# A Model of the World Wine Market

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## 1. Introduction

The world wine market is the subject of increasing interest to Californian, Australian and other New World wine producers as their national outputs grow and they become more export oriented. Some fear that, with world wine consumption declining slightly while output is rising, the boom in the new World will be followed by a collapse in export prices. However, despite per capita consumption volumes declining in a number of significant wine-consuming nations in the past decade or so, consumers are substituting quality for quantity by moving up-market to premium wines. As well, wine consumption is increasing in non-traditional markets, again with the main focus on premium wine. In the 1990s the global demand for premium wine outstripped supply growth, causing unit values of bottled wine exports to increase.

New World producers account for most of the global growth in premium wine exports in the 1990s. Australia has been the leader in terms of export volumes among these producers, but Argentina, Chile, New Zealand, South Africa and the United States also are experiencing rapid export growth (Anderson 2001). Winegrape plantings in these nations in the latter 1990s will be reflected in substantial growth in the premium wine supply of New World producers in the first few years of the new millennium. This worries Old World traditional producers and exporters in Europe, where vineyard and winery upgrading has been on-going.

To project the impact of these recent changes in demand and supply (and of other prospective structural or policy changes) on the world wine market requires a multi-region global model that distinguishes between premium and non-premium grapes and wine and that identifies wines by region of origin. The present paper presents the theory and empirical base of such a model, the World Multisectoral Wine Model (WMWM). It also illustrates its usefulness by estimating the impact of the current rapid supply expansion in New World wine production on the global market by 2005.[1]

## 2. The structure of the WMWM model

The model consists of linearized expressions so as to be able to use GEMPACK software (Harrison and Pearson 1994). This provides the relative simplicity of linearized algebra combined with software using multistep solution procedures in order to obtain the solution accuracy of non-linear forms (Hertel, Horridge and Pearson 1992).

### *2.1 Production*

On the supply-side of the model, the multi-input product specification follows the separability assumptions of typical computable general equilibrium (CGE) models. For example, consider the production function for a single-product industry:

$$F(\text{inputs}, \text{output}) = 0 \qquad (1)$$

We write this as:

$$G(\text{inputs}) = \text{Output} \qquad (2)$$

[1] Several other applications are provided in Anderson and Wittwer (2001).

The inputs in turn are derived from nested demands for intermediate inputs and primary factors. In the model, there are two grape industries plus three wine industries whose prices and outputs are endogenous. Intermediate inputs to these industries include grapes that are therefore both inputs and outputs in this model.

Figure 1 shows the structure of production in the World Multisectoral Wine Model for each region. Starting at the bottom left-hand corner of the diagram, producers choose a bundle of inputs from all sources (i.e., domestic and all import sources) so as to minimise the cost of each input, where the production function includes CES substitution possibilities. In percentage change terms, the demand for intermediate inputs *i* from source *s* by endogenous industry *j* in region *n* ($x_{is}^{jn}$) is related to the nested input demand ($x_i^{jn}$) in (3):

$$x_{is}^{jn} - a_{is}^{jn} = x_i^{jn} - \sigma_i^n (p_{is}^{jn} + a_{is}^{jn} - p_i^{jn}) \qquad (3)$$

In (3), $p_{is}^{jn}$ is the source-specific input price and ($p_i^{jn}$) the effective input price. The elasticity of subsitution for intermediate inputs is $\sigma_i^n$. The source-specific preference shifter is $a_{is}^{jn}$. Next, we calculate the effective or nested price of the source-composite input, where $S_{is}^{jn}$ refers to the sales share:

$$p_i^{jn} = \sum_s S_{is}^{jn} (p_{is}^{jn} + a_{is}^{jn}) \qquad (4)$$

The percentage change in the price of each intermediate input by regional source is set equal to the percentage change in the basic price ($p_{is}^o$) of each input, assuming that there are no input taxes or margins:

$$p_{is}^{jn} = p_{is}^o \qquad (5)$$

The percentage change in effective inputs demanded is related to output ( $x^{0jn}$ ) in (6) via a Leontief function:

$$x_i^{jn} - (a_i^{jn} + a^{jn}) = x^{0jn} \qquad (6)$$

The variables $a_i^{jn}$ and $a^{jn}$ refer to percentage changes in effective intermediate and all-inputs unit requirements.

The next set of equations deals with primary factor demands. Within WMWM, there are four substitutable primary factors *f*. They are human capital, fixed capital, variable capital, and a fourth factor which for wine is labour and for grapes is "harvest". The latter factor is a composite of mechanical and manual labour inputs into grape harvesting, determined in a separate substitutable equation (not shown in Figure 1). The percentage change in primary factors demanded ( $x_f^{jn}$ ) is given by:

$$x_f^{jn} - a_f^{jn} = x_1^{jn} - \sigma_1^{jn}(p_f^{jn} + a_f^{jn} - p_1^{jn}) \qquad (7)$$

Percentage changes in the productivity of individual factors are given by $a_{is}^{jn}$, and the primary factor CES parameter by $\sigma_1^{jn}$. The composite quantities demanded are calculated in (8), where the subscript *P* refers to the primary factor composite:

$$x_P^{jn} - (a_P^{jn} + a^{jn}) = x^{0jn} \qquad (8)$$

Equation (9) computes the price term for effective factor demands:

$$p_P^{jn} = \sum_f S_f^{jn}(p_f^{jn} + a_f^{jn}) \qquad (9)$$

One of the primary factors, variable capital, is treated as perfectly mobile between grape and wine industries, so as to equalise the factor price:

$$p_K^{jn} = p_K^{n} \qquad (10)$$

The market clearing expression for variable capital is:

$$x_K^n = \sum_j S_K^{jn} x_K^{jn} \tag{11}$$

Allocation of mechanical and manual inputs into grape harvesting in industry $g$ (a subset of $j$) is determined by CES substitution in (12), while (13) computes the effective price:

$$x_h^{gn} - a_h^{gn} = x_H^{gn} - \sigma_H^{gn} (p_h^{gn} + a_h^{gn} - p_H^{gn}) \tag{12}$$

$$p_H^{gn} = \sum_h S_h^{gn} (p_h^{gn} + a_h^{gn}) \tag{13}$$

In the current version of the model, we assume that most factors used in grape and wine production are fixed. This is reasonable for the short to medium term, given the large fixed costs and partly irreversible nature of vineyard and winery investments. Labour is a mobile factor within each region but human capital is fixed, and all factors are assumed to be immobile internationally.[2] This degree of mobility ensures that in response to external shocks, most comparative static adjustments are through price (including changes in factor rewards) rather than output changes.

