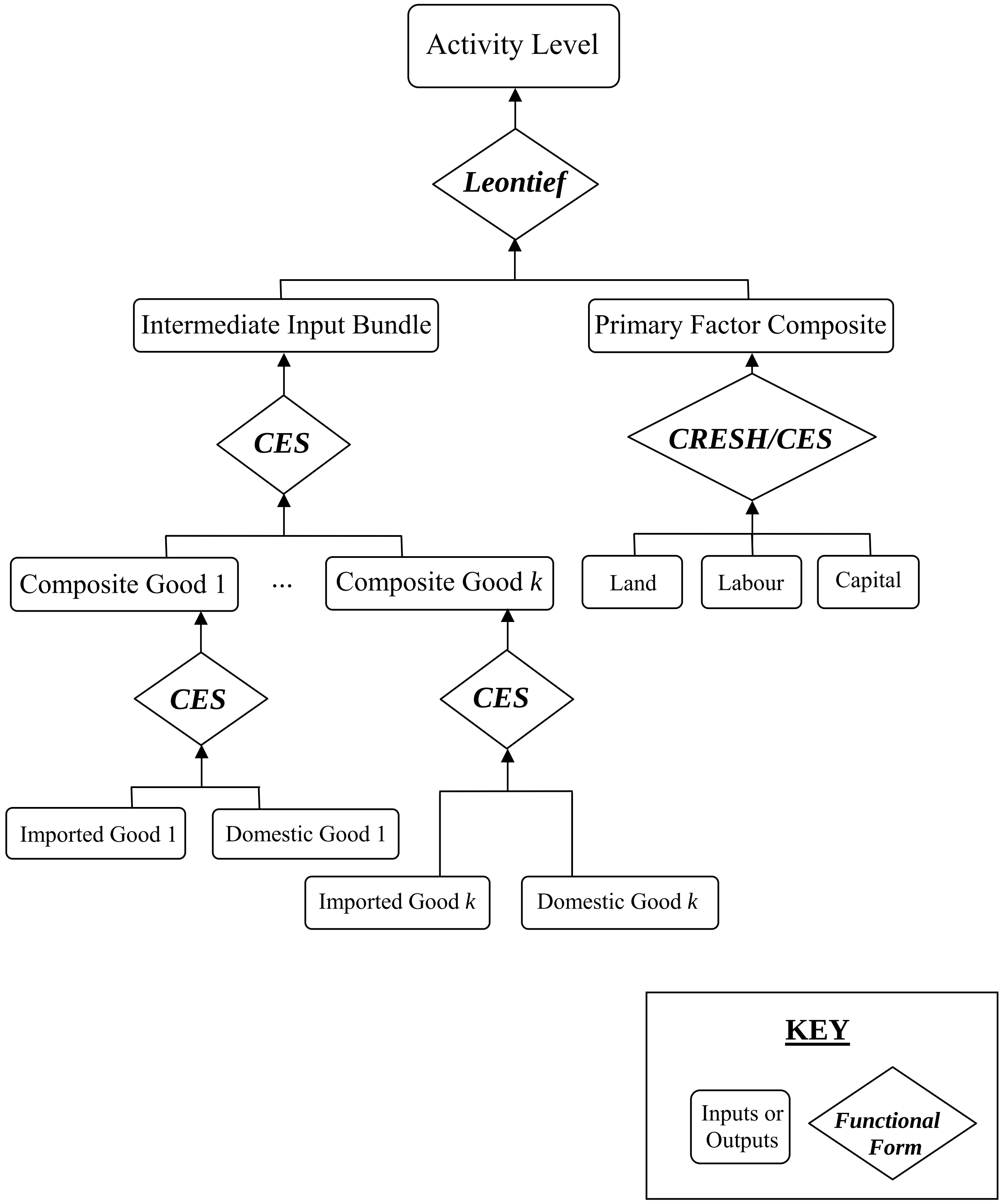
Similar to the primary factor composite, Leontief technology is assumed to determine demand for total intermediate inputs by all industries,

$$x_{jr}^{I} = z_{jr}, \qquad j = 1,\ldots,l; r = 1,\ldots,c, \qquad (2.11)$$

With z_{jr} representing the firm's activity level, equations (2.11) imply that intermediate inputs are non-specific to outputs and only provide a general capacity to produce.

To summarise, WOOLMOD industries' production technology for the use of inputs follows a three-level nested structure within the restriction of constant returns to scale (see figure 1). At the top level of the nest firms combine the primary factor bundle (value-added) with the intermediate input bundle using a Leontief input function. At the second level of the nest CES input functions are used to combine two types of inputs: (i) the *y* primary factors are combined to produce the primary factor bundle; and (ii) the *k* composite intermediate inputs are combined to produce the intermediate input bundle. At the third level of the nest CES production functions are used to combine imported and domestic varieties of each of the *k* goods used as intermediate inputs to produce each of the *k* composite intermediate input goods. Thus, each of the three primary factors are substitutable with each other, each of the composite intermediate inputs are substitutable with each other, and the imported and domestic varieties of the same intermediate input good are substitutable with each other. But the degree of substitution in each case will depend on the values adopted for the elasticity of substitution in each case: σ_{fjr}^{F} for primary factors; σc_{ir}^{I} and σdm_{ir}^{I} for intermediate inputs.

Figure 1 **Input technology for WOOLMOD industries**



2.1.3 Commodity supplies

All industries in WOOLMOD are modelled as multi-product industries. In fact, the actual outputs producible by each industry are strictly limited by the initial data, so that there are only two classes of multi-product industries: (i) the sheep industry in each region; and (ii) the six worsted top industries in each region. All industries in WOOLMOD choose their outputs subject to a constant elasticity of transformation (CET) production possibilities frontier (Powell and Gruen 1967, 1968). The linearised form of supply response functions for such a frontier can be represented as[9]

$$x^{O}_{ijr} = z_{jr} - \theta^{O}_{jr}\left(p^{O}_{ir} - p^{O}_{jr}\right), \qquad i = 1,...,k; j = 1,...,l; r = 1,...,c. \qquad (2.12)$$

In equations (2.12) we have used the superscript O to denote variables relating to output by firms, all subscripts are the same as those used in earlier sections. We have also used x to denote commodities produced by firms. The general interpretation of equations (2.12) is as follows: in the absence of price changes, output of commodity i by industry j will move strictly with industry j's activity level – the expansion effect; in the absence of any change in industry j's activity level, output of commodity i by industry j will expand by the excess of the price of good i, p^{O}_{ir}, over the price of composite outputs by industry j, p^{O}_{jr}, adjusted by the (negative) transformation parameter (θ) – the transformation effect. Note that in (2.12), the price of composite outputs, p^{O}_{jr}, is computed as the output-value weighted-average of the equilibrium price of good i in region r, p^{O}_{ir}. This price contains no industry subscript as we assume that all industries producing good i receive the same price. There are only three multi-industry products in WOOLMOD, and these are the three types of noils produced by the worsted top industries. All other products are produced by a single industry. Even though the output response functions are written like equations (2.12) for all industries in WOOLMOD, there is no choice to make for the single-product industries. In the case of single-product industries, the transformation effect is zero as the firm produces only one product, and output of this product will move strictly with the activity level of the firm.

2.2 Household demands

The linear hierarchy in production ends in WOOLMOD with the production of fourteen different retail garments in each region. The representative regional household in each region is assumed to consume the total output of the fourteen retail garment industries (i.e., there is no international trade in retail garments).[10] Retail garments are further separated into seven mens' and seven womens' retail garments. Besides the consumption of retail garments, each regional household is

[9] Dixon et al. (1992), chapter 3, section C show how the percentage-change form of the output supply functions are derived from a CET production possibilities frontier.

[10] Appendix A lists all commodities in the WOOLMOD database.

also assumed to consume the total output of the single non-wool output of the sheep industry – sheep meat (i.e., sheep meat is also non-traded).

The demand for goods by households in WOOLMOD applies Theil's (1980) differential approach to consumption theory. Theil and Clements 1987 (chapters 1 and 4) show how assuming a utility function with no explicit functional form, the following demand equations can be derived in differential form

$$W_i x_i = \theta_i x + \phi \sum_{j=1}^{n} \theta_{ij} \left(p_j - p' \right), \qquad i = 1, \ldots, n, \qquad (2.13)$$

where W_i are the budget shares for good *i*; x_i is the proportional change in demand for good *i* or any other variable; θ_i is the marginal budget share for the *i*-th good and $\sum_i \theta_i = 1$, and $\sum_{j=1}^{n} \theta_{ij} = \theta_i$; *x* is the Divisia volume index for total consumption; ϕ is the reciprocal of the income elasticity of the marginal utility of income, also known as the *income flexibility*; and p' is the *Frisch price index*, which differs from the Divisia price index, *p*, in that the former uses marginal shares as weights $\left(p' = \sum_{i=1}^{n} \theta_i p_i \right)$ and the latter uses budget shares as weights $\left(p = \sum_{i=1}^{n} W_i p_i \right)$.

The term on the left-hand-side (LHS) of (2.13) can be interpreted in two ways: (i) as the quantity component of the *i*-th budget share; or (ii) as the contribution of good *i* to the Divisia volume index *x*. Whichever interpretation of $W_i x_i$ is applied, it is made up of two effects; an income effect and a substitution effect. The first term on the right-hand-side (RHS) of (2.13) says that $W_i x_i$ will increase as real consumption rises, adjusted by marginal share for the *i*-th good – the income effect. The second term on the RHS of (2.13) says that if the price of the *j*-th good rises relative to the *Frisch price index* of the basket of all goods consumed, then $W_i x_i$ will increase adjusted by the positive term $\phi\theta_{ij}$ – the substitution effect. The term $\phi\theta_{ij}$ is the (*i*, *j*)-th price coefficient, consisting of the *income flexibility* (ϕ) and the *normalised price coefficients* (θ_{ij}). If θ_{ij} and ϕ are both negative then $\phi\theta_{ij}$ will be positive. In this case, as $\theta_{ij} < 0$ goods *i* and *j* are specific substitutes (Houthakker 1960).

The differential approach allows us to derive demand equations of the form (2.13) from a utility function with no explicit functional form. Thus the coefficients of the demand equations (2.13) can vary, e.g., they can be functions of income and prices.

2.2.1 The demand for commodity groups under block independence

Households in WOOLMOD only consume two classes of goods: (i) the fourteen different types of retail garments; and (ii) sheep meat. Group (i) is dissected into a further two subgroups: (a) the seven mens' retail garments; and (b) the seven womens' retail garments. We can adapt equations (2.13) to model the demands for the goods *within* these three groups of goods, and for each the three groups *as a whole*.

If we assume that the representative household's utility function is additive (i.e., *preference independence* holds between goods), then $\theta_{ij} = 0$ for $i \neq j$, and $\theta_{ii} = \theta_i$, thus all cross-price coefficients are zero, and equations (2.13) can then be rewritten as

$$W_i x_i = \theta_i x + \phi\theta_i \left(p_j - p' \right), \qquad i = 1,...,n. \qquad (2.14)$$

With all cross-price coefficients zero, equations (2.14) say that no pair of goods is a specific substitute or complement – an intuitive result given the assumption of preference independence. However, this result seems unnecessarily strong.

A weaker version of preference independence is *block independence*. Here the additive nature of the utility function is applied to groups of goods rather than individual goods. So we divide the *n* goods into *G*<*n* groups, $S_1,...,S_G$, and the members of each group are non-overlapping. The utility function is then additive across groups, and the marginal utility of a good only depends on the consumption of goods belonging to the same group. Under these conditions the utility function is known as *block-independent preferences*.

