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# A Computable General Equilibrium Model for Open Economies with Imperfect Competition and Product Differentiation

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## Abstract

*This paper corrects a shortcoming in the literature on computable general equilibrium models and imperfect competition with free entry and increasing returns to scale. The trade integration simulations applied to the US suggest that the shortcoming is quantitatively insignificant if key conditions are fulfilled. The model also shows how to incorporate iceberg trade costs in both constant and increasing returns to scale sectors. A fall in trade costs can have a large impact on welfare as less resources are wasted. In addition, the same model is proposed for competition policy experiments against illegal collaboration among competitors. The results of the simulations provide interesting insights, showing extraordinarily large welfare gains if competition policies are introduced to break the collusive behaviour in the US market among either domestic firms or foreign firms. However, if these policies are brought in to weaken the collusive behaviour among exporting firms, then a welfare loss can be generated because of a large deterioration of terms of trade.*

- **JEL Classification:** C68, D58, F12, F15
- **Key Words:** trade costs, competition policies, increasing returns, conjectural variation, CGE analysis

## I. Introduction

General equilibrium trade models have been available since the 1950's (Meade,

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1952; Johnson, 1959). However, a reliable general equilibrium empirical tool to determine the economic implications of openness to foreign markets and regional integration was provided only in the 1970's (Shoven and Whalley, 1974; Miller and Spencer, 1977). Since then a large number of computable general equilibrium (CGE) models for both developed and developing countries have been constructed to study a variety of empirical questions. International organisations, such as the World Bank, the OECD and the WTO, use them regularly for policy issues; and several economic departments provide courses in applied general equilibrium as well as applied econometrics, viewing them as complementary tools for economic policy analysis.

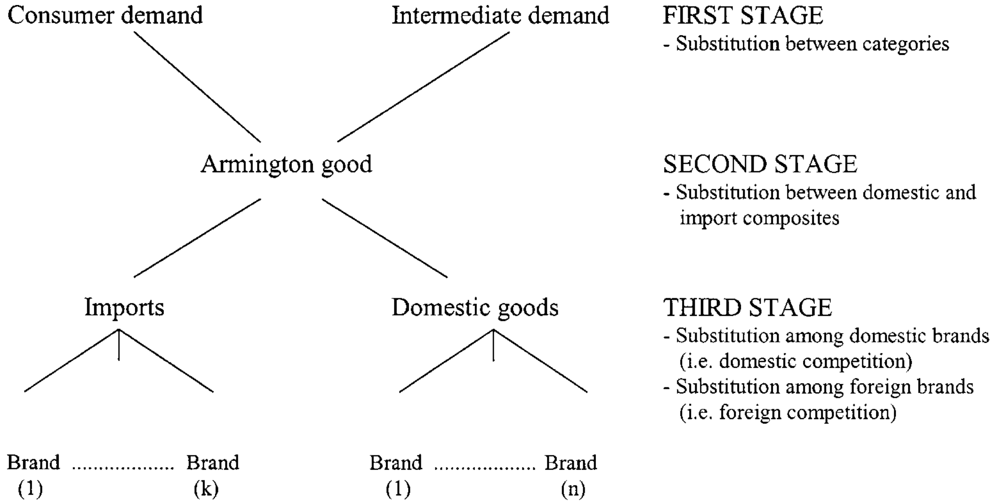
Initially, CGE models were constructed under the assumption of perfect competition and constant returns to scale (CRS), primarily to answer questions related to public finance and international trade (Shoven and Whalley, 1972, 1973, 1974; Miller and Spencer, 1977; Whalley, 1985). However, at the end of the 1970's, new analytical models facing imperfect competition and increasing returns to scale (IRS) were accepted by the scientific community to explain the gains from trade. The so called 'new trade theory' argues that, alongside the gains from trade due to the conventional comparative advantage, by enlarging markets international trade raises competition and allows greater exploitation of economies of scale (Krugman, 1979, 1981; Dixit and Norman, 1980; Lancaster, 1980; Helpman, 1981; Ethier, 1982). Under the wave of the 'new trade theory', in the middle eighties, CGE models with industrial organisation features were used to study the impact of trade policy actions when industries are characterised by free entry, and the economies to scale are exploited at firm level (Harris, 1984; Devarajan and Rodrik, 1989, 1991). More recently, Gasiorek, *et al.* (1992) and Harrison, Rutherford and Tarr (1996, 1997) (henceforth, HRT) have calibrated multicountry CGE models, where the price cost margin is defined as an inverse function of the endogenous price elasticity of demand perceived by the representative firm.[1] Gasiorek, *et al.* assume a Dixit-Stiglitz utility function; whilst HRT (1996, 1997) derive the perceived price elasticity of demand under the Armington specification, which states that goods produced by industries located in different countries, but which compete in the same market, are imperfect substitutes (Armington, 1969). The studies by HRT assume nonzero conjectural variations between firms from the same country, because initial prices are set equal to one and the marginal costs

[1] By calibration procedure I mean the estimation of unknown parameters, such that the observed values of endogenous variables constitute an equilibrium of the CGE model.

and the price elasticity of demand perceived by firms are calibrated. The gap between the sectoral price cost margins and the inverse of the absolute value of the price elasticities of demand is filled with a vector of conjectural variation parameters. Hence, there is a need for conjectural variations in CGE models with imperfect competition and IRS so as to help modellers in the calibration of the key parameters of the markup equations, which is tricky and certainly demanding, causing problems associated with the convergence of the model. However, the approach suggested by HRT is analytically incorrect, because the price elasticities of demand perceived by a firm in both the domestic and foreign markets depend upon the conjectural variations (see also De Santis, 2002). Given the importance of the CGE approach in the academic as well as non-academic world, it is important to correct this shortcoming and examine the possible bias of policy simulations.