Equation (14) ensures zero pure profits in computing the producer price ($p_1^{jn}$), calculated using the cost shares for intermediate ($S_i^{jn}$) and primary inputs ($S_P^{jn}$):

$$p_1^{jn} - a_1^{jn} = \sum_i (S_i^{jn} (p_i^{jn} + a_i^{jn})) + S_P^{jn} (p_P^{jn} + a_P^{jn}) \tag{14}$$

*2.2 Consumer prices*

The relationship between producer and consumer prices ($p_{cs}^{wn}$) is:

$$V_s^{wn} p_{cs}^{wn} = [B_s^{wn} + \sum_g T_s^{wng}](p_{0s}^{w} + \sum_g t_s^{wng}) + \sum_u (M_s^{wnu} p^{nu}) \quad (15)$$

in which the upper-case terms refer to levels. The total consumption value of a transaction ($V_s^{wn}$), for sales from source *s* to region *n*, is equal to the basic value $B_s^{wn}$ (i.e., at producer prices), plus all tariffs and consumer taxes on wine ($\sum_g T_s^{wng}$, where *g* is the type of tax) plus margins ($\sum_u M_s^{wnu}$, where *u* is the type of margin). The variable $t_s^{wng}$ denotes percentage changes in the power of a tax and $p^{nu}$ is the percentage change in the margin price. Margins are used in the ORANI school of CGE models (Horridge, Parmenter and Pearson 1998) to distinguish between prices by type of sale. Here they are important because retail mark-ups are a large proportion of the total value of a wine, particularly in the case of on-premise consumption. Another type of margin within the *u* set is transport costs. In the present version of the model, margins are not added to the cost of intermediate inputs.

*2.3 Consumer demands*

Consumer demands are based on the Klein-Rubin utility function:

$$U^n = \frac{1}{Q^n} \prod_j (X_c^{jn} - \psi_c^{jn})^{\beta_{jn}} \quad (16)$$

In levels terms, $U^n$ represents utility, $Q^n$ the number of households, $X_c^{jn}$ the total consumption of good *j*, $\psi_c^{jn}$ the subsistence component of this consumption and $\beta_{jn}$ the marginal budget share of good *j* ($0 \leq \beta_{jn} \leq 1$ and $\sum_j \beta_{jn} = 1$). Also note that

[2] In specific scenarios, we could alter the assumptions concerning international factor mobility, for example, by allowing wine industry human capital to be partly mobile between regions.

$$\psi_c^{jn} = Q^n A_j^{Sn} \tag{17}$$

where $A_j^{Sn}$ is the individual household subsistence demand.

The maximisation of utility subject to the budget constraint $Y_n = \sum_j P_c^{jn} X_c^{jn}$ gives rise to the linear expenditure function of the following form:

$$P_c^{jn} X_c^{jn} = P_c^{jn} \psi_c^{jn} + \beta_{jn}(Y_n - \sum_j P_c^{jn} \psi_c^{jn}) \tag{18}$$

Assume $V_n = (Y_n - \sum_j P_c^{jn} \psi_c^{jn})$, which is the aggregate supernumerary expenditure. Equation (18) then becomes

$$P_c^{jn} X_c^{jn} = P_c^{jn} \psi_c^{jn} + \beta_{jn} V_n \tag{19}$$

By totally differentiating equations (17) and (19) and dividing by $P_c^{jn} X_c^{jn}$, the percentage change in $X_c^{jn}$ can be expressed as a function of the percentage changes in $V_n$, $P_i$, $Q_n$ and $A_j^{Sn}$:

$$x_c^{jn} = \phi^{jn} (v_n - p_c^{jn}) + (1 - \phi^{jn}) (q_n + a_j^{Sn}) \tag{20}$$

where $\phi^{jn} = \frac{V_n \beta_{jn}}{P_c^{jn} X_c^{jn}} = 1 - \frac{\psi_c^{jn}}{X_c^{jn}}$ is the supernumerary proportion of total expenditure on $X_c^{jn}$. The Frisch parameter $\gamma_n$ is the (negative) ratio of total to luxury expenditure, given by $-\frac{Y_n}{V_n}$. Since $\beta_{jn} = \frac{\varepsilon_{jn} P_c^{jn} X_c^{jn}}{Y_n}$, where $\varepsilon_{jn}$ is the expenditure elasticity of good $j$, it follows that $\phi^{jn} = -\frac{\varepsilon_{jn}}{\gamma_n}$.

Endogenous grape and wine types $w$ are a subset of $j$. In applications of this model, non-grape and non-wine commodities comprise a single composite with an exogenously determined price. The supernumerary ($a_j^{Ln}$) and subsistence shifts

($a_j^{Sn}$) in preferences are related to the exogenous consumer preference shifter ($a_c^{jn}$):

$$a_j^{Sn} = a_j^{Sn} - \sum_j S_c^{jn} a_c^{jn} \tag{21}$$

and

$$a_j^{Ln} = a_j^{Sn} - \sum_j \beta_{jn} a_j^{Sn} \tag{22}$$

where the expenditure shares of aggregate consumption are given by $S_c^{jn}$.

We differentiate wine through disaggregation into wine types *w*, plus the Armington (1969) assumption of imperfect substitution by source *d* (1 = domestic, 2 = import composite) used to determine the domestic-import demands ($x_d^{wn}$):

$$x_d^{wn} - a_d^{wn} = x^{wn} - \sigma^{wn}(p_d^{wn} + a_d^{wn} - p^{wn}) \tag{23}$$

In equation (23), $\sigma^{wn}$ is the Armington elasticity and $a_{cd}^{wn}$ the domestic-import preference shifter. Demands for imports from specific sources are determined in equation (24):

$$x_s^{wn} - a_s^{wn} = x_m^{wn} - \sigma_s^{wn}(p_s^{wn} + a_s^{wn} - p_m^{wn}) \tag{24}$$

The parameter $\sigma_s^{wn}$ is the elasticity of substitution between import sources. Subscript *m* refers to the import composite, and subscript s to the source of purchase. Hence, the demand for purchases by source entails a two-stage nesting process, between domestic purchases and a composite of imported purchases, and between different imports.