Theil and Clements (1987, chapters 1 and 4) show how under *block-independent preferences* the demand equations (2.14) can be rewritten as

$$W_g x_g = \theta_g x + \phi\theta_g \left(p'_g - p' \right), \qquad g = 1,...,G, \qquad (2.15)$$

where p'_g is the change in the Frisch price index for group *g*. Equations (2.15) are the composite demand equations for S_G as a group. Thus the (budget-share adjusted) demand for group *g* as a whole, $(W_g x_g)$, is a function of real consumption (*x*) and the Frisch price index for the group relative to the Frisch price index for total consumption $\left(p'_g - p' \right)$, adjusted by θ_g and $\phi\theta_g$, respectively. Moving W_g to the RHS of (2.15), we note that θ_g / W_g is the income elasticity of the demand for group g,[11] and $\phi\theta_g / W_g$ is the own-price elasticity of demand for group g.

Using (2.15) we can write the demand equations for the g commodity groups consumed by households in WOOLMOD as

$$x_{gr}^{H} = \frac{\theta_{gr}^{H}}{W_{gr}^{H}} x_{r}^{H} + \phi_{r}^{H} \frac{\theta_{gr}^{H}}{W_{gr}^{H}} \left(p_{gr}'^{H} - p_{r}'^{H} \right), \qquad g = 1,\ldots,G; r = 1,\ldots,c. \tag{2.16}$$

A H superscript has been added to (2.16) denoting variables and shares relating to household consumption.

2.2.2 The demand for commodities within groups under block independence

The demand equations that determine the demand for commodities within groups are known as the *conditional demand equations*. These demand equations can be derived by rearrangement of (2.15) so that only x appears on the LHS, and then substituting the rearranged form of (2.15) into (2.13) gives

$$W_i x_i = \theta_i \frac{W_g}{\theta_g} x_g + \phi \sum_{j \in S_g} \theta_{ij} \left(p_j - p_g' \right), \qquad g = 1,\ldots,G; i \in S_g. \tag{2.17}$$

Equations (2.17) apply for all $i \in S_g$, and say that demand for good i depends on demand for the group S_g, x_g, and the price of good i relative to the Frisch price index for the group S_g, $\left(p_j - p_g' \right)$. Notice that the demands and prices for $i \notin S_g$ do not appear in (2.17). As θ_{ij} is a symmetric matrix, then $\theta_{ij} = \theta_{ji}$ where $i, j \in S_g$.

We use the conditional demand equation (2.17) to determine household demand for all goods within each of the three commodity groups in WOOLMOD. First, we assume that there are no cross-price effects between commodities within groups, so that $\theta_{ij} = 0$ where $i \neq j$. Thus, θ_{ij} collapses to θ_i for $i \in S_g$. Thus, we write

$$x_{ir}^{H} = \frac{\theta_{ir}^{H}}{\theta_{gr}^{H}} \frac{W_{gr}^{H}}{W_{ir}^{H}} x_{gr}^{H} + \phi \frac{\theta_{ir}^{H}}{W_{ir}^{H}} \left(p_{ir}^{H} - p_{gr}'^{H} \right), \qquad i \in S_g, i = 1,\ldots,k; g = 1,\ldots,G; r = 1,\ldots,c. \tag{2.18}$$

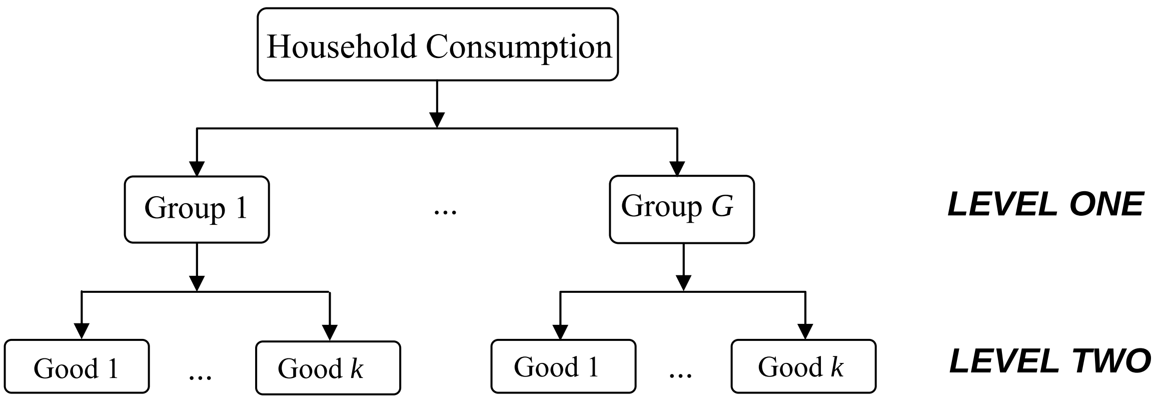
Again, we have added H superscripts signifying variables relating household consumption, and an r subscript denoting regions. Note that i=1 for $S_g = 1$ and i=7

[11] Strictly speaking, θ_g / W_g is the consumption elasticity of the demand for group g, as x in (2.15) is real consumption not real income.

for $S_g = 2,3$, that is, the sheep meat group contains only a single commodity, and the mens' and womens' retail garments groups each contain seven commodities.

Under block-independent preferences, the utility maximisation problem for the household is solved in two steps (see figure 2). First, expenditure on each of the G groups is determined via the group demand equations (2.16), which is a function of total real household expenditure and the Frisch group price index relative to the Frisch price index for total household expenditure. Second, expenditure on goods within each of the G groups is determined via equations (2.18), which are a function of real expenditure on the group and the price of the good relative to Frisch group price index. We can see that the second decision is indeterminate unless the first decision has already been made.

Figure 2 **Decision hierarchy for household demands in WOOLMOD**



2.3 Bilateral trade demands

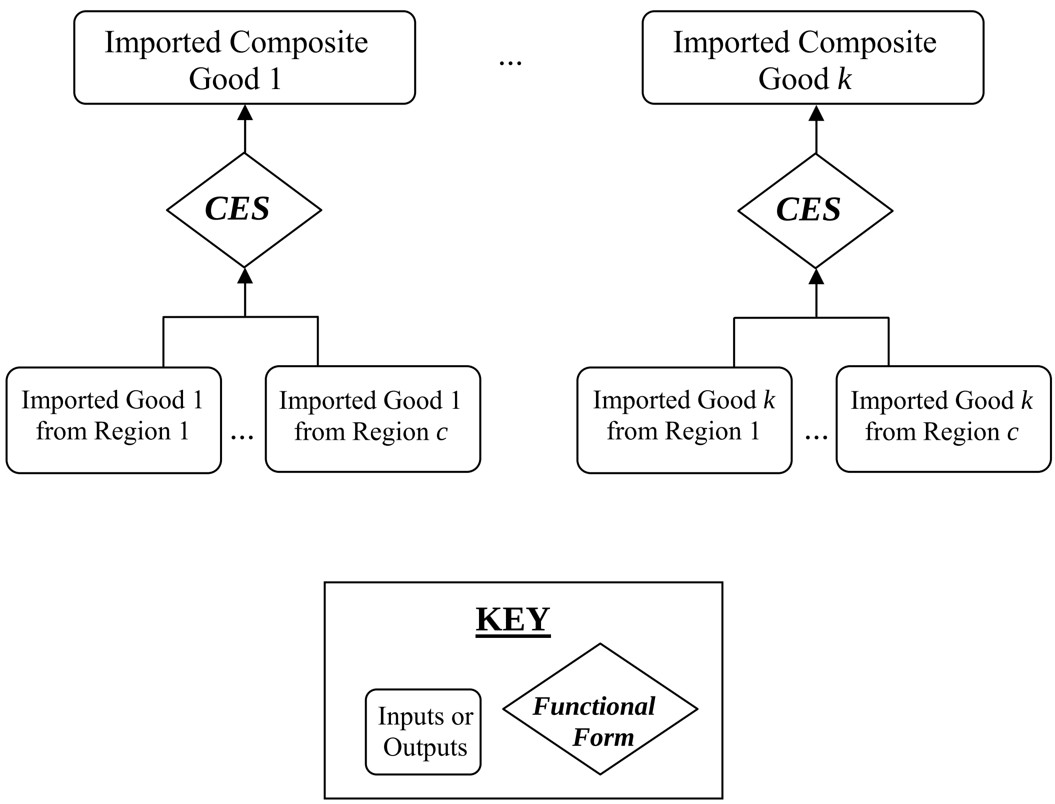
Imported commodities in WOOLMOD are exclusively used by firms as intermediate inputs in current production. We have already described the cost minimisation choice faced by firms in choosing *composite* imports for use as intermediate inputs in current production; that is, firms do not choose between imports of a given good from different sources. The decision on imports from different sources – bilateral import demands – is made by a representative importer. This importer is assumed to minimise the total costs of a given import from all sources, subject to CES production technology. Thus, we can write the demand functions for bilateral imports in WOOLMOD as follows,

$$x_{isr}^{X} = x_{ir}^{M} - \sigma_{ir}^{M}\left(p_{isr}^{M} - p_{ir}^{M}\right), \qquad i = 1,...,k; r,s = 1,...,c, \qquad (2.19)$$

where X and M superscripts are used in equations (2.19) to denote variables relating to exports and imports, respectively; i, s and r subscripts are used to denote commodities, source regions and destination regions, respectively. Thus bilateral demand for exports (or imports) of good i from region s to region r, x_{isr}^{X}, is a function of an expansion effect driven by composite imports of good i $\left(x_{ir}^{M}\right)$, and a substitution effect driven by the relative price of good i $\left(p_{isr}^{M} - p_{ir}^{M}\right)$ adjusted by a (positive) substitution parameter $\left(\sigma_{ir}^{M}\right)$.

Figure 3 summarises the input technology used by importers in forming the k import composites; the i-th import composite is a CES aggregation of the imported goods from the c source regions, subject to a substitution effect and an expansion effect. Once demand for the k import composites have been determined by firms (level two in figure 1), the composition by source region of each of these import composites is determined by the CES bilateral import demand functions (figure 3).

Figure 3 **Input technology for importers in WOOLMOD**



2.4 Inventories demands

In constructing the WOOLMOD database differences between the value of total costs and total sales for a given good produced by a given industry, were eliminated by assigning the differences as the change in inventories or stocks. Thus the values for changes in stocks in the benchmark data do not represent actual or observed changes for the base year; these values have been created as a way of balancing the initial data set. Nevertheless, changes in industry stocks represent a component of industry sales. Thus, we must decide on some treatment of the behaviour of this component of industry sales. In order to minimise the influence of changes in stocks on WOOLMOD projections, we choose to set the change in the volume of stocks of good *i*, produced and held by industry *j* in region *r*, X_{ijr}^{S}, as an exogenous variable with zero change. We choose to define X_{ijr}^{S} as a *differential* or *actual change* variable rather than as a percentage-change variable, as the initial values of many of the (changes in) industry stocks are non-positive in the benchmark data. A differential or actual change variable will handle any alternative treatment of (changes in) industry stocks, whereby it is set as endogenous, with no difficulties if the initial value passes through zero. We note the actual change equivalent of X_{ijr}^{S} as dX_{ijr}^{S}.