In order to understand the problem, let me sketch a figure where the strategic interactions among domestic and foreign firms are clearly identifiable. Figure 1 depicts a typical three stage demand tree for the imperfect competitive good employed in the CGE literature (see for example HRT, 1996, 1997). At the first stage, the final demand of the representative consumer and the intermediate demand of industries are satisfied by the supply of composite commodities. At the second stage, the aggregate demand for composite commodities is satisfied by the supply of domestic goods and imports, treated as imperfect substitutes. At the third stage, having decided the demand for domestic goods and for imports,

**Figure 1.** The Demand System



consumers and industries purchase a variety of domestic goods and a variety of imports. Hence, domestic firms (as well as foreign firms) compete against each other at the third stage of the demand tree. It is at this stage that the expectation of a domestic (foreign) firm about the action of other domestic (foreign) firms to their own actions is formed. Therefore, the elasticity of demand perceived by the firms is not independent of conjectural variations.

In this paper, I derive a general formulation for the price markup, where the price elasticity of demand is a function of the conjectured reactions of the rival firms from the same market. I show that the price cost margin formula used by HRT can be obtained as a special case when firms behave in a Cournot fashion. I also show how to calibrate the conjectural variation parameters. In order to understand how welfare and output might be affected by the use of alternative conjectural variations, a single country open economy CGE model has been built for the US economy to study the economic implication of trade integration and competition policies.

The US has been applying small tariff rates for a long time. Consequently, trade integration has been more the results of the fall in non-tariff barriers, transport and communication costs. This study shows how to model these in a CGE framework in the form of iceberg trade costs for both constant and increasing returns to scale sectors. Policy simulations suggest that they can have large economic implications especially on welfare and, therefore, should not be disregarded by CGE models dealing with trade issues.

In addition, I propose to use this type of model to study the impact of competition policies by changing the conjectural variation parameters. There are strong objections to the conjectural variation approach (see Tirole, 1988, Ch. 6; Helpman and Krugman, 1989, Ch. 8; Varian, 1992, Ch. 16), mainly because a static model does not permit firms to respond to the other firm's output choice. It is argued that the notion of conjectural variation is *ad hoc* (Daughety, 1985), or that strategic responses require a temporal setting (Makowski, 1987). However, it is also understood that the conjectural variation approach is an approximation of the solution, which emerges from the equilibrium of a dynamic oligopolistic game (Schmalensee, 1989; Ferrel and Shapiro, 1990).[2] It is also well known that the

[2]Note that in linear oligopolies, and for an open set of values of the discount factor, the conjectural variation solution is the reduced form of the equilibrium of a quantity-setting repeated game with minimax punishments during $T$ periods (Cabral, 1995). Similarly, Pfaffermayr (1999) shows that a conjectural variation model may represent a reduced form of a price-setting supergame in a differentiated product market, which allows a wide range of outcomes from perfect competition to joint unconstrained monopoly.

conjectural variation models are used by empirical industrial economists because they can cover the entire range of market performance from competition to monopoly (Cowling, 1976; Cowling and Waterson, 1976; Slade, 1987; Machin and Van Reenen, 1993; Haskel and Martin, 1992, 1994). Also trade economists have employed the conjectural variation approach in a partial equilibrium setting: examples of fixed-entry quantitative models are those of Krugman (1987), Laussel, *et al.* (1997), and Dixit (1987, 1988); examples of free-entry quantitative models are those of Smith and Venables (1988), and Baldwin and Krugman (1988). As pointed out by Helpman and Krugman (1989), the justification for employing the conjectural variation approach in empirical studies is to be found in the fact that it can give a helpful indication of what the effects of policies might be once the industry conduct is specified. It is important to note that in April 2000, the US Department of Justice and Federal Trade Commission issued the antitrust guidelines for collaboration among competitors. The accompanying statement by the commissioner Mozelle Thompson states: {"*... in the modern market, competitors often need to collaborate. Companies that enter strategic alliances often do so in response to the dynamic competitive forces that are reshaping much of our economy. Moreover, many collaborations are being undertaken to unable companies to expand into foreign markets, fund expensive innovation and research efforts, and lower costs. But, some may raise competition issues*."}[3] Clearly, some forms of collaboration among competitors are tolerated, but others are considered illegal. This feature of the variegated US antitrust regulation is captured by the conjectural variation parameters.

The remaining sections of this paper have been organised as follows: Section 2 describes the modelling framework; Section 3 derives the price markups of a representative firm in the domestic and foreign markets; Section 4 describes the CGE model for the US, the benchmark data set and the calibration procedure; Section 5 discusses the numerical results; Section 6 presents a summary.

## II. The Structure of the Model

### A. The Supply Behaviour

Assume that within an industry $i$ a firm $s$ faces fixed costs, $f_i$, and produces

[3]The guidelines and the statement can be found respectevely at the following electronic addresses: www. FTC.gov/os/2000/04/antitrustguidethompson.htm and www.usdoj.gov/atr/public/guidelinesa/guidelin.htm

goods, which are supplied in the domestic market, $\tilde{d}_{is}$, and exported, $\tilde{e}_{is}$. Note that $i$ denotes the sectors facing IRS, whereas $j$ denotes all economic sectors.

The profit function of a representative domestic firm, $\pi_i$, takes the following form:

$$\tilde{\pi}_{is} = (\tilde{p}^d_{is} - c_i)\tilde{d}_{is} + (\tilde{p}^e_{is} - c_i - t_i)\tilde{e}_{is} - f_i \tag{1}$$

where $\tilde{p}^d_{is}$ and $\tilde{p}^e_{is}$ denote the brand prices of domestic output and exports, respectively; $c_i$ the marginal cost, which is assumed to be independent of output, and $t_i$ the specific iceberg trade cost. It is important to note that given (13) any collaboration among firms would be illegal, as a fall in costs would not occur. The first order conditions yield

$$\frac{\tilde{p}^d_{is} - c_i}{\tilde{p}^d_{is}} = \frac{1}{\left|\tilde{\tau}^d_{is}\right|} \qquad \tau^d_{is} < -1 \tag{2}$$

$$\frac{\tilde{p}^e_{is} - c_i - t_i}{\tilde{p}^e_{is}} = \frac{1}{\left|\tilde{\tau}^e_{is}\right|} \qquad \tau^d_{is} < -1 \qquad , \tag{3}$$