Next, we calculate the effective price of the source-composite wine commodity ($p_c^{wn}$), where $S_d^{wn}$ refers to the share of the sales of *d* in total sales to region *n*:

$$p^{wn} = {}_{d}\, S_d^{wn}(p_d^{wn} + a_d^{wn}) \tag{25}$$

The import composite price equation is:

$$p_m^{wn} = S_m^{wn}\,(p_m^{wn} + a_m^{wn}) \tag{26}$$

*2.4 Margins, market clearing equations and national income*

The percentage change in the quantity of margin services ($x_s^{wnu}$) demanded is set equal to that of the wine type:

$$x_s^{wnu} = x_s^{wn} \tag{27}$$

The market-clearing equation sets the supplies by source equal to the sum of demands (intermediate plus household) by region:

$$x^{0ws} = \sum_n (S_s^{wn}\, x_s^{wn}) + \sum_n \sum_i (S_{ws}^{in}\, x_{ws}^{in}) \tag{28}$$

In (28), $S_s^{wn}$ and $S_{ws}^{in}$ are the shares of each sale in total sales of *w*, calculated at producer prices. In the present version of the model, only multipurpose grapes have sales as both intermediate inputs and household commodities.

Before calculating changes in income, we need to calculate the change in indirect taxes:

$$T^n t^n = \sum_w \sum_s [(B_{cs}^{wn} + \sum_g T_{cs}^{wng}) \sum_g t_{cs}^{wng} + \sum_g T_{cs}^{wng}\,(p_{0s}^{w} + x_{cs}^{wn}) \tag{29}$$

where $t^n$ is the percentage change in tax and tariff revenue, and $T^n$ the level of tax plus tariff revenue.

In comparative static runs (i.e., in which we assume that national endowments are unchanged), the change in income ($Y^n y^n$) is calculated as the percentage change in income earned by non-mobile factors multiplied by the non-mobile factor income level ( $F_h^{jn}$ , where subscript $h$ is the non-mobile subset of all factors) in the grape and wine sectors, plus the percentage change in wine tax and tariff revenue.

$$Y^n y^n = \sum_j \sum_h F_h^{jn} (p_h^{jn} + x_h^{jn}) + T^n t^n \quad (30)$$

The percentage change in income calculated in (30) appears in the consumption function, to determine nominal aggregate consumption ( $w_c^n$ ), where ( $f_c^n$ ) denotes shifts in savings:

$$w_c^n = \frac{Y^n}{C^n} y^n - f_c^n \quad (31)$$

If changes in household expenditure equal changes in income (i.e., $f_c^n$ is exogenous so the marginal propensity to save is set to zero), we can use (32), in which real aggregate consumption is solved (where $p^n$ is CPI), to calculate changes in welfare:

$$x_c^n = w^n - p^n \quad (32)$$

But we are also concerned with the distribution of income between grape growers, wineries and the rest of the economy (or "consumers"). In projecting from one time period to another, the change in aggregate consumption is imposed exogenously, rather than determined by changes in income in the grape and wine industry. So that our calculation is valid with either $x_c^n$ or $f_c^n$ exogenous, we divide the change in real aggregate consumption ( $C_c^n x_c^n$ ) between the industry and rest of the economy ( $C_{c*}^n x_{c*}^n$ ):

$$C_c^n x_c^n = \sum_j \sum_h F_h^{jn} (p_h^{jn} + x_h^{jn} - p^n) + C_{c*}^n x_{c*}^n \quad (33)$$

Equation (33) is based on the medium-term assumption that some factors remain specific to each industry. In the longer term, with greater mobility of factors, we would expect greater adjustments in factor quantities than prices in response to shocks, so that the gains or losses to the wine industry from such shocks would be reflected in movements in resources rather than changes in factor prices.

## 3. Product and regional disaggregation in the WMWM model

The database of WMWM in its present form includes six intermediate input commodities (chemicals, water, premium grapes, multipurpose grapes, non-premium wine, and other) and five endogenous outputs (premium winegrapes, multipurpose grapes, premium wine, non-premium wine and non-beverage wine).

The model currently divides the world into ten regions:[3] Western European wine Exporters (WEE), United Kingdom (UK), Germany (GER), Rest of Western Europe (OWE), Central & Eastern Europe (CEE), United States & Canada (USC), Australia (AUS), New Zealand (NZ), Other Southern Hemisphere wine Exporters (OSE), and the Rest of the World (ROW). The choice of aggregation requires further comment. Western European Exporters (France, Italy, Portugal and Spain) are the largest wine producers in the world and, together with other Western European nations, also the largest consumers, accounting for roughly half the global wine market. The United Kingdom is treated separately because of its importance as a destination for New World wine, and Germany because it is the world's largest wine-importing country. Four of the regions, Australia, New

Zealand, United States & Canada, and Other Southern Hemisphere Exporters (Argentina, Brazil, Chile, Uruguay and South Africa) experienced rapid export growth in the 1990s and now account for more than one-quarter of world production and exports. North America is exceptional among New World regions, in that most sales growth is likely to be in its domestic rather than export markets. The Rest of the World accounted for over 20 per cent of global grape production in the late 1990s but made only 4 per cent of the world's wine (FAO 2000). This group includes a number of nations with sizeable Moslem populations who consume little alcohol.

### *3.1 Production, consumption and trade data*

The starting points for constructing a global database are the historical statistics compiled by Berger, Anderson and Stringer (1998) and Berger, Spahni and Anderson (1999) that are based on FAO, OIV and (for trade data) UN sources. These relate to wine as a single commodity for years up to 1997. Given the importance we attach to distinguishing between the expanding premium and shrinking non-premium segments of the world wine market, a crucial part of database preparation was to estimate this split. We also updated the data to 1999. The resulting database is still subject to revision as new information comes to light. It has 23 per cent of the value and 60 per cent of the volume of world wine production in the non-premium category in 1999, similar to the Rabobank estimates (Geene et al. 1999).

[3] The Berger et al. (1998, 1999) statistical compilations provide details for 39 regions for wine as a whole. As better data become available to make the premium/non-premium split easier, so further regional disaggregation will be possible.