2.5 The price systems

We have assumed that all firms in WOOLMOD operate in a competitive environment and are efficient. We will further assume that our benchmark data represents an equilibrium situation for all firms, factor owners (households), exporters and importers, in that no economic agent earns pure profits. We define basic values or prices as the value or price of a commodity received by the producer or importer from the purchaser, exclusive of (i) any taxes paid (or subsidies received) by the purchaser of the good, and (ii) any margin costs incurred in getting the good from the producer to the purchaser or user. We define purchasers' prices as the amounts paid by the purchaser to take receipt of a commodity from a producer or importer, inclusive of the basic price of the good and (i) and (ii) above. Thus, the basic value of a commodity will usually be equivalent across purchasers and producers for domestic goods, and across importers for imported goods.

2.5.1 Zero pure profits in current production

Most of the complexity associated with the distinction between basic prices and purchasers' prices is avoided in WOOLMOD, as the benchmark data includes only one form of tax (i.e., import duties) and no transport margins, on either domestic or imported goods. Given our assumptions about zero pure profits in current production and uniform basic values, the percentage-change form of the zero pure profits condition can be written in terms of the prices of composite outputs, composite intermediate inputs and the effective price of the primary factor bundle,

$$p_{jr}^{O} = \sum_{f=1}^{y} S_{fjr}^{O}\left(p_{jr}^{F} + a_{jr}^{F}\right) + \sum_{i=1}^{k} S_{ijr}^{O} p_{ijr}^{I}\,, \qquad f = 1,\dots,y; i = 1,\dots,k; j = 1,\dots,l; r = 1,\dots,c\,. \quad (2.20)$$

Equations (2.20) say that the percentage-change in the basic price of composite outputs received by industry *j* in region *r*, p_{jr}^{O}, is a cost-weighted average of the effective price of the primary factor bundle and the purchasers' prices of composite intermediate inputs. With no Hicks-neutral technical change, $a_{jr}^{F} = 0$, the basic price received by the firm will move strictly with the change in firm's costs. With no changes in any of the prices in (2.20), any improvement in technology relating to the use of the primary factor bundle, e.g., $a_{jr}^{F} < 0$, will initially raise the firm's activity level from a given set of primary factor inputs. At a given activity level, the firm's demand for primary factor inputs will fall. With no change in input or output prices, the ratio of revenue to costs will rise leading to non-zero pure profits, but this is prevented by (2.20) which will cause the both the *effective* price of the primary factor bundle and the basic price received by the firm to fall, thus restoring zero pure profits.

2.5.2 Zero pure profits in exporting

Exporters are also assumed to earn no pure profits. Thus, our second zero pure profits condition is

$$p_{isr}^{X} = p_{is}^{O}\,, \qquad i = 1,\dots,k; r, s = 1,\dots,c\,, \quad (2.21)$$

where p_{isr}^{X} is the f.o.b. price of good *i* exported from region *s* to region *r*, and p_{is}^{O} is the basic price of good *i* produced in region *s*. Thus, the f.o.b. price of exports by region *s*, to all destinations, is equal to the basic price of commodity *i* in region *s*. Equations (2.21) imply that there are no destination-specific export prices, and that each *r*-th importing region faces the same price for *i*-th good from the *s*-th region.

2.5.3 Zero pure profits in international shipping

The transport of exports from source regions' borders to destination regions' borders is assumed to occur at a constant proportion to the f.o.b. price. Thus the c.i.f. price of imports is related to the f.o.b. price of exports as follows,

$$\overline{p}^{M}_{isr} = p^{X}_{isr}, \qquad i = 1,...,k; r, s = 1,...,c, \qquad (2.22)$$

where $\overline{p}^{M}_{isr}$ is the c.i.f. price of good *i* from source region *s* imported by region *r*, p^{X}_{isr} has already been defined earlier as the f.o.b. price of good *i* exported from region *s* to region *r*. Equations (2.22) ensure that the international transport margins remain equal to their initial levels, i.e., zero, over the course of any model simulation.

2.5.4 Zero pure profits in importing

As is the case for firms and exporters, we assume that importers earn no pure profits. Thus, we write our third zero pure profits condition as

$$p^{M}_{isr} = \overline{p}^{M}_{isr} + t^{M}_{isr}, \qquad i = 1,...,k; r, s = 1,...,c, \qquad (2.23)$$

where p^{M}_{isr} is the basic price, $\overline{p}^{M}_{isr}$ is c.i.f. price, and t^{M}_{isr} is the *power* of the *ad valorem* tariff on good *i* from source region *s* imported by region *r*. p^{M}_{isr} is the price that importers pay and this includes any import duty applied on the good's c.i.f. price. Note also that (2.23) contains no exchange rate variable. As the WOOLMOD database is specified in common currency for all regions, i.e., $US, there is no need to convert c.i.f. prices, which are usually quoted in foreign currency terms, to domestic (currency) prices.

2.5.5 Purchasers' prices

We define prices for two purchasers, firms and households, as

$$pd^{I}_{ijr} = p^{O}_{ir}, \qquad i = 1,...,k; j = 1,...,l; r = 1,...,c, \qquad (2.24)$$

$$pm^{I}_{ijr} = p^{M}_{ir}, \qquad i = 1,...,k; j = 1,...,l; r = 1,...,c, \qquad (2.25)$$

$$p^{H}_{ir} = p^{O}_{ir}, \qquad i = 1,...,k; r = 1,...,c. \qquad (2.26)$$

Equations (2.24) and (2.26) set the purchasers' price of *domestic intermediate input i* used by industry *j* in region *r*, and the purchasers' price of good *i* consumed by *households* in region *r*, equal to the basic price of good *i* in region *r*, respectively. Equations (2.25) set the purchasers' price of *imported intermediate input i* used by industry *j* in region *r* equal to basic price of the *i*-th imported composite – the basic price of total imports of good *i* from all source regions.

2.6 The market-clearing conditions

There are two types of market-clearing equations imposed in WOOLMOD; one for the supply of and demand for domestically-produced commodities, another for the supply of and demand for imported commodities.

2.6.1 Domestic goods

The supplies and demands of domestic commodities are related to each other as follows,

$$V_{ir}^{O} x_{ir}^{O} = \sum_{j=1}^{l} VD_{ijr}^{I} xd_{ijr}^{I} + V_{ir}^{H} x_{ir}^{H} + V_{ir}^{S} x_{ir}^{S} + V_{ir}^{X} x_{ir}^{X} + fx_{ir}^{O} ,$$

$$i = 1,\ldots,k;\ j = 1,\ldots,l;\ r, s = 1,\ldots,c , \qquad (2.27)$$

where V is used to denote levels value of supplies or demands. Thus, the market-clearing conditions can be specified as the sum of the percentage changes in demand quantities, weighted by normalised values (i.e., prices set equal to 1), so that the LHS of (2.27) represents the output of commodity i by industry j in region r, summed across the l industries, giving the total output of i-th commodity in the r-th region. The RHS of (2.27) represents total sales of commodity i produced in region r, consisting of:

(i) sales of domestic commodity i for intermediate-input usage by industry j in region r summed across the l industries $\left(xd_{ijr}^{I}\right)$;

(ii) sales of commodity i for household consumption in region r $\left(x_{ir}^{H}\right)$;

(iii) sales of commodity i held as inventories by industry j in region r summed across the l industries $\left(x_{ir}^{S}\right)$; and

(iv) sales of commodity i produced and exported by region r to destination region s summed across the c destination regions $\left(x_{ir}^{X}\right)$.[12]

2.6.2 Imported goods

Our second set of market-clearing conditions relate the supplies and demands of imported commodities to each other, which in percentage changes are

$$V_{ir}^{M} x_{ir}^{M} = \sum_{j=1}^{l} VM_{ijr}^{I} xm_{ijr}^{I} , \qquad i = 1,\ldots,k;\ j = 1,\ldots,l;\ r = 1,\ldots,c , \qquad (2.28)$$

[12] Equations (2.27) also contain a shift variable, fx_{ir}^{O}, which allows us to “turn off” the market-clearing condition for particular commodities.

where x_{ir}^{M} is composite good *i* imported by region *r* (i.e., bilateral export quantities summed over all source regions), and xm_{ijr}^{I} is the quantity of imported good *i* used as an intermediate input by industry *j* in region *r*. Also note that as basic value (ex-duty) weights are used in (2.28), x_{ir}^{M} is the basic value (ex-duty) weighted import composite.

2.7 Wage relativities

In the short-run closure for WOOLMOD, land and capital is assumed to be nonshiftable between industries within any given region. Thus, the factor demand equations determine the prices of land and capital across industries in a given region. However, industry usage of labour is endogenous in the short-run closure. This requires that either employment relativities or wage relativities between industries within a region are held constant. We assume that industry wage relativities remain constant by indexing them to a common price. This assumes that, for a given a region, labour will move between industries in order to maintain wage relativities. Therefore, wage relativities are assumed to be at long-run equilibrium as reflected by the share of labour in industry costs from the benchmark data. Under this assumption, WOOLMOD determines how labour is to be distributed across industries (within a given region) in order to accommodate any exogenous shocks, while holding constant relative wages in all industries (in a given region).

Next, we must decide on the common indexing factor for industry wage rates. Our model only represents a small segment of the economy-wide use of labour in each region. Thus, it is reasonable to assume that any changes in demand for labour by raw wool and wool-products industries have no effect on the economy-wide wage rate in each region. So we fix the *national* wage rate in each region, and index industry wage rates to the national wage rate in all regions. Following this, we must decide on the degree, if any, of inter-regional labour mobility. Of the ten regions in the benchmark data,[13] inter-regional labour mobility is an issue for two groups of regions in particular: (i) the two subnational Australian regions – Western Australia (WA) and the Rest of Australia (ROA); and (ii) the four European Union regions – France, Germany, Italy and the United Kingdom (UK).

Being a single country with no legal or other barriers to internal migration, we would expect Australia to have relatively high degree of intra-regional labour mobility. Two recent studies confirm this expectation – see Dixon and Shepherd

[13] The ten regions are France, Germany, Italy, the United Kingdom, the United States of America, Japan, China, Western Australia, the Rest of Australia, and the Rest of the World.

(2001) and Lawson and Dwyer (2002). Thus, we do not treat the Australian regions as a single labour market.

As of 2004, the European Union (EU) is a common market made up of 25 European nations (EUROPA 2004b). Since 1993, all legal barriers to inter-regional migration have been removed within the EU, and labour is (potentially) free to move between the 25 member countries (EUROPA 2004a). But recent evidence suggests that the degree of labour mobility between EU members is limited – see Nahuis and Parikh (2002).[14] Thus, we do not treat the EU regions as a single labour market.

We implement the assumptions outlined above as follows. We divide the *c* regions into two groups or subsets, S_1, S_2. The first subset, S_1, is comprised of all national regions; France, Germany, Italy, the UK, the United States of America (USA), Japan, China, and the Rest of the World (ROW). Then, in percentage changes, we write

$$p^F_{fjr} = p^F_{fr}, \qquad f = labour; j = 1,...,l; r \in S_1, \tag{2.29}$$

where p^F_{fjr} is the price of labour used by industry *j* in region *r*, and p^F_{fr} is the national wage rate in region *r*. Thus, industry wage rates in subset S_1 will move with the national wage rate.

Next, we define the set of subnational Australian regions, $S_2 = WA, ROA$. We then write, in percentage changes,

$$p^F_{fjs} = p^F_{fr}, \qquad f = labour; j = 1,...,l; r = Australia; s \in S_2, \tag{2.30}$$

where p^F_{fr} in (2.30) is the national wage rate in Australia. Thus, industry wage rates for the (subnational Australian) regions in subset S_2 will move with the national (Australian) wage rate.