where $\tau^d_{is}$ and $\tau^e_{is}$ represent the price elasticities of domestic and export demands perceived by a domestic firm $s$, respectively. HRT (1997) would argue that $(\tilde{p}^d_{is} - c_i)/\tilde{p}^d_{is} = (1 + \Omega^d_i)/\left|\gamma^d_{is}\right|$ and $(\tilde{p}^e_{is} - c_i - t_i)/\tilde{p}^e_{is} = (1 + \Omega^e_i)/\left|\gamma^e_{is}\right|$, where $\Omega^d_i$ and $\Omega^e_i$ denote the conjectural variations in the domestic and export markets, respectively (with $\Omega_i^d = \Omega_i^e = 0$ representing the Cournot case); and $\gamma^d_{is}$ and $\gamma^e_{is}$ represent the price elasticities of domestic and export demands perceived by a domestic firm's, respectively, computed with the HRT approach. However, they implicitly assume that $\gamma^d_{is}$ and $\gamma^e_{is}$ are independent of conjectural variations parameters. Conversely, as suggested by Smith and Venables (1988), the perceived price elasticities of demand also depend on the perceived effect of the firm's action on industry aggregate supply. Note that the approach used in both HRT study and this paper is based upon the assumption that the equilibrium number of firms is large and finite as suggested by Yang and Heijdra (1993).

## B. The Demand Behaviour

A typical CGE model with imperfect competition and IRS is characterised by the three stage demand system as depicted in Figure 1. At the first stage, the final demand of the representative consumer, $C_i$, and the intermediate demand of industries, $X_i$, are satisfied by the supply of composite commodities, $Q_i$:

$$C_i = \alpha_i I / p_i \tag{4}$$

$$X_i = \sum_j a_{ij} Y_j \tag{5}$$

$$Q_i = C_i + X_i = [\varphi_i D_i^{(\varepsilon_i^d - 1/\varepsilon_i^d)} + (1 - \varphi_i) M_i^{(\varepsilon_i^d - 1/\varepsilon_i^d)}]^{\varepsilon_i^d/(\varepsilon_i^d - 1)} \tag{6}$$

where $\alpha_i$ denotes household budget shares, $I$ household income, $p_i$ the price of the Armington goods, $Y_j$ sectoral output, $a_{ij}$ the input requirements by sectors $i$ which are supplied by sectors $j$, $D_i$ domestic output, $M_i$ imports, $\varepsilon_i^d$ the elasticity of substitution between imports and domestic goods, and $\varphi_i$ the share parameter of the Armington function. Equation (4) is derived by maximising the consumer's Cobb-Douglas utility function subject to his budget constraint, whereas the derivation of (5) is based upon the assumption that intermediate inputs are net complements (i.e. Leontief specification). Equation (6) gives the equilibrium in the goods market.

At the second stage, the aggregate demand for composite commodities is satisfied by the supply of domestic goods and imports, according to the CES Armington specification. At the upper level, the solution of the Armington-dual problem yields the demand for domestic goods, $D_i$, the demand for imports, $M_i$, and the Armington price, $p_i$:

$$D_i = \varphi_i^{\varepsilon_i^d} p_i^{d\,-\varepsilon_i^d} p_i^{\varepsilon_i^d} Q_i \tag{7}$$

$$M_i = (1 - \varphi_i)^{\varepsilon_i^d} p_i^{m\,-\varepsilon_i^d} p_i^{\varepsilon_i^d} Q_i \tag{8}$$

$$p_i = \left\{ \varphi_i^{\varepsilon_i^d} p_i^{d(1 - \varepsilon_i^d)} + (1 - \varphi_i)^{\varepsilon_i^d} p_i^{m(1 - \varepsilon_i^d)} \right\}^{1/(1 - \varepsilon_i^d)}, \tag{9}$$

where $p_i^d$ denotes the domestic price index and $p_i^m$ the import price index.

At the third stage, having decided the demand for domestic goods and for imports, consumers and industries purchase a variety of domestic goods and a variety of imports, based again on CES functions:

$$D_i = \left[ \sum_{s=1}^{n^d} \tilde{d}_{is}^{(\varsigma_i^d - 1)/\varsigma_i^d} \right]^{\varsigma_i^d/(\varsigma_i^d - 1)}, \quad \varsigma_i^d > 1, \tag{10}$$

$$M_i = \left[ \sum_{r=1}^{n^m} \tilde{m}_{ir}^{(\varsigma_i^m - 1)/\varsigma_i^m} \right]^{\varsigma_i^m/(\varsigma_i^m - 1)}, \quad \varsigma_i^m > 1, \tag{11}$$

where $\varsigma_i^d$ and $\varsigma_i^m$ represent the elasticities of substitution among $n^d$ domestic varieties and $n^m$ imported varieties, respectively; and $\tilde{m}_{ir}$ denotes output of each foreign brand *r*. Given (10) and (11), the solution of the dual problems yields

$$\tilde{d}_{is} = p_i^{d\varsigma_i^d} \tilde{p}_{is}^{d-\varsigma_i^d} D_i, \tag{12}$$

$$p_i^d = \left[ \sum_{s=1}^{n^d} \tilde{p}_{is}^{d(1-\varsigma_i^d)} \right]^{1/(1-\varsigma_i^d)}, \tag{13}$$

$$\tilde{m}_{ir} = p_i^{m\varsigma_i^m} \tilde{p}_{ir}^{m-\varsigma_i^m} M_i, \tag{14}$$

$$p_i^m = \left[ \sum_{r=1}^{n^m} \tilde{p}_{ir}^{m(1-\varsigma_i^m)} \right]^{1/(1-\varsigma_i^m)} \tag{15}$$

where $\tilde{p}_{ir}^m$ denotes the price vector of imported brands gross of the trade costs.