Disaggregated data for the Australian region were drawn from two official agencies (ABS 1999, 2000 and AWEC 2000) and from a recent thesis by Wittwer (2000). ABS data for Australia distinguish between premium and non-premium wines by container, with premium wines referring to those distributed in bottles of 1.5 litres of less. We have amended this slightly so that two-litre casks also are categorised as premium wine. Among the other Southern Hemisphere exporters, there are sufficient New Zealand industry data to estimate disaggregated production and sales, with non-premium production now being a small proportion of the total (WINZ 2000). South African data indicate that a larger proportion of production is of non-premium quality than in other New World regions (SAWIS 2000). Estimates of the split between premium and non-premium production for the remaining Southern Hemisphere exporters are based on Jenster, Jenster and Watchurst (1993), but updated to reflect an increasing proportion of premium in total production in the New World.

The industry in a number of European nations is classified by quality, but such classifications vary from country to country. The publication by Onivins (1998) provides some indicators of the quality split of consumption and production in France. Geene et al. (1999, Figure 2.10) provides a split between premium and other table wine for EU-12 consumption based on European Commission data. The premium proportion has been adjusted downwards in our database because, according to Geene et al., this category may include some wine inappropriately classified as premium.

Aggregate per capita wine consumption is much lower in North America than in Western Europe, but the premium proportion of the total is higher. Data in

WIC (2000) indicate that until 1999, the volume of North American exports exceeded that of Australia. But the unit value and total value were substantially lower. US producers, particularly premium suppliers, have been able to rely mostly on an ever-growing domestic market for increased sales, in contrast to Southern Hemisphere producers. The 1999 data used for Central and Eastern Europe, as for the Rest of the World, are based on the authors' best guesses of trends in the latter 1990s using available OIV and FAO statistics.

### *3.2 Price data*

Some indicative winegrape price data are readily available for Australia (PISA 1996; PGIBSA 2000), South Africa (SAWIS 2000), the United States (WIC 2000) and New Zealand (WINZ 2000). We assume that winegrapes account for approximately 25 per cent of the costs of wine production (based on discussions with Winemakers' Federation of Australia). Otherwise, prices are based to a considerable extent on UN unit value trade data, as in Berger (2000). Onivins (1998) and Geene et al. (1999) also provide some guidance in estimating producer prices for winegrapes and wine.

### *3.3 Tax data*

Berger and Anderson (1999) have compiled wine consumer and import tax rates in all the key wine countries. An important feature of that tax database which is reflected in WMWM is that ad valorem and volumetric tax rates are separately included, since changes in the latter (and hence a switch from one form to the other) affect the premium and non-premium markets to different extents.

*3.4 Transport and related margins*

We assume that transport costs for domestic wine sales are equal to 15 per cent of the producer price for premium wine and (reflecting its lower unit value) 20 per cent for non-premium wine. The corresponding transport costs assumed for imported wine are 25 per cent for premium and 30 per cent for non-premium wine. Based on discussions with the Winemakers' Federation of Australia, retail margins at liquor stores are assumed to be 33 per cent of the tax-inclusive wholesale price for premium wine and 25 per cent for non-premium wine. But since approximately one-fifth of wine consumption is on licensed premises with mark-ups typically exceeding 100 per cent, the overall retail margins are assumed to be 46 per cent for premium and 40 per cent for non-premium wine.

## 4. Elasticities in the WMWM model

We impose Armington (1969) elasticities of substitution in consumption between domestic and imported wine of 8.0, higher than for beverages within the GTAP database for the global economy because of greater possibilities for substitution the more disaggregated a product category (Hertel 1996). For substitution between different sources of wine imports, we chose an elasticity of 16.0.

The expenditure elasticities in the initial database are 1.5 for premium wine and 0.6 for non-premium, based on estimates for Australia (CIE 1995). The Frisch parameter is initially –1.82 in Australia, the European nations and USC, and a slightly larger (absolute) value elsewhere, reflecting the latter's lower per capita incomes.

On the supply side, in which industry-specific factors are exogenous, the elasticity of substitution between primary factors is set at 0.5. Were we to allow for endogeneity of primary factors other than labour, supply within the model would be more price-responsive.

As better parameter estimates for the wine market become available, we can readily fit them into the model or (on the supply side) alter the theory of the model. For the time being, the GEMPACK software allows us to undertake systematic sensitivity analysis to track the influence of parameter choice (and policy and growth uncertainty) on modelled outcomes (Arndt and Pearson 1996).

## 5. Projecting the WMWM model from 1999 to 2005

By way of illustrating its usefulness, the following application projects the model from 1999 to 2005 to estimate the impact of known winegrape plantings of the late 1990s on grape and wine producers and consumers in different regions of the world. Our assumptions concerning the projection are summarised in Table 1. In addition to using the macroeconomic assumptions of Hertel et al. (2001) and Anderson and Strutt (1999), we also assume that there is a taste swing from non-premium towards premium wine consumption among consumers, based on Wittwer and Anderson (2001). Also within the projection is the assumption of an effective market promotion by Australia, as called for in the Australian industry's wine marketing strategy released in November 2000 (WFA and AWBC 2000), which is assumed to cause specific taste swings towards Australian wine in the UK, Germany, USC and OWE by 2005.

The main feature of the projected scenario is that despite a rapid increase in premium wine output in the New World regions (i.e., Australia, United States, Canada, New Zealand, and Other Southern Hemisphere Exporters), downward pressure on producer prices is either minor or reversed by positive income and taste effects in consumer demand. Table 2 shows the producer price changes, and Table 3 a decomposition of the projected changes in consumer demand, computed from equation (20) above. In Europe, producer prices for premium winegrapes rise while those for wine fall. This assumes that in Europe there is little growth in premium winegrape production and a fall in non-premium production, without a matching reduction in wine processing capacity.