2.8 The complete model

As described earlier, we could represent the linear equations in WOOLMOD as in equations (2.2), which are reproduced below,

$$\boldsymbol{A}v = 0, \tag{2.31}$$

14 As further evidence of the heterogeneity of the EU labour market, Sjaastad (2004, p. 1) notes that "…98 per cent of the euro zone members of the labour force are employed in the country of their birth".

where $\boldsymbol{A}$ is an $m \times p$ matrix and v is the vector of the percentage-change (or change) variables in WOOLMOD. The m rows of the $\boldsymbol{A}$ matrix represent the number of linearised equations in WOOLMOD and the p columns represent the number of linear variables in WOOLMOD. Thus, $\boldsymbol{A}$ is rectangular as $m<p$, i.e., the number of variables exceeds the number of equations. Thus, $(p-m)$ variables must be set as exogenous, and most of these will have a value of zero.

Table 1 contains a list of exogenous variables for a short-run closure of WOOLMOD. Industry usage of land and capital, x^F_{fjr} (f = *land, capital*), is assumed to be nonshiftable. Thus, land and capital are assumed to be industry-specific in the short-run. With x^F_{fjr} (f = *land, capital*) set as exogenous, the industry demands for factors equations (2.5) – (2.6) determine the price of land and capital by industry, p^F_{fjr} (f = *land, capital*). WOOLMOD can project the effects on endogenous variables, such as output, exports, imports, etc., from exogenous changes in production technology. It cannot, however, project or determine technical change itself, consequently we set the two technical change variables, a^F_{fjr} and a^F_{jr}, as exogenous.

Table 1 **A possible list of exogenous variables for WOOLMOD**

Variable	*Subscript range*	*Description*
x^F_{fjr}	*f = land, capital*; *j* = 1,…,*l*; *r* = 1,…,*c*	Industry demands for land and capital
a^F_{fjr}	*f* = 1,..,*y*; *j* = 1,…,*l*; *r* = 1,…,*c*	Factor-specific technical change by industry
a^F_{jr}	*j* = 1,…,*l*; *r* = 1,…,*c*	Hicks-neutral technical change
dX^S_{ijr}	*i* = 1,..,*k*; *j* = 1,…,*l*; *r* = 1,…,*c*	Demands for (change in) industry inventories
t^M_{isr}	*i* = 1,..,*k*; *r*, *s* = 1,…,*c*	Power of import tariff
x^H_r	*r* = 1,…,*c*	Regional real household consumption
p^F_{fr}	*f = labour*, $r \in S_1$, *Aust*	National wage rates
p^O_{ir}	*i = other inputs, synthetics, sheep meat*; *r* = 1,…,*c*	Basic price of other inputs, synthetics, sheep meat

Section 2.4 discussed how the values for inventories in the WOOLMOD database are the result of the differences between the value of total costs and total sales in the initial data. Thus, in order to minimise the influence of changes in stocks on WOOLMOD projections, we choose to set the change in the volume of inventories, dX^S_{ijr}, as an exogenous variable with zero change. The only tax rate in WOOLMOD, the power of the tax on bilateral imports $\left(t^M_{isr}\right)$, is also set as exogenous. By setting

t^{M}_{isr} to nonzero values we can project the effects of changes in rates of protection (either multilateral, bilateral, or any other combination of interest) on the endogenous variables. Thus, we are able to observe the effects of historical changes in protection rates, or expected future changes in protection rates.

Next we set real household consumption in each region, x^{H}_{r}, as exogenous, as there is no reason to expect that changes in regional household consumption of sheep meat and retail garments should be affected by regional factor income generated by the raw wool and wool-products industries. For similar reasons we also set the national wage rates, $p^{F}_{fr}\left(f = labour, r = S_1, Aust\right)$, as exogenous, as there is no reason to expect changes in the demand for labour by the raw wool and wool-products industries to affect the national wage rate.

Our choice of exogenous variables is completed by fixing three price variables. The price of the 'other inputs' composite and synthetics is assumed to be exogenous and unchanging given that their costs are determined outside the model. We also fix the price of sheep meat given the sparse nature of our demand-side data for this commodity. At the same time, we set the shift variable in the market-clearing equations, fx^{O}_{ir} in (2.27), as endogenous for the other inputs composite, synthetics and sheep meat. This has the effect of "turning off' these market-clearing equations in the WOOLMOD system.

3 Data and parameters

3.1 Constructing the model database

The starting point for the WOOLMOD database is data provided by DAWA (2003), which contains information on production, consumption and trade in raw wool and wool-products commodities. The data is for 1995 and is specified in $US. However this database is not internally consistent. By remedying this we construct the basis of the WOOLMOD database. We describe this construction below.

First, we determine the imported intermediate inputs matrix at c.i.f. prices by adjusting it for consistency with bilateral trade matrix at c.i.f. prices. The imported intermediate inputs matrix at ex-duty values is then determined by applying import protection data for each region. Ad valorem import duty rates for 1995 are taken from IWS (1995) for all non-European countries. For Japan, China and Australia, *ad valorem* rates are taken directly from IWS (1995). *Ad valorem* rates for the ROW are calculated as the simple average of 13 countries.[15] *Ad valorem* rates for the US are calculated by combining *ad valorem* and specific duty rates.[16] For France, Germany, Italy and the UK, 1996 *ad valorem* import duty rates are used (TWC 2003).

Primary factor usage by industry provided by DAWA (2003) is presented as labour and 'fixed'. For the sheep industry we interpret fixed as the sum of land and capital usage; for each processing industry (that is, all other industries) we interpret 'fixed' as capital usage.[17] Where industries use only a single factor of production synthetic factor usage data is created by setting factor usage for the missing factor equal to the industry's average for all regions. The data on the 14 retail garment industries report only labour usage. We create synthetic capital usage for each of these regional industries by multiplying labour usage by the ratio of capital usage to labour usage in the regional *Wholesale and retail trade* industry in the GTAP 5 database (Dimaranan and McDougall 2002). For each regional sheep industry we split the usage of the land/capital composite in each regional sheep industry by applying the shares of capital and land in total capital/land usage from the equivalent regional *Wool* industry in the GTAP 4 database (McDougall, Elbehri and Truong, 1998).[18, 19]

The usage of non-wool non-factor inputs – the 'other inputs' composite[20] – is adjusted so that all regional industries which use factors, traded intermediate inputs and synthetic intermediate inputs, also consume the other inputs composite. We set household consumption of sheep meat and retail garments in each region equal to the value of production of these commodities in each region. We then compare industry costs and sales for consistency and find some differences, which we assign as the change in industry stocks.

15 The 13 are Canada, Chile, Hong Kong, Indonesia, Malaysia, Mexico, New Zealand, Papua New Guinea, Philippines, Singapore, South Korea, Taiwan and Thailand.

16 Specific duty rates are specified in cents per kilogram. These are converted to $US using quantity trade data provided by DAWA (2003).

17 So we assume that only the sheep industry uses land as a factor input.

18 China, Japan, the USA, the UK and Germany are all separate regions in GTAP 4, allowing them to be exactly mapped to equivalent regions in the data provided by DAWA (2003). Australia is used as a proxy for WA and the ROA. The rest of the European Union (excluding the UK and Germany) is used for France and Italy, and the average for all other GTAP 4 regions is used for the ROW.

19 The GTAP 4 shares are used for the sheep industry as it applies to 1995, which corresponds to the year of the data provided by DAWA (2003). The GTAP 5 shares are used for the retail garment industries as GTAP 4 does not contain a separate *Wholesale and retail trade* industry.

20 This composite represents inputs like fertilisers and water for the sheep industry, and electricity and dyes for processing industries.

3.2 Data summary

The full listing of WOOLMOD commodities is presented in appendix A. Table 2 presents the global cost shares by *broad* inputs for each *broad* industry in the resulting database. It is immediately apparent that the input-output tables are largely comprised of zeros, with positive values mostly along the diagonal. Also notice that the only common inputs across industries are the 'other inputs' composite and factors of production; most other inputs are specific to certain industries. Also note that sheep meat and retail garments are not used as inputs by any industry as their total output is consumed by the representative household in each region. As expected, we notice that the other inputs composite and factors of production comprise larger shares of total cost in late stage industries than in early stage industries.

Table 2 **Input cost shares by major industry, World** (fraction)

Broad inputs	*Broad industry*							
	Sheep	*Scoured wool*	*Carboni-sed wool*	*Worsted top*	*Yarn*	*Fabric*	*Whl/sale garment*	*Retail garment*
Sheep meat	0	0	0	0	0	0	0	0
Greasy wool	0	0.88	0	0	0	0	0	0
Scrd wool	0	0	0.79	0.74	0	0	0	0
Carb wool	0	0	0	0	0.13	0	0	0
Wrstd tops	0	0	0	0	0.20	0	0	0
Noils	0	0	0	0	0.02	0	0	0
Yarns	0	0	0	0	0	0.38	0.01	0
Fabrics	0	0	0	0	0	0	0.05	0
W/sale garm	0	0	0	0	0	0	0	0.39
Retail garm	0	0	0	0	0	0	0	0
Other inputs	0.28	0.02	0.04	0.05	0.27	0.23	0.44	0.09
Factors	0.72	0.10	0.17	0.21	0.39	0.39	0.51	0.52

Table 3 presents regional trade (value) shares by broad commodity. Note that there is no trade in sheep meat, retail garments and 'other inputs'. At the primary end of the wool pipeline note the dominance of Australia in exports of greasy, scoured and carbonised wool, with other major exporters forming part of the composite ROW region. Turning to carding and combing (i.e., worsted tops and noils), France, Germany, Australia and the ROW are dominant exporters. Italy's traditional importance in spinning (yarns) and weaving (fabrics) is reflected as the dominant exporter in these commodities, along with Germany and the ROW region. Exports of garment-making are dominated by Italy, China and the ROW region which contains other significant garment exporters such as Hong Kong and India.[21] Italy's dominance over China in garments partly reflects the relatively higher value nature of its exports.