## III. The Strategic Interaction Among Firms

Assume that domestic and foreign firms respond to output choices of rivals from the same country with constant conjectures. From (12), the inverse demand function can be log-linearised as

$$\ln \tilde{p}_{is}^d = \frac{1}{\varsigma_i^d} \ln D_i - \frac{1}{\varsigma_i^d} \ln \tilde{d}_{is} + \ln p_i^d \tag{16}$$

By definition the derivative of (16) with respect to $\ln \tilde{d}_{is}$ yields the inverse of the price elasticity of domestic demand perceived by a firm:

$$\frac{1}{\tau_{is}^d} = \frac{1}{\varsigma_i^d} \frac{d \ln D_i}{d \ln \tilde{d}_{is}} - \frac{1}{\varsigma_i^d} + \frac{d \ln p_i^d}{d \ln \tilde{d}_{is}} \tag{17}$$

The appendix shows that under symmetry among domestic firms and constant conjectures

$$\frac{1}{\tau_i^d} = \frac{1}{\varsigma_i^d} - \frac{1}{n_i^d} \left[ \frac{1}{\varepsilon_i^d} - \frac{1}{\varsigma_i^d} + \Psi_i^d \left( \frac{1}{\chi_i^d} - \frac{1}{\varepsilon_i^d} \right) \right] [1 + (n_i^d - 1) \lambda_i^d] \tag{18}$$

where $\Psi_i^d = p_i^d D_i / [p_i^d D_i + p_i^m M_i]$ represents the domestic industry market share in the domestic market; $\chi_i^d$ is the absolute value of the price elasticity of aggregate demand; and $\lambda_i^d = \partial \tilde{d}_{it} / \partial \tilde{d}_{is}$ denotes the conjectured reaction of rival domestic firms, $t = 1, \ldots, n-1$. Regarding the price elasticity of aggregate demand, by using (4)-(6), it can be shown that $\chi_i^d = C_i / Q_i$. This implies that $\chi_i^d$ is endogenous and ranges between zero and one (see appendix).

Also the foreign industry is assumed to be imperfectly competitive. In general, the inverse of the price elasticity of demand perceived by a representative firm in the *v* market (*v* stands for the domestic market, the export market and the import market) is:

$$\frac{1}{\tau_i^v} = \frac{1}{\varsigma_i^v} - \frac{1}{n_i^v}\left[\frac{1}{\varepsilon_i^v} - \frac{1}{\varsigma_i^v} + \Psi_i^v\left(\frac{1}{\chi_i^v} - \frac{1}{\varepsilon_i^v}\right)\right][1 + (n_i^v - 1)\lambda_i^v]^4 \qquad (19)$$

The absolute value of (19) corresponds to the price cost margin formula employed by HRT (1997) only under Cournot competition. In addition, (19) is consistent with the theory (Varian, 1992), which argues that a more collusive outcome is obtained for positive conjectural variations, if $\varsigma_i^v > \varepsilon_i^v > \chi_i^v$.

It is interesting to note that under Cournot conjectures, $\lim_{n_i^v \to \infty} (1/\tau_i^v) = -1/\varsigma_i^v$. In other words, the firm's price cost margin would be equal to the inverse of the elasticity of substitution among individual producers, as the number of brands converges to infinite. This result is in line with the monopolistic competitive literature (Dixit and Stiglitz, 1977; Krugman, 1979). Since I assume that the number of firms is finite, the price cost margin is larger than $1/\varsigma_i^v$, if $\lambda_i^v > (1 - n_i^v)^{-1}$.

In order to get further insights regarding the expression which define the price markups, it is very useful to compute the total differential of (19), which is:

$$d\frac{1}{|\tau_i^v|} = \frac{(n_i^v - 1)\lambda_i^v + 1}{n_i^v}\left[-\frac{A_i^v}{n_i^v} dn_i^v + \left(\frac{1}{\chi_i^v} - \frac{1}{\varepsilon_i^v}\right) d\Psi_i^v - \frac{\Psi_i^v}{\chi_i^{v^2}} d\chi_i^v\right], \qquad (20)$$

where $A_i^v = 1/\varepsilon_i^v - 1/\varsigma_i^v + \Psi_i^v(1/\chi_i^v - 1/\varepsilon_i^v)$. This exercise allows one to arrive at the following conclusions under the assumptions that $\varsigma_i^v > \varepsilon_i^v > \chi_i^v$:

- entry of new firms leads to a fall in the price-cost margin;
- a larger aggregate price elasticity (in absolute value) implies a larger price elasticity of demand perceived by a firm (in absolute value);
- an increase in the industry's market share implies a rise in the price-cost margin in its own market.

All these conditions are fulfilled if $\lambda_i^v > (1 - n_i^v)^{-1}$. Hence, a check on the value of

[4] Note that in a multiregional framework, $\tau_i^e$ is also affected by the ratio between the exports of domestic firms and total exports to a given region r. In a single country case, this ratio is obviously equal to one. Note also that, given the definition of *v*, $\varepsilon^d = \varepsilon^m$ and $\chi^d = \chi^m$.

is very useful in understanding and interpreting the numerical results.

Similarly, the total differential of the HRT price cost margins, , can be written as:

$$d\mu_i^v = \frac{(1+\Omega_i^v)}{n_i^v}\left[-\frac{A_i^v}{n_i^v}dn_i^v + \left(\frac{1}{\chi_i^v} - \frac{1}{\varepsilon_i^v}\right)d\Psi_i^v - \frac{\Psi_i^v}{\chi_i^{v^2}}d\chi_i^v\right] \quad (21)$$

This implies that the three above results are fulfilled if $\varsigma_i^v > \varepsilon_i^v > \chi_i^v$ and $\Omega_i^v > -1$. In summary, if $\varsigma_i^v > \varepsilon_i^v > \chi_i^v, \lambda_i^v > (1-n_i^v)^{-1}$, and $\Omega_i^v > -1$, the HRT and the approach suggested in this study would produce similar results, in particular as far as the direction of the variables' changes is concerned.

## IV. A CGE Model for the United States

### A. The model

The single country 3-sector CGE model presented in this section is used firstly to check if the results of the model are in line with the economic principles and, secondly, to examine whether lower trade costs and alternative conjectural variation parameters lead to different quantitative effects. The CGE model contains two categories of industries: those where perfect competition and CRS are assumed to prevail (agriculture and services), and those characterised by IRS (industry).