Table 4 contains a decomposition of premium wine output growth. The method of decomposition is based on a modified version of market clearing equation (28) of the model. The *X* terms refer to sales from source *s* and the *M* terms to purchases by region *r* from other regions.

$$X^{s}x^{s}=(X^{ss}+\sum_{s}M^{sr})x^{s*}+\sum_{r}X^{rs}x^{rs}-\sum_{s}M^{sr}m^{sr} \tag{34}$$

In percentage change terms, total output of region *s* is $x^{s}$, local sales $x^{s*}$, exports $x^{sr}$ and imports $m^{sr}$. The decomposed components of equation (34) will not add exactly to $X^{s}x^{s}$ when large change solutions are computed.[4] To overcome this, we define an ordinary change variable $q^{s}$ so that

$$X_{0}^{s}q^{s}=X^{s}x^{s}, \tag{35}$$

where $X_0^s$ is the initial quantity of total sales. In ordinary change terms,

$$q^s = q^l + q^x + q^m \tag{36}$$

where $q^l$ is the local market contribution, $q^x$ the export contribution and $q^m$ the import replacement contribution. We define the local market contribution as the percentage change in local sales from local and imported sources, weighted by the value of locally sourced sales:

$$q^l = \frac{X^{ss} x^{s*}}{X_0^s} \tag{37}$$

The export contribution is $\frac{\sum_{r} X^{rs} x^{rs}}{X_0^s}$ and the import contribution is calculated from equation (36).

The decomposition shown in Table 4 reveals key differences between New World and European producers. In the New World, output growth of premium wine is large, and will be heavily reliant on export sales. In the European regions (WEE, Germany and OWE), local market growth accounts for most if not all output growth. Germany’s relatively large import substitution and export growth are based on the assumption of a taste swing away from white wine in Germany towards red wine: this will induce an increase in both exports and imports in Germany, as that country produces predominately white wine. The United States and Canada, despite rapid output expansion, have sufficient local demand growth (through the various positive consumption effects shown in Table 3) to absorb a large proportion of their output growth.

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[4] The GEMPACK software used by WMWM may use multistep solution procedures in large change cases (Harrison and Pearson 1994). Such multistep computation percentage changes are compounded, whereas ordinary changes are added.

The SSA (Systematic Sensitivity Analysis) facility of the GEMPACK software used to run WMWM allows us to explore how uncertainty relating to growth or other assumptions affects the modelled outcome. Although we have relatively accurate information on winegrape plantings for Australia, United States and Canada and New Zealand, the growth assumptions for the other regions are somewhat speculative. For example, we assume that in Europe, premium winegrape production increases slightly while non-premium production falls sharply between 1999 and 2005, whereas it may be possible that adjustments to grape production in Europe could occur through quality upgrades with a much smaller change in net production.

We use SSA to consider uncertainty in two sets of assumptions: first, in wine output growth of OSE, and second, in the magnitude of the global taste swing towards premium wine consumption between 1999 and 2005. In each case, we vary the shocks by plus or minus 80 per cent of the magnitude of the changes shown in Table 1. This applies to Table 1's growth in premium wine and winegrape factors for OSE in the 8$^{th}$ column, and the taste swing shown in the 3$^{rd}$ row.

The estimated standard deviations associated with each set of uncertain shocks are shown in parentheses in Tables 2 to 4. In each set, the shocks are varied uniformly from their mean values, that is, without a bias towards the mean. In the case of uncertainty in OSE growth, the standard deviation of the producer price change for OSE premium winegrapes (a non-traded input) is 32.7 per cent, while for OSE premium wine (a traded commodity) it is only 2.7 per cent. With winemaking capacity virtually fixed, primary supply uncertainty transmits to uncertainty in the primary product price. In other regions, uncertain supply in OSE causes smaller standard deviations, for example, 1.2 per cent for the price of both premium winegrapes and wine in Australia.

The standard deviation of OSE's price effect is 1.6 per cent, accounting for most of the uncertainty in overall consumption, which is 1.9 per cent (Table 3). Elsewhere, the standard deviations of consumption growth are between 0.2 and 0.8 per cent (Table 3). In the decomposition of output, as shown in Table 4, the only notable standard deviations are those for OSE's export contribution (17.4 per cent) and total output (18.7 per cent).[5]

Turning to uncertainty in the taste swing towards premium wine, the standard deviations of the winegrape producer prices are relatively large in all regions, being 1.9 per cent in Australia, for example, and 4.9 per cent in WEE, where we project a large increase in winegrape prices. This time the standard deviations for premium wine producer prices are only marginally smaller than for winegrapes (Table 2). The standard deviations with respect to consumption show that the direct uncertainty surrounding tastes accounts for most of the uncertainty in the consumption outcome (e.g. in Australia, the standard deviation of the taste change effect is 4.1 per cent, and that of total consumption 4.6 per cent, Table 3). But uncertain demand shifts imply uncertain prices. Hence, moderate standard deviations also appear for the price effect in each region (1.1 per cent for Australia, Table 3). Overall, however, the uncertainty attributable to taste shifts is

[5] Although OSE remains a small contributor to global trade, a similar pattern emerges among the standard deviations using SSA to depict growth uncertainty in WEE. The standard deviation of the winegrape producer price for WEE again is large, as is that for the export contribution to WEE output, while other standard deviations with respect to WEE growth uncertainty are relatively small.

small relative to projected total consumption growth, which exceeds 30 per cent in most regions (Table 3).

Finally, we examine output growth. While taste uncertainty provides uncertainty in both the local market and export effects, the impact on the totals is relatively small, as indicated by the respective standard deviations in Table 4. In Australia, for example, the standard deviations of the local market and export effects are 2.1 and 2.2 per cent respectively, yet that for total growth is only 0.3 per cent. This indicates some interchange between local and export sales at the national level in the face of uncertainty surrounding the extent of the global demand shift.

## 6. Conclusion

WMWM models a small industry in the global economy and therefore is a partial equilibrium model, although it draws on some of the restrictions imposed on general equilibrium models, especially in modelling household demands. The supply side of the model in its present form is mostly exogenous, reflecting the medium-term constraints on adjustment in the winegrape and wine industry. As there are lags of four years or more between winegrape plantings and production, it is possible to project several years ahead on the basis of known plantings. Systematic sensitivity analysis (SSA) helps the modeller explore uncertainty associated with unavailable plantings data in particular regions, or other assumptions involved in projecting from one time period to another. SSA is also a tool for analyzing the implications of parameter or policy uncertainty (Wittwer 2000).