Table 3 **Regional trade shares by major commodity** (fraction)

Broad commodities	*Exports at f.o.b. values*								
	France	*Germ*	*Italy*	*UK*	*USA*	*Japan*	*China*	*Aust*	*ROW*
Sheep meat	0	0	0	0	0	0	0	0	0
Greasy wool	0	0	0	0	0	0	0	0.88	0.12
Scrd wool	0.02	0.01	0.00	0	0	0	0	0.68	0.29
Carb wool	0.03	0.01	0.05	0.02	0	0	0	0.80	0.09
Wrstd tops	0.27	0.18	0.02	0.06	0.03	0	0	0.17	0.27
Noils	0.17	0.16	0.02	0.02	0.02	0	0	0.12	0.49
Yarns	0.05	0.28	0.36	0.11	0.01	0.03	0	0	0.16
Fabrics	0.06	0.17	0.51	0.08	0.01	0.07	0	0	0.10
W/sale garm	0.05	0.03	0.33	0.07	0.02	0	0.20	0	0.28
Retail garm	0	0	0	0	0	0	0	0	0
Other inputs	0	0	0	0	0	0	0	0	0
TOTAL	0.06	0.08	0.28	0.06	0.01	0.02	0.09	0.16	0.22
	Imports at c.i.f. values								
	France	*Germ*	*Italy*	*UK*	*USA*	*Japan*	*China*	*Aust*	*ROW*
Sheep meat	0	0	0	0	0	0	0	0	0
Greasy wool	0.13	0.11	0.20	0.04	0.04	0.05	0.21	0	0.22
Scrd wool	0.02	0.10	0.08	0.06	0.05	0.23	0.06	0	0.40
Carb wool	0.02	0.03	0.13	0.02	0.01	0.22	0.27	0	0.29
Wrstd tops	0.03	0.11	0.30	0.03	0.02	0.16	0.11	0	0.24
Noils	0.10	0	0.59	0.08	0.06	0.10	0.01	0	0.05
Yarns	0.07	0.11	0.16	0.12	0.04	0.04	0	0	0.47
Fabrics	0.06	0.17	0.03	0.05	0.05	0.09	0	0	0.55
W/sale garm	0.11	0.09	0.06	0.06	0.18	0.19	0.12	0	0.19
Retail garm	0	0	0	0	0	0	0	0	0
Other inputs	0	0	0	0	0	0	0	0	0
TOTAL	0.09	0.11	0.11	0.06	0.09	0.14	0.10	0	0.30

As expected, the distribution of imports across regions differs markedly from exports. The largest importers of early-stage processing commodities (greasy, scoured and carbonised wool) are those regions which are significant late-stage processors of wool (either for exports or domestic consumption), i.e., Italy, Japan, China and the ROW region. Italy and the ROW are also important importers at the carding and combing stage (i.e., worsted tops and noils). The largest importers of spinning and weaving commodities are Germany, Italy, the UK and,

[21] Note that the database is reflective of the mid-1990s, before China gained the dominant export position in garment-making.

overwhelmingly, the ROW. At the end of the wool pipeline we note the import dominance of large domestic users of garments, e.g., the USA and Japan, and large exporters, e.g., China and the ROW.

3.3 Model parameters

To parameterise WOOLMOD we use a combination of (i) consulting the literature on elasticities, and (ii) consulting experts on the wool industry. We base the CRESH elasticities of substitution for the sheep industry $\left(\sigma shp_{fr}^{F}\right)$ in the European regions on Salhofer (2000); these range from 0.2 to 0.35.[22] The values of σshp_{fr}^{F} for the Australian regions and the USA are based on O'Donnell and Woodland (1995); these range from 0.1 to 0.6.[23] The values of σshp_{fr}^{F} for China and the ROW are set between the values chosen for the Australian and European regions for land and labour (0.2 and 0.4, respectively), and greater than the values chosen for the Australian and European regions for capital (0.6).

The CES elasticities of substitution $\left(\sigma_{jr}^{F}\right)$ for all industries, except garment making, in all regions except China and the ROW are based on Ramcharran (2001), and are set at 0.3.[24] Following the results in Jha et al. (1993), we set the values of σ_{jr}^{F} for the same set of industries in China and the ROW at half those used for all other regions (0.15). The values of σ_{jr}^{F} for the garment making industries are assumed to be approximately twice those in other industries.

Following the advice of a wool industry expert,[25] the CES elasticities of substitution between imports from different sources $\left(\sigma_{ir}^{M}\right)$ are set at values which achieve close convergence of the percentage changes in prices of a given import from different sources (20). Similarly, the CES elasticities of substitution between imported and domestic intermediate inputs $\left(\sigma_{ir}^{I}\right)$ are set at values which achieve close convergence of percentage changes in prices of a given domestic and imported intermediate input. These assumptions are intended to reflect close to perfect substitution between given imports from different sources, and between

[22] See table 4, p.6. The elasticity value for land is set as simple average of mean values in columns 1 & 2; the value for labour is set as simple average of mean values in columns 1 & 3; and the value for capital is set as the simple average of mean values in columns 2 & 3.

[23] See table 2, p.560. The elasticity value for land is set as the simple average of value in column 1, rows 1, 5 & 9; the value for labour is set as the simple average of values in column 4, rows 4 & 12; and the value for capital is set as the simple average of values in column 2, rows 2, 6 & 10.

[24] See table 1 (p.521), column 4 (σ), final row (1993).

[25] Stanton, J., Department of Agriculture Western Australia, pers. comm., 31 May 2004.

given domestic and imported intermediate inputs. This is justified on the basis of the very detailed aggregation of the commodities in the database.[26]

The values of CES elasticities of substitution between composite intermediate inputs and carbonised wool, worsted tops and noils in non-EU regions $\left(\sigma c_{ir}^{I}\right)$ and for carbonised wool and noils in the EU regions are taken from Beare and Meshios (1990), and range from 1 to 1.9.[27] The values of σc_{ir}^{I} for worsted tops in the European regions and for synthetics in all regions are taken from Swan Consultants (1992) and set at 0.5.[28]

Following Connolly (1992) and Tulpule, Johnston and Foster (1992), we set the CET elasticity of transformation $\left(\theta_{jr}^{O}\right)$ for the sheep industry in all regions to 0.5, and to zero for all other industries in all regions.

The value of the income flexibility (ϕ) is taken from a number of studies supporting a value of -0.5, all of which are discussed in Clements, Lan and Zhao (2003, p.14). Values for the marginal budget shares (θ_i) are calculated as the product of the income elasticity of demand (θ_i/W_i) or η_i, and the actual budgets shares (W_i) which are taken from benchmark data. Values of η_i for sheep meat in France, the UK, the USA and the ROW, and retail garments in all regions are taken from Theil, Chung, and Seale (1989); these are set at 0.27, 0.33, 0.14, 0.5 and 0.96 respectively.[29] Values of η_i for sheep meat in China are taken from Sullivan et al. (1992) and set at 0.8.[30]

4 Enhanced productivity in Australian raw wool production and its effect on the world wool market

We demonstrate the usefulness of WOOLMOD by projecting the effects of an improvement in total factor productivity (TFP) in the Australian sheep industry. The

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26 Thus, we are rejecting the relevance of the Armington assumption at this level of commodity aggregation.

27 See table 4, p.64.

28 See table 5.3 (p.17): the values for worsted tops are simple average of own-price elasticities of Crossbred and Merino; the values for synthetics are the simple average of own-price elasticities of acrylic, polyester and nylon.

29 The values for meat in France, the UK, and the USA are taken from table 5-5 (p.106), column 4; for ROW we use the values for Argentina and Uruguay. The values for garments are taken from column 6.

30 As quoted in Wu (1999); table 3.7 (p.34), column 2, row 3.

effects of such a change are of interest for two reasons. First, due to the existence of levies on Australian wool producers which are used to fund research and development in wool production and downstream industries (AWIL 2004); the effects of research and development in raw wool production are of interest to industry stakeholders and analysts. Second, as the single largest producer and exporter of raw wool, industry stakeholders and analysts are also interested in understanding the effects of TFP improvement in the Australian sheep industry on the world wool market. WOOLMOD allows us to inform these issues on a number of levels: globally, regionally and by commodity. Thus, we apply a 5 per cent improvement in TFP in the Australian sheep industry. This is consistent with two to three years worth of annual TFP growth in the Australian agriculture, forestry and fishing industry, as estimated by Dixon and Rimmer (2002) from 1987 to 1994.[31]

4.1 The effects on sheep growers

The improvement in TFP initially reduces the demand for primary factors by Australian sheep growers at a given level of production. This places downward pressure on factor prices, however only the prices of fixed factors $\left(p_{LK}\right)$ (land and capital) are endogenous here, as the price of labour $\left(p_{N}\right)$ (the variable factor) is set as exogenous with zero change; the combination of lower prices for fixed factors and TFP improvement reduces the *effective* price of the primary factor bundle $\left(p_{FAC}\right)$. Thus, the price of each factor relative to the price of primary factor bundle (the "real" price) moves differentially: the "real" price of fixed and variable factors both rise, but the "real" price of labour rises by more. Following Adams (2003), we can use the changes in the "real" price of non-labour factors and labour to explain the use of factors by a given industry, as follows,

$$n_j-\left(l_j+k_j\right)=\sigma_{FAC_j}\left(rp_{LK_j}-rp_{N_j}\right). \qquad j=1,...,l \qquad (4.1)$$

where the ratio of labour $\left(n_j\right)$ to non-labour factors $\left(l_j+k_j\right)$ used by the *j*-th industry is a function of the ratio of the real price of non-labour factors $\left(rp_{LK\,j}\right)$ to the real price of labour $\left(rp_{N\,j}\right)$ in the *j*-th industry, multiplied by the elasticity of substitution between non-labour factors and labour $\left(\sigma_{FAC_j}\right)$ in the *j*-th industry (a positive parameter).

We can see from table 4 that $\left(rp_{LK\,j}-rp_{N\,j}\right)$ falls by around 10 per cent for the Australian sheep industry, thus encouraging a 1 per cent (roughly) fall in the use of

31 Table 5.5, p. 53.

labour, and a small contraction in value-added. Despite this, total (or gross) output rises by around 5 per cent – the full amount of the increase in TFP. The symmetry of the rise in gross output and TFP reflects the partial equilibrium nature of the model. With the price of labour (for all industries) and produced inputs (for the sheep industry) held constant, there are no output-constraining rises in the prices of labour and produced inputs in response to the increased demand for these inputs by the sheep industry. Hence, gross output is able to rise by the full extent of the reduction in the costs of factors of production.

Table 4 **Factor prices, factor usage and output for regional sheep industries** (percentage change)

Region[a]	p_{LK}[b]	p_N[c]	p_{FAC}[d]	rp_{LK}[e]	rp_N[f]	$rp_{LK} - rp_N$[g]	$n - (l+k)$[h]	va[i]	x^O[j]
France	-8.10	0	-7.01	-1.17	7.54	-8.10	-2.72	-0.38	-0.38
UK	-5.22	0	-4.52	-0.74	4.74	-5.22	-1.73	-0.24	-0.24
USA	-3.12	0	-2.70	-0.43	2.78	-3.12	-0.36	-0.05	-0.05
China	-7.07	0	-6.12	-1.01	6.51	-7.07	-1.57	-0.22	-0.22
Aust	-9.58	0	-13.19	3.67	14.66	-9.58	-1.15	-0.18	5.08
Rst Wrld	-5.93	0	-5.13	-0.84	5.41	-5.93	-1.32	-0.18	-0.18

[a] Germany, Italy and Japan do not have a sheep industry. [b] Price of non-labour factors. [c] Price of labour (exogenous). [d] Effective price of the primary factor composite. [e] Real price of non-labour factors. [f] Real price of labour. [g] Ratio of rp_{LK} to rp_N. [h] Ratio of labour to non-labour factors. [i] Value-added. [j] Gross output.

The expansion in gross output by the Australian sheep industry is sufficiently high to lead to increased production of all outputs (table 5). There are, however, large differences in the size of the expansion for different outputs. The TFP improvement reduces the prices of all types of greasy wool (GW), but the price of sheep meat is exogenous in our simulation. Hence, the relative price of sheep meat rises while the relative price of all types of greasy wool falls. The result is sheep meat output rising by more than any other sheep industry output (around 10 per cent). The allocation of output across greasy wool types is a pure reflection of the relative prices of each greasy wool type, as the CET supply elasticity is constant across all sheep industry outputs (in Australia and in all other regions).

Three types of GW stand out for significant output increases in Australia: DH-, D+H-, and D+H. These three wool types are, generally, those parts of the world wool market in which Australia has the least market power (in terms of export shares).[32] Thus, the *global* export supply curves for these wools do not closely approximate the Australian export supply curves (due to significant production by regions other than Australia), whereas the *global* export supply curves for wools in which Australia has little or no significant competition closely approximate the

[32] Even though other regions export GW DH Australia is the dominant exporter at around 80 per cent of global output.