The production function has a two stage nested CES structure. At the first stage, I assume a Leontief function among primary factors of production and intermediate inputs, which are in turn assumed to be net complements. At the second stage, the elasticity of substitution among the mobile labour and the mobile capital is assumed to be positive. The production possibility frontier of the industries facing perfect competition and CRS is a constant elasticity transformation (CET) specification of domestic products and exports, treated as imperfect substitutes. On the demand side, the representative household demand, government spending, and the intermediate demand are satisfied by a composite of domestic and imported goods, as described in section 2. Government spending is set exogenously, so it does not play any role. The household demand is derived from a Cobb-Douglas utility function. The country is assumed to be a price taker for the commodities traded internationally, with the exception of goods produced by sectors facing IRS, for which a downward sloping export demand curve is supposed. The latter has been derived by assuming that a hypothetical foreign consumer purchases a variety of domestic goods and a variety of US exports, treated as their substitutes. Also the domestic price of imports is endogenously determined as indicated by (15). The marginal cost of the foreign firms and foreign domestic production are set exogenously. The trade balance and the public budget balance are always in equilibrium and firms make zero profits. The world price of the CRS goods is used as the numeraire of the model. The entire model is reported in the appendix.

## B. Benchmark and Calibration

The theoretical model outlined above and applied to the US requires a benchmark data set to calibrate unknown parameters, such that the observed value of endogenous variables constitutes an equilibrium of the numerical model.[5] I employ the social accounting matrix (SAM) for the US constructed for the year 1989 and available in Reinert and Roland-Holst (1997). The activities and commodities are disaggregated into 3 different types: agriculture, industry and services. Clearly, the original SAM has been adjusted for the needs of the present model (see Table 1).

In order to calibrate the variables of the sector facing IRS, the algebraic structure of the model required further information on price-cost margin, fixed costs and the number of symmetric firms. I assume that labour and capital inputs used in fixed proportion are 40 per cent of the primary factor inputs used by the industry. This allows me to calibrate the marginal cost and the cost disadvantage ratio, which is equal to 14.2 per cent. I also assume that the number of domestic

**Table 1.** A 1989 SAM for the United States

(Billion of Dollars)

| | Agriculture | Industry | Services | Labour | Capital | Household | Government | RoW | Duties | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Agriculture | 38,1 | 104,9 | 15,3 | | | 24,5 | 4,6 | 28,1 | | 215,5 |
| Industry | 33,5 | 1438,0 | 497,1 | | | 725,5 | 1009,1 | 341,8 | | 4045,0 |
| Services | 22,7 | 749,1 | 1332,5 | | | 2700,2 | 783,0 | 121,1 | | 5708,6 |
| Labour | 35,8 | 900,5 | 2142,6 | | | | | | | 3078,9 |
| Capital | 65,9 | 304,9 | 1316,3 | | | | | | | 1687,1 |
| Household | | | | 3078,9 | 1687,1 | | | | | 4766,0 |
| Government | 8,2 | 60,5 | 311,0 | | | 1315,8 | | 83,7 | 17,5 | 1796,7 |
| RoW | 11,1 | 469,8 | 93,8 | | | | | | | 574,7 |
| Duties | 0,2 | 17,3 | | | | | | | | 17,5 |
| Total | 215,5 | 4045,0 | 5708,6 | 3078,9 | 1687,1 | 4766,0 | 1796,7 | 574,7 | 17,5 | |

Source: Author's data elaboration from Reinert and Roland-Holst (1997).

[5]Variables and parameters with ^ mean that they are calibrated, whilst variables with $^0$ are observed in the base year.

**Table 2.** Calibrated conjectures and firms' price elasticities

| | Conjectural variation parameters | | | Price elasticities | | |
|---|---|---|---|---|---|---|
| | Domestic market | Export market | Import market | Domestic market | Export market | Import market |
| HRT | + 0.021 | + 1.281 | + 0.923 | – 7.173 | – 16.026 | – 13.512 |
| DES | – 0,001 | + 0.132 | + 0.058 | – 7.026 | – 7.026 | – 7.026 |

HRT: HRT approach; DES: De Santis's approach.

and foreign firms is 50 of each type. The number of firms is large enough to avoid problems associated with integer values.

The conjectural variation parameters are endogenously calibrated. Under the HRT approach, the conjectural variation parameters are calibrated as follows: $\Omega_i^v = \hat{\theta}_i|\hat{\gamma}_i^v| - 1$, where $\ddot{\theta}_i$ denotes the calibrated price cost margin, which is assumed equal to the cost disadvantage ratio for both domestic and foreign firms. Thus, $\ddot{\theta}_i$ is equal to 0.142. Under the approach presented in this study, the vector of conjectural variation parameters is calibrated as follows:

$$\hat{\lambda}_i^v = \frac{1}{n_i^{v^0} - 1}\left[\frac{n_i^{v^0}(\hat{\theta}_i - 1/\varsigma_i^v)}{1/\varepsilon_i^v - 1/\varsigma_i^v + \hat{\Psi}_i^v(1/\chi_i^v - 1/\varepsilon_i^v)} - 1\right]. \tag{22}$$

It is important to note that (22) can be re-arranged as $\hat{G}_i^v = n_i^{v^0}(\hat{\theta}_i - 1/\varsigma_i^v)/\hat{A}_i^v$. Hence if, and only if, $\ddot{\theta}_i > 1/\varsigma_i^v$, $\hat{G}_i^v$ has the same sign of $\hat{A}_i^v$.

In order to obtain calibrated values that are consistent with those discussed in section 3, I set $\varsigma_i^v = 20$, so that $sign(\hat{G}_i^v) = sign(\hat{A}_i^v)$. The vector of the CET elasticities in the CRS sectors is assumed equal to 2.5, whereas the vector of the Armington elasticities is assumed to be equal to 1.5 such that $\varsigma_i^v > \varepsilon_i^v > \chi_i^v$. The elasticity of substitution among primary factors of production is assumed equal to 0.5 in agriculture, 1.4 in industry and 2 in services.[6] This permits the calibration of the firms' perceived price elasticities in each market.