In its present form, WMWM is well suited to analyzing a rapid growth phase, as is occurring in the premium segment of production in the New World. The theory of supply within the model may need modifications to analyse the market as growth subsides. Research based on real options theory, as described in Dixit and Pindyck (1996), depicting the partly irreversible nature of vineyard and winery investments, may lead to useful modifications to the model. Developing a dynamic version of the model would be a consequence of this research.

The structure of the model could be adapted readily to analyse other commodities. The world olive market, for example, is a similarly small industry suitable for modelling in this framework.

**Table 1: Key assumptions in projecting from 1999 to 2005**

(percentage change over the 6 years)

| | AUS | WEE | OWE | UK | GER | CEE | USC | OSE | NZ | ROW | World |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Aggregate consumption** | 19.4 | 14.6 | 14.6 | 14.6 | 14.6 | 17.3 | 18.0 | 19.4 | 18.7 | 18.7 | 17.1 |
| **Population** | 6.0 | 0.6 | 0.6 | 0.6 | 0.6 | 1.6 | 6.8 | 8.7 | 5.0 | 4.9 | 4.7 |
| **Taste swing to premium** | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| **Fixed capital, premium grapes** | 130.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 50.0 | 80.0 | 100.0 | 15.0 | 23.6 |
| **Human capital, premium grapes** | 100.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 40.0 | 70.0 | 80.0 | 10.0 | 20.0 |
| **Fixed & human cap., multigrapes** | 10.0 | -5.0 | -5.0 | -5.0 | -5.0 | -5.0 | -5.0 | -5.0 | -5.0 | -5.0 | -4.9 |
| **Fixed capital, premium wine** | 80.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 40.0 | 60.0 | 70.0 | 10.0 | 23.8 |
| **Human capital, premium wine** | 80.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 40.0 | 60.0 | 70.0 | 10.0 | 16.2 |
| **Fixed capital, non-premium wine** | -25.0 | -25.0 | -25.0 | -25.0 | -25.0 | -25.0 | -25.0 | -25.0 | -25.0 | -25.0 | -25.0 |
| **Human cap., non-premium wine** | -30.0 | -30.0 | -30.0 | -30.0 | -30.0 | -30.0 | -30.0 | -30.0 | -30.0 | -30.0 | -30.0 |
| **Variable capital, grape & wine** | 90.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 30.0 | 60.0 | 70.0 | 15.0 | 22.0 |
| **Total factor productivity, wines**[a] | 15.0 | 12.6 | 12.6 | 12.6 | 12.6 | 1.8 | 10.0 | 12.6 | 12.6 | 1.8 | 11.0 |

*Sources*: Anderson and Strutt (1999); Hertel et al. (2001); ABS (2000); and authors' own assumptions.

[a] In addition, for premium grapes we have assumed that TFP declines by 1.4 per cent in Australia between 1999 and 2005 due to quality improvements that require reduced yields per hectare. Elsewhere, we assume no change in grape TFP.

**Table 2: Grape and wine producer price changes**

(% change from 1999 to 2005 in 1999 constant US dollars)

| | AUS | WEE | GER | OWE | CEE | USC | OSE | NZ | ROW | World |
|---|---|---|---|---|---|---|---|---|---|---|
| Premium grapes | 0.9 | 37.3 | 12.0 | 17.5 | 12.0 | -4.0 | -3.6 | -2.7 | -8.7 | 18.5 |
| SOE growth[a] | (1.2) | (2.5) | (2.1) | (2.2) | (0.6) | (1.1) | (32.7) | (1.2) | (1.7) | (3.3) |
| Taste change[b] | (1.9) | (4.9) | (3.6) | (3.5) | (3.2) | (2.7) | (2.5) | (1.8) | (2.5) | (3.6) |
| Multipurpose grapes | 1.8 | 8.8 | 3.4 | 8.7 | 4.7 | 19.0 | 33.8 | -5.8 | 20.2 | 17.0 |
| SOE growth[a] | (0.7) | (0.7) | (2.4) | (0.7) | (0.4) | (0.7) | (4.1) | (1.7) | (0.4) | (0.2) |
| Taste change[b] | (0.1) | (0.1) | (0.7) | (0.2) | (0.2) | (0.1) | (0.3) | (0.6) | (0.1) | (0.1) |
| Premium wine | 1.5 | 0.7 | -11.0 | -4.8 | 9.2 | -11.9 | -10.2 | -9.6 | 0.1 | -3.8 |
| SOE growth[a] | (1.2) | (1.0) | (0.9) | (1.1) | (0.4) | (0.8) | (2.7) | (1.1) | (1.1) | (1.1) |
| Taste change[b] | (1.9) | (2.0) | (1.6) | (1.7) | (2.0) | (2.0) | (1.6) | (1.7) | (1.6) | (1.8) |
| Nonpremium wine | 10.1 | 12.4 | 11.2 | 11.6 | 17.5 | 14.0 | 7.5 | 11.0 | 16.2 | 12.6 |
| SOE growth[a] | (1.3) | (1.4) | (1.6) | (1.3) | (1.1) | (1.4) | (4.6) | (1.5) | (1.2) | (1.7) |
| Taste change[b] | (1.1) | (0.9) | (0.9) | (0.8) | (0.7) | (1.1) | (0.9) | (1.2) | (0.7) | (0.9) |

[a] All OSE growth shocks are varied by ±80 per cent, with standard deviations arising from this variation in parentheses.

[b] $a_c^{jn}$ = 8±6 for $j$ = premium wine and all $n$.

*Source*: Authors' WMWM model results.