Australian export supply curves (i.e., GW D-H-, D-H, DH, D-H+, DH+, D+H+). Consequently, when the Australian export supply curves shift downwards and outwards (due the improvement in TFP), the result is a smaller price fall for the DH-, D+H-, and D+H wools (both in Australia and globally) than is the case with other wool types. With smaller relative price reductions for DH-, D+H- and D+H, Australian growers swing their production towards these wools.

Table 5 **Commodity supplies and prices by regional sheep industry**
(percentage change)

Region[a]	*Sheep meat*	*Greasy wool*								
		D-H-[b]	*DH-*[c]	*D+H-*[d]	*D-H*[e]	*DH*[f]	*D+H*[g]	*D-H+*[h]	*DH+*[i]	*D+H+*[j]
	Output									
France	2.28	**na**	-0.28	**na**	**na**	-3.70	**na**	**na**	**na**	**na**
UK	1.45	**na**	**na**	-0.25	**na**	-5.30	**na**	**na**	**na**	**na**
USA	0.95	**na**	-0.54	**na**	**na**	**na**	**na**	**na**	**na**	**na**
China	2.09	**na**	-0.29	0.12	**na**	-3.66	-1.21	**na**	**na**	**na**
Aust	10.27	2.20	5.69	7.17	1.18	2.48	4.96	1.07	1.50	1.05
Rst Wrld	1.74	**na**	-0.79	-0.20	**na**	-5.05	-1.53	**na**	**na**	**na**
World	6.71	2.20	0.68	0.21	1.18	1.03	0.18	1.07	1.50	1.05
	Prices									
France	0	**na**	-4.93	**na**	**na**	-11.35	**na**	**na**	**na**	**na**
UK	0	**na**	**na**	-3.33	**na**	-12.87	**na**	**na**	**na**	**na**
USA	0	**na**	-2.94	**na**	**na**	**na**	**na**	**na**	**na**	**na**
China	0	**na**	-4.60	-3.82	**na**	-10.94	-6.36	**na**	**na**	**na**
Aust	0	-14.10	-8.14	-5.61	-15.84	-13.62	-9.42	-16.05	-15.28	-16.05
Rst Wrld	0	**na**	-4.91	-3.78	**na**	-12.92	-6.34	**na**	**na**	**na**
World	0	-14.10	-5.50	-3.86	-15.84	-13.33	-7.13	-16.05	-15.28	-16.05

a Germany, Italy and Japan do not have a sheep industry. **b** Diameter <20 μm; hauteur <56 mm. **c** Diameter 20-23 μm; hauteur <56 mm. **d** Diameter >23 μm; hauteur <56 mm. **e** Diameter <20 μm; hauteur 56-65 mm. **f** Diameter 20-23 μm; hauteur 56-65 mm. **g** Diameter >23 μm; hauteur 56-65 mm. **h** Diameter <20 μm; hauteur >65 mm; **i** Diameter 20-23 μm; hauteur >65 mm. **j** Diameter >23 μm; hauteur >65 mm. **na** Not applicable.

On the demand side, note that, in general, demand for all wools, whether raw (such as GW) or transformed (such as scoured and carbonised), is essentially inelastic. That is, for the most part we assume that wool inputs are combined in fixed proportions with each other and with other non-wool inputs. Thus, we should note that, in general, any outward and downward shift in the supply function for a given type of wool, whether raw or transformed, will lead to larger price changes than quantity changes. This is evident if we compare the global price and quantity effects in table 5; price changes dominate quantity changes. This is consistent with long term documented evidence of large variability in the prices of primary commodities (see, for instance, Cashin and McDermott 2001). The exceptions to this general input demand characteristic are the yarn or spinning industries, for which it is assumed that the various wool inputs and synthetics are substitutable depending on the behaviour of relative prices. In this case, our parameter choices determine that coarser wools (i.e., >23 μm) are more price responsive than finer wools (i.e., ≤ 23 μm).

Being the single most dominant exporter of raw wool, the TFP induced expansions in output by the Australian sheep industry make other wool producers less competitive in terms of price. Thus, we see from table 5 that production of nearly all raw wools by other regions falls, reflected mainly by lower domestic sales but also lower export sales. With demand for raw wools in the non-Australian regions shifting away from domestic producers and towards Australian imports, they attempt to reduce output. In doing so, the prices of their fixed factors fall by more than the variable factor, causing $\left(rp_{LK\,j} - rp_{N\,j}\right)$ to fall and encouraging substitution away from the variable (and now relatively more expensive) factor of production (see table 4).

To the extent that Australian imports of GW compete with domestically-produced GW, the more reliant domestic wool processors are on GW imports in general, and on Australian imports of GW in particular, the more the domestic production of GW is affected. Furthermore, the pattern of GW output by domestic sheep growers also affects the extent to which their output contracts due to cheaper Australian imports. Thus, we observe that GW production falls least in the USA (e.g., -0.5 per cent) as they only produce GW DH-, which suffers the lowest global price fall of all GW types due to Australia's relatively low market power in this type of wool. Cf. with France which experiences the largest reduction in overall GW output (e.g., -1.7 per cent [not reported]); a large proportion of GW output in France consists of DH wool, which experiences a relatively large price fall due to Australia's relatively high market power in this type of wool.

4.2 The effects on early-stage processors

We use the term 'early-stage processors' here to refer to industries which are at later stages of production than sheep growers but at earlier stages of production than spinning (or yarn production), i.e., in terms of the broad industries identifiable in WOOLMOD these are the scouring, carbonising and carding/combing (or worsted top) industries. There are nine distinct scouring industries in WOOLMOD (see appendix A for a full listing). Thus, for the purposes of presenting the effects on domestic, export and total sales for these industries we aggregate them (table 6). Notice that, in general, scouring industries benefit from the TFP improvement in Australia; either via cheaper GW imports or cheaper domestic GW inputs, both a result of cheaper Australian GW imports driving down the world price of all types of GW. With GW making up a large proportion of input costs in scouring (see table

2) and the prices of all GW types falling significantly, the output-expanding effects are, in general, quite large. The sign of the regional output changes for different types of scoured wool (SW) generally follows the *broad* SW results in table 6. The pattern of the output changes across SW types approximate the pattern observed in table 5 across GW types; GW types (used as inputs) which experience the largest price falls induce, in turn, the largest falls in production costs, increases in demand and output for equivalent SW types.

Table 6 **Domestic, export and total sales for regional *broad* early-stage processing industries**

Region	*Scouring*			*Carbonising*			*Worsted top*		
	xd^{a}	$x^{X b}$	$x^{O c}$	xd^{a}	$x^{X b}$	$x^{O c}$	xd^{a}	$x^{X b}$	$x^{O c}$
France	0.80	0.04	0.84	0.38	-0.14	0.24	0.43	0.47	0.90
Germ	1.01	0.20	1.22	0.93	-0.31	0.62	0.57	0.38	0.95
Italy	0.87	0.05	0.92	0.68	0.00	0.67	0.86	0.03	0.88
UK	1.28	-0.17	1.11	0.45	0.04	0.48	0.53	2.48	3.03
USA	1.51	**na**	1.51	0.82	**na**	0.82	0.98	0.72	1.70
Japan	-0.34	**na**	-0.34	1.89	**na**	1.89	0.86	-0.02	0.84
China	0.40	**na**	0.40	0.43	**na**	0.43	0.54	**na**	0.54
Aust	0.65	1.37	2.03	**na**	1.34	1.34	**na**	2.54	2.54
Rst Wrld	0.34	0.04	0.38	0.48	-0.01	0.47	0.51	0.20	0.71

[a] Share-weighted percentage change in domestic sales. [b] Share-weighted percentage change in export sales. [c] Percentage change in output. [na] Not applicable.

Notice that scouring industries expand in all regions, except Japan, from lower prices of raw wool. The regional scouring industries which benefit most from lower GW prices are those in Australia, Germany and the USA. In general, the pattern of SW production in these regions is such that they benefit more than other regions from the pattern of lower GW prices. That is, SW production in these regions is skewed towards GW types whose global price falls most (i.e., D-H-, D-H, DH, D-H+, DH+, D+H+). For Japan, total SW output falls as its SW industries are relatively low intensive users of wool inputs. Thus, the SW industries in Japan do not benefit from lower GW prices by as much as SW industries in other regions.

Table 7 presents the global output and price effects for scoured wool by diameter and hauteur. The pattern of these effects is generally repeated across regions. Comparing the global price and output effects for individual raw wools in table 5 with the global price and output effects for individual scoured wools in table 7, we see those raw wools which experience large relative falls in price and large output increases similarly affect their scoured wool counterparts. Thus, the output of longer scoured wools (D-H+, DH+, and D+H+) increases significantly. Similarly, the output of finer scoured wools (D-H-, D-H, and D-H+) also increase significantly.

Table 7 Global commodity supplies and prices of early-stage wool commodities (percentage change)

Variable	D-H-[a]	DH-[b]	D+H-[c]	D-H[d]	DH[e]	D+H[f]	D-H+[g]	DH+[h]	D+H+[i]
					Scoured wool				
Output	2.20	0.65	0.20	1.18	1.01	0.22	0.99	1.43	1.05
Price	-11.46	-4.04	-2.00	-14.05	-10.39	-5.52	-11.87	-12.21	-12.81
		Carbonised wool				*Worsted tops*			
Output	2.15	0.65	0.19	1.11	0.96	0.21	0.95	1.37	1.02
Price	-2.53	-0.89	-0.45	-4.94	-3.97	-3.29	-4.43	-4.22	-3.68

[a] Diameter <20 μm; hauteur <56 mm. [b] Diameter 20-23 μm; hauteur <56 mm. [c] Diameter >23 μm; hauteur <56 mm. [d] Diameter <20 μm; hauteur 56-65 mm. [e] Diameter 20-23 μm; hauteur 56-65 mm. [f] Diameter >23 μm; hauteur 56-65 mm. [g] Diameter <20 μm; hauteur >65 mm; [h] Diameter 20-23 μm; hauteur >65 mm. [i] Diameter >23 μm; hauteur >65 mm.

At the next stage of production, shorter scoured wools (i.e., <56 mm) enter the woollen system as inputs to carbonised wool whereas scoured wools of ≥56 mm hauteur enter the worsted system as inputs to worsted tops. Similar to the presentation of results for the scouring industries, we aggregate the results for the three carbonising and six worsted top (WT) industries into broad industries and present the results in table 6. Note that, in general, the worsted top industries expand by more than the carbonising industries. With longer scoured wools experiencing larger price falls relative to the shorter wools, the users of longer scoured wools – worsted top producers – benefit more from larger relative falls in production costs compared with users of the shorter scoured wools – carbonised wool producers. This is confirmed in table 7 which indicates that, in general, the global prices of H and H+ worsted tops fall by more that the global prices of the H- carbonised wools. We note here the continuing effect of relatively inelastic derived demands for wools causing large price effects relative to quantity effects.

Comparing aggregate carbonised wool (CW) industries across regions, Japan and Australia experience the largest expansions. Australian CW industries benefit directly from cheaper SW inputs that are 100 per cent locally sourced, further, almost 100 per cent of the output of the Australian CW industries is exported and thus faces very price sensitive demand curves. CW industries in Japan benefit more than CW industries in other regions due to (i) their relatively intensive use of imported SW inputs, and (ii) their relatively intensive use of SW imports from Australia. Thus, their production costs are reduced by more than those of CW industries in other regions (besides Australia) and therefore they experience relatively larger output-expanding effects.