Table 2 shows the vector of the calibrated quantity conjectures (22) and of the price elasticity perceived by domestic and foreign firms under both the HRT approach and the approach suggested in this study (DES approach). The conjectural

[6]A detailed study on the Armington elasticities at sectoral level for mining and manufacturing in the US is published by Reinert and Roland-Holst (1992). These elasticities range between 0.01 (other rubber products) and 3.49 (wine, brandy, and brandy spirits). The elasticity employed in this study is somewhat in the middle. With regard to the elasticity of substitution among primary inputs, the elasticity for agriculture is assumed smaller because of the underlying assumption that land is sector specific. The sectoral supply response to shocks should therefore be smaller in agriculture. Similar elasticities of substitution are also suggested by the GTAP data base (McDougall, *et al.*, 1998, pp. 19-9), a statistical source often used in CGE analysis.

variation parameters (22) are very close to the Cournot case. Those obtained under the HRT approach are slightly larger. Note that all of them fulfil the conditions suggested by the total differentials of the price markups (20) and (21).

## V. Scenarios

### A. Trade Integration Policies

CGE models have been widely used to study the economic implications of tariff reduction. The simulations for the US, whose results have been not reported, suggest that the economic implications of tariff liberalisation are minor because the calibrated *ad valorem* tariff rates are small.[7] It must be said that CGE models have generally found a small positive impact on welfare even if increasing returns to scale is postulated (i.e. around 2% of the consumer income). However, it should be stressed that other form of trade costs - such as non-tariff barriers, transport and communication costs - have been often disregarded by the CGE literature. In this section, I show that lowering iceberg trade costs might have a larger effect on welfare, as they capture the potentially sizeable *Krueger rectangle*. As regards the impact on the concentration of the industry, ex-ante protected firms would suffer losses with the less efficient firms exiting the market to restore the zero profit equilibrium condition.

Since trade costs are equal to zero in the benchmark, the numerical exercise consists of introducing trade costs on goods traded in the international markets. However, I consider the results of the simulations as the starting point for the economy. Hence, the comparison between the benchmark and the results will be interpreted as the economic implications of a fall in trade costs. Evidence between 1970 and 1990, provided by Davis (1998) and Rauch (1999), suggest that the transport costs in the US fall by only 2.08 points in agriculture, 0.7 points in industry and 1.01 points in services. However, other costs such as the elimination of non-tariff barriers and the fall of communication costs might have fallen more extensively. Thus, I consider an additional scenario, where trade costs fall by 10 points in all sectors.

A fall in trade costs affects all prices: export prices, import prices and domestic

[7] A conjectural variation CGE model has been applied to Turkey to study the impact of tariff liberalisation policies under alternative conjectural variation parameters. The impact of the trade policy on welfare is found to be small (De Santis, 2002).

**Table 3.** The impact of trade integration (%)

| | Fall in transport costs (Rauch's evidence) | | | | | | Fall in trade costs (10 point fall) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HRT | | | DES | | | HRT | | | DES | | |
| Welfare | | 0.3 | | | 0.3 | | | 3.2 | | | 3.2 | |
| | Agr | Ind | Ser | Agr | Ind | Ser | Agr | Ind | Ser | Agr | Ind | Ser |
| Output | 0.5 | –0.1 | 0.1 | 0.5 | –0.1 | 0.1 | 0.1 | –1.3 | 1.0 | 0.2 | –1.3 | 1.0 |
| Domestic sales | –0.1 | –0.2 | 0.1 | –0.1 | –0.2 | 0.1 | –1.4 | –2.3 | 0.8 | –1.4 | –2.2 | 0.8 |
| Export volume | 4.4 | 0.3 | 0.9 | 4.4 | 0.3 | 0.9 | 11.3 | 8.9 | 10.2 | 11.3 | 8.9 | 10.2 |
| Import volume | 3.6 | 2.0 | 2.7 | 3.6 | 2.0 | 2.7 | 23.9 | 26.5 | 29.2 | 23.9 | 26.1 | 29.1 |
| Domestic industry's market share | –0.1 | –0.1 | –0.0 | –0.1 | –0.1 | –0.0 | –0.4 | –1.1 | –0.1 | –0.4 | –1.1 | –0.1 |
| Export industry's market share | 4.3 | 0.1 | 0.9 | 4.3 | 0.1 | 0.9 | 11.1 | 2.3 | 10.2 | 11.1 | 2.2 | 10.2 |
| Foreign industry's market share | 1.1 | 0.6 | 0.8 | 1.1 | 0.6 | 0.8 | 7.4 | 8.0 | 8.5 | 7.4 | 8.0 | 8.5 |
| Number of domestic firms | | –0.5 | | | –0.5 | | | –5.2 | | | –5.3 | |
| Number of foreign firms | | 0.8 | | | 0.9 | | | 9.3 | | | 10.9 | |
| Domestic firm's domestic output | | 0.3 | | | 0.3 | | | 3.1 | | | 3.2 | |
| Domestic firm's exports | | 0.8 | | | 0.8 | | | 14.9 | | | 15.0 | |
| Domestic firm's output | | 0.3 | | | 0.4 | | | 4.1 | | | 4.2 | |
| Foreign firm's output | | 1.1 | | | 1.0 | | | 15.7 | | | 13.6 | |
| PCM in the domestic market | | –0.0 | | | –0.0 | | | –0.5 | | | –0.6 | |
| PCM in the export market | | 0.1 | | | 0.0 | | | 1.0 | | | 0.4 | |
| PCM in the import market | | –0.2 | | | –0.1 | | | –2.7 | | | –1.2 | |
| Aggregate demand elasticity | | 0.5 | | | 0.5 | | | 5.4 | | | 5.3 | |

HRT: HRT approach; DES: De Santis's approach.

prices, since the latter will adjust due to the substitutability which occurs between internationally and domestically traded goods. The economy will be much more open. Thus, the trade volume will increase and the economy will specialise in producing goods for which it has a comparative advantage. Since the model assumes mobility of factors of production and full employment, trade should allow a greater variety of goods and a greater scale of production (Krugman, 1979). The boost due to openness might even increase both factor prices (Krugman, 1981). In summary, higher factor returns and lower goods prices should be reflected in higher consumer welfare.