**Table 3: Decomposition of growth in the volume of premium wine consumption**
(% change from 1999 to 2005)

| | AUS | WEE | UK | GER | OWE | CEE | USC | OSE | NZ | ROW |
|---|---|---|---|---|---|---|---|---|---|---|
| **Effect of change in:** | | | | | | | | | | |
| Income | 20.3 | 21.7 | 22.1 | 21.3 | 21.9 | 23.8 | 17.1 | 16.6 | 21.3 | 21.2 |
| SOE growth[a] | (0.1) | (0.1) | (0.1) | (0.1) | (0.1) | (0.1) | (0.1) | (0.1) | (0.1) | (0.1) |
| Taste change[b] | (0.4) | (0.3) | (0.4) | (0.4) | (0.4) | (0.3) | (0.2) | (0.3) | (0.4) | (0.4) |
| Price | -0.8 | -0.2 | 4.6 | -4.5 | 0.9 | -4.0 | 2.6 | 6.0 | 3.7 | 2.1 |
| SOE growth[a] | (0.7) | (0.6) | (0.8) | (0.6) | (0.8) | (0.2) | (0.6) | (1.6) | (0.7) | (0.8) |
| Taste change[b] | (1.1) | (1.2) | (1.1) | (1.0) | (1.1) | (0.9) | (1.2) | (1.0) | (1.0) | (1.0) |
| Taste | 8.9 | 8.7 | 8.8 | 8.5 | 8.7 | 8.8 | 9.0 | 9.2 | 9.1 | 9.1 |
| SOE growth[a] | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) |
| Taste change[b] | (4.1) | (3.9) | (4.1) | (3.9) | (4.0) | (4.0) | (4.1) | (4.2) | (4.2) | (4.2) |
| Population | 6.9 | 0.7 | 0.7 | 0.7 | 0.7 | 1.8 | 7.7 | 10.0 | 5.8 | 5.7 |
| SOE growth[a] | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) |
| Taste change[b] | (0.1) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.1) | (0.2) | (0.1) | (0.1) |
| **Total** | 35.3 | 30.9 | 36.2 | 25.9 | 32.2 | 30.4 | 36.4 | 41.8 | 39.8 | 38.1 |
| SOE growth[a] | (0.8) | (0.7) | (0.9) | (0.6) | (0.9) | (0.2) | (0.7) | (1.9) | (0.8) | (1.0) |
| Taste change[b] | (4.6) | (3.5) | (4.5) | (4.0) | (4.2) | (3.5) | (3.6) | (4.7) | (4.8) | (4.7) |

[a] All OSE growth shocks are varied by ±80 per cent.
[b] $a_c^{jn}$ = 8±6 for $j$ = premium wine and all $n$.
*Source*: Authors' WMWM model results.

**Table 4: Decomposition of growth in the volume of premium wine output**
(% change from 1999 to 2005)

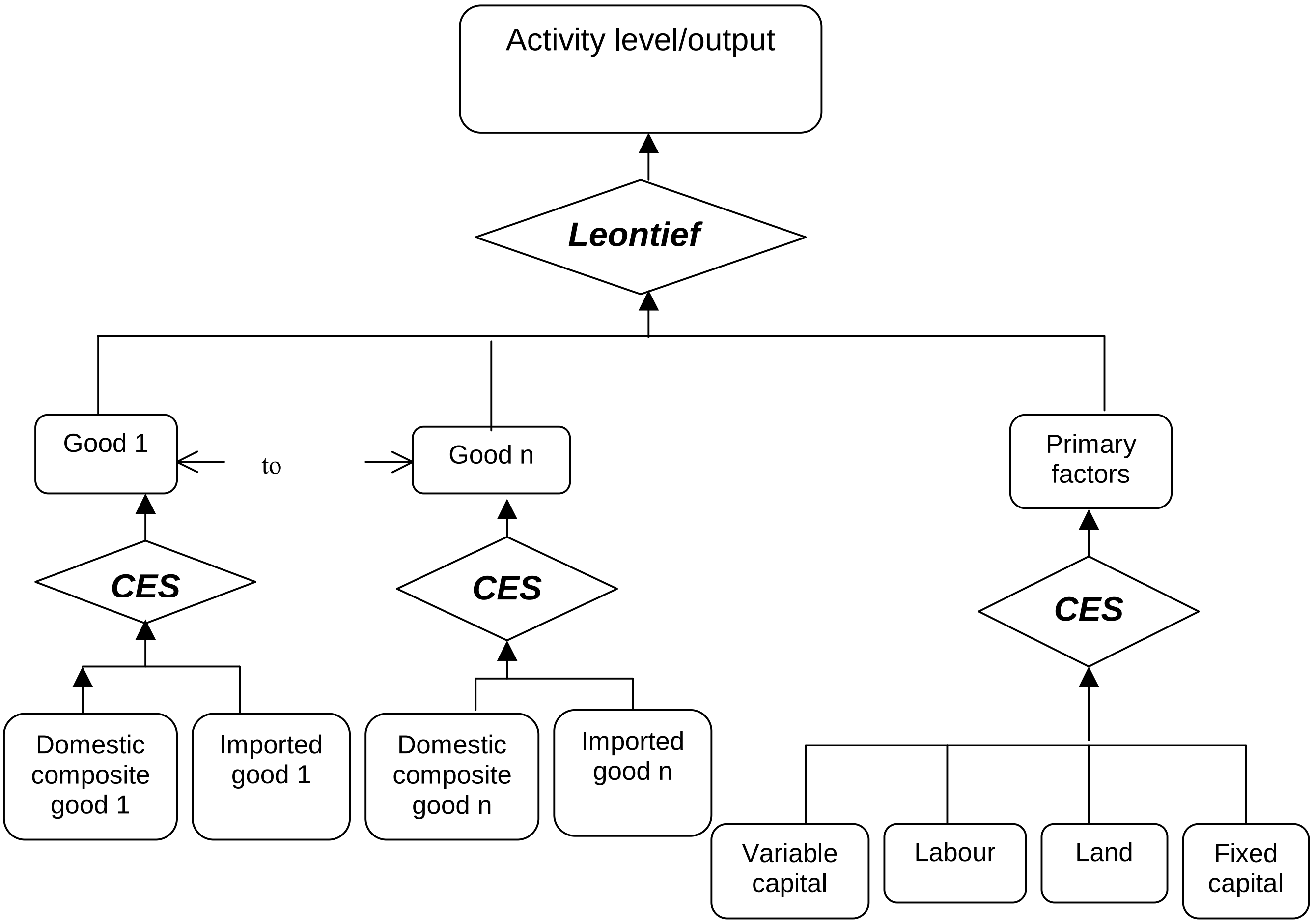
| | AUS | WEE | GER | OWE | CEE | USC | OSE | NZ | ROW |
|---|---|---|---|---|---|---|---|---|---|
| **Effect of change in:** | | | | | | | | | |
| Local Market | 16.1 | 17.3 | 25.0 | 24.0 | 27.4 | 40.7 | 22.8 | 21.0 | 30.3 |
| SOE growth[a] | (0.4) | (0.4) | (0.5) | (0.3) | (0.1) | (0.7) | (1.2) | (0.4) | (0.5) |
| Taste change[b] | (2.1) | (1.9) | (2.8) | (3.1) | (2.9) | (3.1) | (2.6) | (2.4) | (3.3) |
| Import Substitution | -1.0 | -1.0 | -33.1 | -13.5 | -2.4 | 1.7 | 0.2 | 8.6 | -16.3 |
| SOE growth[a] | (0.0) | (0.1) | (0.1) | (0.5) | (0.2) | (0.5) | (0.1) | (0.0) | (1.2) |
| Taste change[b] | (0.1) | (0.1) | (1.3) | (2.0) | (0.7) | (1.3) | (0.0) | (0.1) | (2.6) |
| Export | 109.9 | 1.9 | 21.9 | 7.5 | -2.5 | 9.6 | 71.8 | 68.0 | -0.6 |
| SOE growth[a] | (0.6) | (0.5) | (0.8) | (0.3) | (0.2) | (0.4) | (17.4) | (0.6) | (0.1) |
| Taste change[b] | (2.2) | (1.6) | (1.5) | (1.0) | (0.5) | (1.3) | (3.0) | (2.5) | (0.5) |
| **Total** | 125.1 | 18.1 | 13.7 | 18.0 | 22.5 | 52.0 | 94.8 | 97.6 | 13.4 |
| SOE growth[a] | (0.2) | (0.3) | (0.3) | (0.5) | (0.3) | (0.3) | (18.7) | (0.2) | (0.9) |
| Taste change[b] | (0.3) | (0.6) | (0.6) | (0.8) | (2.0) | (0.8) | (1.3) | (0.3) | (1.3) |