Similarly comparing aggregate WT industries across regions, we note that these industries expand by more in the UK, the USA and Australia cf. other regions. The explanation for Australia is similar to that for the strong expansion in the CW industries – all wool inputs are 100 per cent locally sourced and almost 100 per cent of the output is exported. For the WT industries in the UK and the USA the strong expansion in output is due to the combination of relatively intensive use of wool inputs (particularly for DH wool), thus allowing production costs to fall by more than in other regions, and the relatively strong export orientation (especially the UK) and consequent price sensitive nature of the demand for their output.

4.3 The effects on late-stage processors

Carbonised wool and worsted tops are used as inputs into the manufacture of yarn (or spinning). We refer to all stages of production from the spinning industries onwards as late-stage processors. Hence, this will include the spinning industries, the manufacture of fabrics (or weaving industries) and, finally, garment-making (both wholesale and retail). Yarn production is divided between worsted and woollen yarns. Both worsted yarns and woollen yarns are further separated between pure (i.e., purely woollen or purely worsted) and blended (i.e., woollen blended with synthetics, or worsted blended with synthetics).

We notice a clear pattern emerging in the output and price effects on yarns (table 8). Yarns in the worsted system experience the largest increases in output and falls in price relative to yarns entering the woollen system. There are two reasons for this. First, worsted yarn producers are users of longer wool tops (i.e., ≥ 56 mm) and these wools have already been identified as experiencing the largest relative price falls, whereas woollen yarn producers are users of the shortest wool tops (i.e., <56 mm) and these wools have already been identified as experiencing the smallest relative price falls. Hence, the users of the longer wools experience larger relative falls in production costs and output prices, themselves leading to larger relative increases in production. Second, the woollen spinning industries are much heavier users of non-wool non-factor inputs, i.e., the 'other inputs' composite, compared with the worsted spinning industries. Thus, the woollen spinning industries are relatively less reliant on wool inputs and hence do not benefit to the extent that the worsted spinning industries do when TFP improvement reduces raw wool prices.

Although not readily discernible from the results presented in table 8, the spinning industries in France, in aggregate, experience the largest increases in output (0.64 per cent) compared with all other regions (0.09 per cent or less). Spinning industries in France are much more intensive users of wool inputs [as opposed to synthetics and other (non-wool) inputs] than other regional spinning industries. With spinning industries having the ability to substitute between different wool inputs, and between wool inputs and synthetics, spinning industries in France are able to exploit their relatively intensive use of wool inputs by substitution into inputs whose prices are falling (i.e., wool inputs) and away from inputs whose prices are fixed (i.e., synthetics). This leads to a large export-driven expansion in the output of French spinning industries, as their production costs fall by more than for spinning industries in other regions.

Table 8 **Commodity supplies and prices by regional yarn and fabric industries** (percentage change)

Region	*Yarns*					*Fabrics*					
	Wrs Bl[a]	*Wrs PuLw*[b]	*Wrs PuHw*[c]	*Wol Bl*[d]	*Wol Pu*[e]	*Wrs BlWv*[f]	*WrsPu LwWv*[g]	*WrsPu HwWv*[h]	*Wrs Kn*[i]	*Wol BlWv*[j]	*Wol PuWv*[k]
						Output					
France	1.20	**na**	1.50	0.04	0.03	0.19	-0.09	0.42	0.09	0.00	0.01
Germ	1.31	-0.38	-0.04	0.04	0.16	0.32	0.02	0.04	**na**	0.00	0.00
Italy	-0.28	0.21	-0.33	0.00	0.01	0.06	0.15	0.17	-0.02	0.00	0.04
UK	-0.22	1.70	-0.04	0.01	-0.01	0.00	-0.17	0.02	0.03	-0.01	0.00
USA	0.32	0.55	0.08	0.01	0.02	0.54	0.06	0.21	0.19	0.00	0.01
Japan	-0.03	0.56	0.15	-0.01	0.02	-0.02	0.06	0.11	0.37	0.00	0.03
China	0.05	0.02	0.02	0.00	0.00	0.05	0.02	0.02	0.04	0.00	-0.01
Aust	**na**	**na**	**na**	**na**	**na**	**na**	**na**	**na**	**na**	**na**	**na**
Rst Wrld	0.30	0.81	0.43	0.00	0.00	0.02	-0.09	0.01	-0.09	0.00	0.00
World	0.08	0.08	0.10	0.00	0.00	0.06	0.06	0.06	0.10	0.00	0.00
						Prices					
France	-2.25	**na**	-2.75	-0.12	-0.26	-0.61	-1.26	-0.61	-0.85	-0.05	-0.11
Germ	-2.19	-2.16	-2.50	-0.13	-0.27	-0.62	-1.26	-0.59	**na**	-0.05	-0.12
Italy	-1.93	-2.27	-2.33	-0.10	-0.21	-0.62	-1.28	-0.63	-1.10	-0.05	-0.12
UK	-1.96	-2.35	-2.48	-0.12	-0.24	-0.45	-1.25	-0.57	-1.28	-0.05	-0.12
USA	-1.21	-2.36	-2.40	-0.11	-0.23	-0.41	-1.14	-0.36	-1.17	-0.04	-0.10
Japan	-1.03	-2.53	-2.34	-0.11	-0.26	-0.51	-1.26	-0.57	-1.64	-0.05	-0.14
China	-2.79	-4.29	-3.05	-0.14	-0.21	-0.66	-1.57	-0.58	-0.87	-0.05	-0.12
Aust	**na**	**na**	**na**	**na**	**na**	**na**	**na**	**na**	**na**	**na**	**na**
Rst Wrld	-2.19	-2.54	-2.67	-0.11	-0.22	-0.59	-1.22	-0.56	-1.17	-0.04	-0.11
World	-2.02	-2.36	-2.59	-0.11	-0.23	-0.60	-1.28	-0.58	-1.20	-0.05	-0.11

a Worsted blended yarn. **b** Worsted pure lightweight yarn. **c** Worsted pure heavyweight yarn. **d** Woollen blended yarn. **e** Woollen pure yarn. **f** Worsted blended woven fabric. **g** Worsted pure lightweight woven fabric. **h** Worsted pure heavyweight woven fabric. **i** Worsted knitted fabric. **j** Woollen blended woven fabric. **k** Woollen pure woven fabric. **na** Not applicable.

The pattern of output and price effects on the fabric or weaving industries mirror those of the spinning industries but with greater divergence; worsted fabric industries experience expansions in output and price falls while woollen fabric industries experience no discernible output expansions and relatively small price falls (see table 8). Comparing different worsted fabric types, we note the relatively large increase in output of worsted knitted fabrics. Worsted knitted fabrics are produced using a combination of three worsted yarns: (i) blended; (ii) pure lightweight; and (iii) pure heavyweight. Of these three yarns, the most important is pure heavyweight which also experiences the largest global price fall of these three inputs. Further, worsted knitted fabrics are heavier users of wool inputs compared with other worsted fabrics. This reduces production costs for worsted knitted fabrics by more than other worsted fabrics and, hence, leads to a larger expansion in output.

Fabric industries in France also experience the largest expansion in output (0.19 per cent), with the USA and Japan experiencing smaller increases (0.1 per cent). In contrast to all previous stages of production, these increases in output are driven by increased sales of fabric to the domestic (wholesale) garment-making industries.

Turning to the final stage of production – garment-making – we note the continuation of the now well-worn trend of worsted products experiencing larger relative output expansions and larger relative price reductions, at both the wholesale and retail stages of production (see table 9). With the relative prices of worsted retail garments falling more than woollen retail garments, final consumption on worsted garments expands by more than consumption on woollen garments. The divergence in the output of the worsted and woollen garments also drives the changes in broad wholesale garment-making industries in each region; France (0.007 per cent), the USA (0.1 per cent) and Japan (0.005 per cent) experience the largest increase increases in output and this is almost exclusively due to expansions in the worsted garment-making sectors at the expense of the woollen garment-making sectors.

Note the relatively small changes in global output and prices for retail garments. Our model suggests that a significant improvement in TFP in the world's largest primary producer and exporter of raw wool will a have relatively minor short-run effect on the retail consumption of woollen garments. This result may seem paradoxical but it is not altogether strange; it can be explained as follows. We see from table 2 that, globally, wool inputs account for around 6 per cent of total costs for the broad wholesale garment industries. Thus, even significant changes in the costs of these inputs will lead relatively small changes in retail garment prices. This suggests that changes in the price of margins – 'other inputs' – will be relatively more important in affecting the retail price of garments. Further, it not unusual for retail prices of most commodities to be relatively stable in the short-term. Thus, we should not expect significant changes in TFP in the primary production of wool to lead to significant short-run changes in the retail price of woollen garments. Further, small short-run changes in the retail price of woollen garments will also mean small short-run changes in output of woollen garments.

Table 9 **Global supplies and prices by garment-making industries**
(percentage change)

Wholesale garments			*Retail garments*		
	Output	*Price*		*Output*	*Price*
MnWrsBlWv[a]	0.05	-0.24	MnWrsBlWv[a]	0.04	-0.04
WmWrsBlWv[b]	0.02	-0.23	WmWrsBlWv[b]	0.02	-0.06
MnWrsPuWv[c]	0.03	-0.28	MnWrsPuWv[c]	0.03	-0.08
WmWrsPuWv[d]	0.04	-0.39	WmWrsPuWv[d]	0.04	-0.10
MnWrsKn[e]	0.10	-0.86	MnWrsKn[e]	0.09	-0.20
WmWrsKn[f]	0.05	-0.43	WmWrsKn[f]	0.04	-0.13
MnWolBlWv[g]	0.00	0.00	MnWolBlWv[g]	0.00	0.00
MnWolPuWv[h]	0.00	0.00	MnWolPuWv[h]	0.00	0.00
WmWolBlWv[i]	0.00	-0.03	WmWolBlWv[i]	0.00	-0.01
WmWolPuWv[j]	0.00	-0.05	WmWolPuWv[j]	0.00	-0.02
WolBlKn[k]	0.00	-0.03	MnWolBlKn[m]	0.00	-0.01
WolPuKn[l]	0.00	-0.06	WmWolPuKn[n]	0.00	-0.01
			MnWolPuKn[o]	0.00	-0.02
			WmWolPuKn[p]	0.00	-0.02

[a] Mens' worsted blended woven garments. [b] Womens' worsted blended woven garments. [c] Mens' worsted pure woven garments. [d] Womens' worsted pure woven garments. [e] Mens' worsted knitted garments. [f] Womens' worsted knitted garments. [g] Mens' woollen blended woven garments. [h] Mens' woollen pure woven garments. [i] Womens' woollen blended woven garments. [j] Womens' woollen pure woven garments. [k] Woollen blended knitted garments. [l] Woollen pure knitted garments. [m] Mens' woollen blended knitted garments. [n] Womens' woollen blended knitted garments. [o] Mens' woollen pure knitted garments. [p] Womens' woollen pure knitted garments.