Table 3 shows the results of the simulations. Those labelled 'HRT' are based on the model suggested by HRT; whereas those labelled 'DES' are based upon the model presented in this study. The results of both methods are extraordinarily similar and consistent with the economic principles. Welfare gains from a fall in transport costs are only equal to 0.3 per cent of the consumer income, if transport costs fall according to Rauch's evidence. However, if trade costs fall by 10 points, welfare rises by 3.2-3.3 per cent (157 billion of US dollars). Trade volume increases and domestic sales generally decline due to foreign competition. The market share of the US industry declines in the domestic market, whereas it increases in the foreign market. In particular, the fall in manufacturing shifts resources to agriculture and services, which can expand. Trade openness implies that the less efficient domestic firms exit the market. However, the total number of firms increases enhancing the economy. In fact, the number of domestic firms declines by 0.5 (5.2) per cent, whereas the number of foreign firms rises by 0.8 (9.2) under HRT and by 0.9 (10.7) per cent under DES. The welfare gains are due to the more efficient use of resources within the economy. As the number of manufacturing domestic firms declines, the primary factors of production used previously as fixed costs in the manufacturing sector can now be employed to increase production in CRS sectors. As the total number of firms in the US economy increases, the economy boosts also due to this scale effect. In addition, some of the resources previously wasted in covering trade costs can be now employed to produce goods which can be domestically consumed or exported (i.e. the *Krueger rectangle* declines). The most important difference among the two methods is the impact of a fall in trade costs on the price cost margin of the foreign firm and, as a result, on their size and on the equilibrium number of foreign firms. The price cost margin declines by 0.1 (1.2) per cent under the DES approach, whereas it declines by 0.2 (2.6) per cent under the HRT approach. At first glance, one might have the impression that the DES numerical model is inconsistent because all the variables, which affect the price cost margin of the foreign firm, change by a similar size: the market share of the foreign industry rises by 0.6 (7.9-8) per cent, the price elasticity of aggregate demand rises by 0.5 (5.3-5.4) per cent, while the number of foreign firms increases by a larger amount under the DES approach, which would mean that the price cost margin should be smaller under this approach. In order to understand this result, compute the total differential of the price cost margin of the foreign firm under both the DES and the HRT approach by using (20) and (21), respectively. Then,

$$d\left(\frac{p_i^m - c_i^m - t_i}{p_i^m}\right)\Bigg|_{DES} = -0,0005\,dn_i^m + 0,341\,d\Psi_i^m - 0,640\,d\chi_i^m,$$

$$d\left(\frac{p_i^m - c_i^m - t_i}{p_i^m}\right)\Bigg|_{HRT} = -0,0009\,dn_i^m + 0,171\,d\Psi_i^m - 0,132\,d\chi_i^m$$

It is evident that the calibrated elasticity of the foreign industry's market share under the DES approach is the double that under the HRT approach, and that the

**Table 4.** Changing Conjectures

| | HRT | | | DES | | |
|---|---|---|---|---|---|---|
| | Domestic market | Export Market | Import market | Domestic market | Export market | Import market |
| Ex post | + 0.021 | + 1.281 | + 0.923 | – 0,001 | + 0.132 | + 0.058 |
| Ex ante | + 1.000 | + 3.000 | + 2.000 | + 0.003 | + 0.950 | + 0.950 |

HRT: Harrison-Rutherford-Tarr approach; DES: De Santis's approach.

**Table 5.** The Impact of Competition Policies (%)

| | HRT | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Change in $\hat{\Omega}_i^d$ | | | Change in $\hat{\Omega}_i^e$ | | | Change in $\hat{\Omega}_i^m$ | | |
| Welfare | | 8.9 | | | –0.4 | | | 0.8 | |
| | Agr | Ind | Ser | Agr | Ind | Ser | Agr | Ind | Ser |
| Output | 8.4 | 12.2 | 5.6 | 0.5 | 1.9 | 0.0 | –0.2 | –0.4 | 0.3 |
| Domestic sales | 9.6 | 13.7 | 5.8 | 1.0 | 0.3 | 0.0 | –0.2 | –0.7 | 0.3 |
| Export volume | 1.8 | 0.0 | –3.6 | –2.1 | 19.3 | –2.3 | –0.7 | 2.9 | -0.5 |
| Import volume | 14.5 | –3.4 | 11.9 | 2.8 | 3.1 | 1.5 | 0.1 | 9.2 | 0.7 |
| Number of domestic firms | | –36.4 | | | –2.9 | | | –1.3 | |
| Number of foreign firms | | –4.4 | | | 2.6 | | | –28.2 | |
| Domestic firm's domestic output | | 78.9 | | | 3.3 | | | 0.6 | |
| Domestic firm's exports | | 57.3 | | | 22.9 | | | 4.3 | |
| Domestic firm's output | | 76.6 | | | 4.9 | | | 1.0 | |
| Foreign firm's output | | 1.1 | | | 0.5 | | | 52.1 | |
| PCM in the domestic market | | –36.4 | | | 2.7 | | | –0.3 | |
| PCM in the export market | | 7.8 | | | –42.6 | | | 0.3 | |
| PCM in the import market | | –0.9 | | | –0.4 | | | –29.4 | |
| Terms of trade | | –0.4 | | | –11.2 | | | 7.2 | |
| | HRT | | | | | | | | |
| | Change in $\lambda_i^d$ | | | Change in $\lambda_i^e$ | | | Change in $\lambda_i^m$ | | |
| Welfare | | 14.2 | | | –1.1 | | | 41.1 | |
| | Agr | Ind | Ser | Agr | Ind | Ser | Agr | Ind | Ser |
| Output | 12.3 | 18.3 | 8.6 | –0.1 | 8.3 | –0.0 | 6.2 | –15.7 | 15.4 |
| Domestic sales | 14.3 | 20.4 | 9.0 | 3.4 | 1.2 | 0.4 | –1.1 | –20.8 | 14.3 |
| Export volume | 1.3 | 2.1 | –6.1 | –16.9 | 220.9 | –16.1 | 131.9 | 113.7 | 123.7 |
| Import volume | 22.9 | –3.9 | 19.2 | 17.8 | 16.6 | 11.9 | –40.7 | 4012.8 | –23.6 |
| Number of domestic firms | | –45.8 | | | –10.2 | | | –42.0 | |
| Number of foreign firms | | –10.3 | | | 17.1 | | | –73.1 | |
| Domestic firm's domestic output | | 122.2 | | | 12.7 | | | 36.6 | |
| Domestic firm's exports | | 88.4 | | | 257.4 | | | 268.6 | |
| Domestic firm's output | | 118.4 | | | 20.6 | | | 45.4 | |
| Foreign firm's output | | 7.2 | | | –0.4 | | | 15201.2 | |
| PCM in the domestic market | | –44.8 | | | 9.6 | | | –10.9 | |
| PCM in the export market | | 3.6 | | | –77.7 | | | 3.4 | |
| PCM in the import market | | –5.7 | | | 0.4 | | | –85.2 | |
| Terms of trade | | –0.9 | | | –54.5 | | | 1348.1 | |