[a] All OSE growth shocks are varied by ±80 per cent.

[b] $a_c^{jn}$ = 8±6 for *j* = premium wine and all *n*.

*Source*: Authors' WMWM model results.

**Figure 1: Structure of production**



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**Note for referees (not for publication):**

**Expanding the linear expenditure system**

Consumer demands are based on the Klein-Rubin utility function:

$$U^n = \frac{1}{Q^n}\prod_j (X_c^{jn} - \psi_c^{jn})^{\beta_{jn}} \tag{1}$$

In levels terms, $U^n$ represents utility, $Q^n$ the number of households, $X_c^{jn}$ the total consumption of good $j$, $\psi_c^{jn}$ the subsistence component of this consumption and $\beta_{jn}$ the marginal budget share of good $j$ ($0 \leq \beta_{jn} \leq 1$ and $_j \; \beta_{jn}=1$). The maximisation of utility subject to the budget constraint $Y_n = \sum_j P_c^{jn} X_c^{jn}$ gives rise to the linear expenditure function of the following form:

$$P_c^{jn} X_c^{jn} = P_c^{jn}\psi_c^{jn} + \beta_{jn}(Y_n - \sum_j P_c^{jn}\psi_c^{jn}) \tag{2}$$

Subsistence demands take the form

$$\psi_c^{jn} = Q^n A_j^{Sn} \tag{3}$$

where $A_j^{Sn}$ is the individual household subsistence demand.

Assuming $V_n = (Y_n - \sum_j P_c^{jn}\psi_c^{jn})$, which is the aggregate supernumerary expenditure, equation (2) becomes

$$P_c^{jn} X_c^{jn} = P_c^{jn}\psi_c^{jn} + \beta_{jn} V_n \tag{4}$$

Next, totally differentiate (4) and divide by $P_c^{jn} X_c^{jn}$ to obtain

$$\frac{d\,P_c^{jn} X_c^{jn} + d\,X_c^{jn} P_c^{jn}}{P_c^{jn} X_c^{jn}} = \frac{\psi_c^{jn}\, dP_c^{jn}}{P_c^{jn} X_c^{jn}} + \frac{d\psi_c^{jn}\, P_c^{jn}}{P_c^{jn} X_c^{jn}}\frac{\psi_c^{jn}}{\psi_c^{jn}} + \frac{\beta_{jn}\, d.V_n}{P_c^{jn} X_c^{jn}}\frac{V_n}{V_n} \tag{5}$$

Then rearrange (5) to express the percentage change in $X_c^{jn}$ as a function of the percentage changes in $V_n$, $P_i$, $Q_n$ and $A_j^{Sn}$. By differentiating (3), one can obtain $\frac{d\psi_c^{jn}}{\psi_c^{jn}} = q_n + a_j^{Sn}$, where the lower-case terms denote percentage changes. Thus (5) can be rewritten as

$$x_c^{jn} + p_c^{jn} = (p_c^{jn} + \frac{d\psi_c^{jn}}{\psi_c^{jn}})\frac{\psi_c^{jn}}{X_c^{jn}} + \frac{V_n \beta_{jn}}{P_c^{jn} X_c^{jn}} v_n \qquad (6)$$

which can be simplified to

$$x_c^{jn} = \phi^{jn}(v_n - p_c^{jn}) + (1 - \phi^{jn})(q_n + a_j^{Sn}) \qquad (7)$$

where $\phi^{jn} = \frac{V_n \beta_{jn}}{P_c^{jn} X_c^{jn}} = 1 - \frac{\psi_c^{jn}}{X_c^{jn}}$ is the supernumerary proportion of total expenditure on $X_c^{jn}$, which follows from the expression for the marginal budget share:

$$\beta_{jn} = \frac{P_c^{jn}(X_{jn} - \psi_c^{jn})}{V_n} \qquad (8)$$

The Frisch parameter $\gamma_n$ is the (negative) ratio of total to luxury expenditure, given by $-\frac{Y_n}{V_n}$. Since $\beta_{jn} = \frac{\varepsilon_{jn} P_c^{jn} X_c^{jn}}{Y_n}$, where $\varepsilon_{jn}$ is the expenditure elasticity of good $j$, $\phi^{jn} = -\frac{\varepsilon_{jn}}{\gamma_n}$. This allows us to subdivide demands into the price effect $-\frac{\varepsilon_{jn}}{\gamma_n} p_c^{jn}$, the expenditure effect $\frac{\varepsilon_{jn}}{\gamma_n} v_n$, population growth $(1 - \frac{\varepsilon_{jn}}{\gamma_n}) q_n$ and taste changes $(1 - \frac{\varepsilon_{jn}}{\gamma_n}) a_j^{Sn}$