4.4 Sensitivity analysis

In choosing the behavioural parameters for WOOLMOD we rely on a combination of (i) consulting the literature on elasticities, and (ii) consulting experts on the wool industry. Whichever approach is taken uncertainty about the parameter values chosen should be acknowledged. To explicitly acknowledge this uncertainty we employ the technique developed by Pagan and Shannon (1985) and calculate sensitivity (*S*) elasticities – the elasticity of the solution value of an endogenous variable with respect to a parameter value. More formally, following Pagan and Shannon (1987), let γ be a solution value for a(n endogenous) model variable which is a function of θ, a model parameter. Then the *S* elasticity can be approximated by $\Delta\gamma/\Delta\theta$, where $\Delta\gamma$ is the change in γ from varying θ by the amount $\Delta\theta$.

We calculate the *S* elasticities for all WOOLMOD parameters and present the results in table 10. To restrict to a manageable number the *S* elasticities computed, we choose for γs the global output of each broad commodity. We calculate the *S* elasticities for all parameters in the model; thus we vary all components of a given parameter simultaneously. Pagan and Shannon (1985) consider that *S* elasticities of around 0.5 or more, in absolute value, should be of concern, but only if the solution value is significant. To help in evaluating the *S* elasticities we present in table 10 the solution values for global output of each broad commodity; notice that only the values for the primary production of wool and early-stage processing wool products are significant. Thus, we suggest, only significant *S* elasticities for these results should be of concern.

Table 10 **Sensitivity (*S*) elasticities for various WOOLMOD parameters**[a]

Global output[b]		σ_{ir}^{M} [c]	σdm_{ir}^{I} [d]	θ_{jr}^{O} [e]	σshp_{fr}^{F} [f]	σ_{jr}^{F} [g]	σc_{ir}^{I} [h]	ϕ [i]	η_i [j]
Sheep meat	(6.71)	0.00	0.00	0.22	-0.06	-0.11	-0.04	0.00	0.00
Greasy wool	(0.86)	0.01	0.00	-0.49	-0.05	0.56	0.19	0.01	0.01
Scoured wool	(0.82)	0.01	0.01	-0.48	-0.05	0.54	0.19	0.01	0.01
Carb wool	(0.55)	0.01	0.02	-0.39	-0.08	0.57	0.10	0.00	0.00
Worsted tops	(0.94)	0.00	0.00	-0.53	-0.04	0.51	0.23	0.01	0.01
Noils	(0.93)	0.01	0.00	-0.52	-0.04	0.53	0.23	0.01	0.01
Yarns	(0.03)	0.15	0.08	-0.50	-0.04	0.86	-0.56	0.27	0.23
Fabrics	(0.03)	0.14	0.05	-0.51	-0.04	0.84	-0.55	0.32	0.21
Whl garments	(0)	**na**	**na**	**na**	**na**	**na**	**na**	**na**	**na**
Ret garments	(0.00)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

a All components of each parameter are varied together. **b** Bracketed figures are percentage changes in original solution. **c** Import source elasticities. **d** Import/domestic elasticities. **e** Elasticities of transformation across outputs for the sheep industries. **f** Elasticities of factor substitution for the sheep industries. **g** Elasticities of factor substitution for non-sheep industries. **h** Elasticities of substitution between composite intermediate inputs. **i** Income flexibility. **j** Income elasticities of demand. **na** Not applicable – an *S* elasticity cannot be calculated where the original solution value is zero.

Using the criteria already outlined, there are only two groups of *S* elasticities of concern: (i) the elasticities of transformation across outputs by the sheep industries $\left(\theta_{jr}^{O}\right)$; and, (ii) the elasticities of factor substitution by non-sheep industries $\left(\sigma_{jr}^{F}\right)$. In each case, the *S* elasticities are around 0.5 (in absolute values), i.e., a 1 per cent increases in the absolute values of each of each of these parameters causes the solution value for global output of each commodity to rise by around 0.5 per cent.[33] Both of these parameters affect the slope of the supply curves for commodities produced by each of these groups of industries. Thus, flatter supply curves lead to larger quantity responses in the simulation evaluated earlier. This result is consistent with Pagan and Shannon (1987), where parameters determining the slope of the supply curves were found to be more important than those determining the slopes of the demand curves, for a simplified economy-wide model of the Australian economy. These results suggest that individually estimating these parameter values for each region and broad industry is probably the most important estimation task which would aid analysing TFP improvements using WOOLMOD.

[33] Note that θ_{jr}^{O} is a negative (transformation) parameter while σ_{jr}^{F} is a positive (substitution) parameter, thus the *S* elasticities are <0 and >0 for each parameter, respectively.

All parameter values chosen for WOOLMOD, except two, are taken from the literature: (i) the import source elasticities of substitution, σ_{ir}^{M}; and (ii) the import/domestic elasticities of substitution, σdm_{ir}^{I}. These were based on the view that the commodity detail in WOOLMOD is such that very close to perfect substitution can be assumed for a given good wherever it is produced. It is reassuring that the *S* elasticities for these two parameters are close to zero. Thus, our assumption is not a crucial one with respect to the global output of each broad commodity in WOOLMOD.

5 Conclusion

This paper provides a technical description of WOOLMOD – a detailed short-run, comparative-static model of the world wool market. The framework incorporates aspects of the applied general equilibrium tradition. It models the production of raw wool, through six stages of processing, ending in the production of retail garments in 10 regions of the world, and each region is linked via bilateral trade flows. The model distinguishes 560 separate industries and around 38,000 separate wool commodities in total. The combination of a high degree of commodity and industry detail, the comprehensive modelling of the production of raw wool through to its end use, and bilateral trade between all major producing and consuming regions represents the major contribution of this work. It allows changes in very specific parts of the world wool market, both geographically and by production stage, to be modelled with a high degree of detail. As such, the framework is useful to industry analysts, policy makers and wool researchers alike.

The model represents a short-run environment, that is, industry land and capital stocks are fixed in each region, whereas labour usage is variable. Under this environment we illustrate the usefulness of the model by simulating two to three years' worth of total factor productivity (TFP) improvement in the Australian sheep industry – the world's largest single producer and exporter of raw wool. The model allows us to evaluate the transmission mechanisms of the world wool market as the effect of the TFP improvement is transferred to other regions via changes in factor prices and usage, and trade volumes and prices. With Australia being the largest producer and exporter of raw wool, the TFP improvement leads to significant price, output and trade effects on the wool economies of other regions.

At the primary end of the market, raw wool production and exports increase by Australia at the expense of other raw wool producers. This trend does not continue for early- and late-stage processing industries; cheaper raw wool imports from Australia and other regions reduces production costs for industries using raw wool inputs, and this generally benefits all regions in terms of increased output. The effects on early-stage processing industries (scouring, carbonising and top making) are broadly significant. The TFP improvement generally reduces the prices of finer and longer wools by more than other wools. This benefits wools entering the worsted system over wools entering the woollen system. Once the TFP change has reached the late-stage processing end of the market, the effects become much less significant as non-wool inputs (factors of production and 'other inputs') become a significant proportion of production costs. However, the effects are still generally positive for all regions with a bias towards those regions whose production is concentrated towards worsted yarns, fabrics and retail garments. At the retail end of the market, the effects on output and prices have dissipated almost completely but they are still generally favourable for all regions and particularly for the consumption of worsted garments.

The framework presented here can be developed further in a number of ways. The model currently assumes that the price of wool fibre substitutes – synthetics – and non-wool non-factor inputs to the production process are exogenous. Further, the price of fixed factors in each region is driven solely by fixed factor demands by wool and wool products industries, and the price of labour is assumed to be exogenous. These assumptions are unrealistic; however they can be relaxed by adding to WOOLMOD a generic industry representing the rest of the economy. This would allow the development of full general equilibrium closure. In this way, the price of wool fibre substitutes can be determined by the costs of producing wool fibre substitutes, and the price of factors can determined by the relative demand of all industries in a region. Further, this would allow a cost of capital function to be added to the theoretical framework facilitating the representation of industry investment and, hence, capital accumulation. In this way industry usage of capital could be set as endogenous and a long-run closure also developed.

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Appendix A

Table A.1 WOOLMOD commodities

1. Sheep meat	36. Woollen pure yarn
2. Greasy wool D-H-[a]	37. Worsted blend woven fabric
3. Greasy wool DH-[b]	38. Worsted pure lightweight woven fabric
4. Greasy wool D+H-[c]	39. Worsted pure heavyweight woven fabric
5. Greasy wool D-H[d]	40. Worsted knitted fabric
6. Greasy wool DH[e]	41. Woollen blend woven fabric
7. Greasy wool D+H[f]	42. Woollen pure woven fabric
8. Greasy wool D-H+[g]	43. Wholesale mens’ worsted woven garments (blend)
9. Greasy wool DH+[h]	44. Wholesale mens’ worsted woven garments (pure)
10. Greasy wool D+H+[i]	45. Wholesale mens’ worsted knitted garments
11. Scoured wool D-H-[a]	46. Wholesale mens’ woollen woven garments (blend)
12. Scoured wool DH-[b]	47. Wholesale mens’ woollen woven garments (pure)
13. Scoured wool D+H-[c]	48. Wholesale womens’ worsted woven garments (blend)
14. Scoured wool D-H[d]	49. Wholesale womens’ worsted woven garments (pure)
15. Scoured wool DH[e]	50. Wholesale womens’ worsted knitted garments
16. Scoured wool D+H[f]	51. Wholesale womens’ woollen woven garments (blend)
17. Scoured wool D-H+[g]	52. Wholesale womens’ woollen woven garments (pure)
18. Scoured wool DH+[h]	53. Wholesale woollen knitted garments (blend)
19. Scoured wool D+H+[i]	54. Wholesale woollen knitted garments (pure)
20. Carbonised wool D-H-[a]	55. Retail mens’ worsted woven garments (blend)
21. Carbonised wool DH-[b]	56. Retail mens’ worsted woven garments (pure)
22. Carbonised wool D+H-[c]	57. Retail mens’ worsted knitted garments
23. Worsted top D-H[d]	58. Retail mens’ woollen woven garments (blend)
24. Worsted top DH[e]	59. Retail mens’ woollen woven garments (pure)
25. Worsted top D+H[f]	60. Retail mens’ woollen knitted garments (blend)
26. Worsted top D-H+[g]	61. Retail mens’ woollen knitted garments (pure)
27. Worsted top DH+ [h]	62. Retail womens’ worsted woven garments (blend)
28. Worsted top D+H+[i]	63. Retail womens’ worsted woven garments (pure)
29. Noil D-HH+[j]	64. Retail womens’ worsted knitted garments
30. Noil DHH+[k]	65. Retail womens’ woollen woven garments (blend)
31. Noil D+HH+[l]	66. Retail womens’ woollen woven garments (pure)
32. Worsted blend yarn	67. Retail womens’ woollen knitted garments (blend)
33. Worsted pure lightweight yarn	68. Retail womens’ woollen knitted garments (pure)
34. Worsted pure heavyweight yarn	69. Synthetics
35. Woollen blend yarn	70. Other inputs

[a] Diameter <20 μm; hauteur <56 mm. [b] Diameter 20-23 μm; hauteur <56 mm. [c] Diameter >23 μm; hauteur <56 mm. [d] Diameter <20 μm; hauteur 56-65 mm. [e] Diameter 20-23 μm; hauteur 56-65 mm. [f] Diameter >23 μm; hauteur 56-65 mm. [g] Diameter <20 μm; hauteur >65 mm; [h] Diameter 20-23 μm; hauteur >65 mm. [i] Diameter >23 μm; hauteur >65 mm. [j] Diameter <20 μm; hauteur >56 mm. [k] Diameter 20-23 μm; hauteur >56 mm; [l] Diameter >23 μm; hauteur >56 mm.