HRT: Harrison–Rutherford-Tarr approach; DES: De Santis's approach.

aggregate demand elasticity under the DES approach is almost five times that under the HRT approach. This implies that the aggregate price elasticity plays a key role in explaining the different results obtained with the two methods at firm level. It is also interesting to note that the impact on the equilibrium number of firms is not an important variable to determine the price cost margin. Hence, in this modelling framework, it is the price cost margin that affects the equilibrium number of firms.

In summary, the two models yield very similar results, which implies that the trade integration scenarios available in the literature obtained with CGE models, which employ the HRT approach, are very good approximations if $\varsigma_i^v > \varepsilon_i^v > \chi_i^v$ and $\Omega_i^v > -1$.

## A. Competition Policies

Can this type of model be used to study the impact of competition policies? In this subsection, I show that the conjectural variation approach should be exploited in CGE models because it can give a helpful indication of the effects of competition policies against anti-competitive collaborations among firms by changing the conjectural variation parameters. The scenarios assume that the equilibrium of the economy is ex post given by the benchmark, whereas the conjectural variation parameters are assumed *ex ante* to be larger (se Table 4). I can, therefore, study the impact of competition policies in US manufacturing, by comparing the benchmark with the new equilibrium solutions.

The results presented in Table 5 differ according to the model employed because the marginal effects of the two approaches are of a different magnitude: $\partial[1/\tau_i^v]/\partial\lambda_i^v = A_i^v(n_i^v - 1)/n_i^v > 0$ under the DES approach, and $\partial\mu_i^v/\partial\Omega_i^v = A_i^v/n_i^v > 0$ under the HRT approach.[8] The absolute value of the marginal effect is larger under the DES approach, which implies that the impact on variables will be greater under this approach, whilst the direction of the impact should not be affected. Here, I interpret the results produced with the DES approach.

The first column of Table 5 shows the impact of policies, which favour the competitiveness of US firms in the US market. The competition policies halve the price markup in the domestic market and, as a result, reduce the equilibrium number of domestic firms by 45.8 per cent. Given the Armington specification, consumers and entrepreneurs prefer cheaper domestic goods to imports. As a

[8]Note that a strengthened collusive behaviour results in larger price markups if $s_i^v > \varepsilon_i^v > \chi_i^v$, which is always postulated in this paper.

result, the import volume declines and 10.3 per cent of foreign firms exit the US market. Note that the size of domestic firms almost doubles (118.4 per cent). The efficient use of resources and the greater exploitation of economies of scale allow all sectors to expand. The welfare gains of this policy are equal to 14.2 per cent of the consumer income, an extraordinary impact compared to the small gains shown in the CGE literature.

The second column of Table 5 shows the impact of policies, which favour the competitiveness of US firms in the foreign market. The competition policies reduce the price markup in the export market by 77.7 per cent and, as a result, reduce the number of competing domestic firms by 10.2 per cent, although export sales increase exponentially (220.9 per cent). The huge amount of exports is offset by an expansion of a variety of foreign brands, which increase by 17.1 per cent to keep the current account deficit constant. Despite the rise by 20.6 per cent of the size of the domestic firms, the efficient use of resources and the more appropriate exploitation of economies of scale do not lead to welfare gains, because of a large deterioration of terms of trade. In fact, the latter declines by 54.5 per cent bringing about a welfare loss equal to 1.1 per cent.

Finally, the last column of Table 5 shows the impact of policies, which favour the competitiveness of foreign firms in the US market. The competition policies reduce the price markup of the foreign firms by 85.2 per cent and, as a result, reduce the number of competing foreign firms by 73.1 per cent, although the import volume in manufacturing increases exponentially (almost 40 times). The huge amount of imports is offset by an expansion of exports in all sectors to keep the current account deficit constant. Given the Armington specification, consumers and entrepreneurs prefer cheaper imports to domestic products. Hence, manufacturing domestic sales and their price decline. The negative impact on domestic demand causes the exit of domestic firms, which are reduced by 42 per cent. However, the size of the domestic firms rises by 45.4 per cent. The efficient use of resources and the greater exploitation of economies of scale, plus the extraordinarily large positive terms of trade effect, lead to extraordinary large welfare gains, which amount to 41.1 per cent of the consumer income. It is important to emphasise that foreign marginal costs are constant, which implies that foreign firm's output can expand (152 times) without affecting foreign factor prices. This assumption has been required because of the single country hypothesis. As a result, the impact on import volume and, hence, on welfare is due to the partial equilibrium hypothesis postulated for the foreign economy.

Nevertheless, the results are consistent with economic theory; though a multiregional model would be required to better examine the implications of competition policies to break the collusive behaviour of foreign firms.

## VI. Summary

This study proposes a procedure to construct CGE models with imperfect competition for open economies, which are characterised by IRS and free entry. The model is similar to that used by HRT (1997), where firms compete in a quantity setting oligopoly with calibrated constant conjectures. It assumes that the price cost margin faced by national firms is endogenous, and derives the price elasticities of demand perceived by a firm in a multi-stage demand system, which, however, are also a function of the conjectured reactions of the rival firms from the same market. I show that the formulas suggested by HRT can be obtained under the hypothesis of Cournot competition. In addition, I indicate an approach to calibrate the conjectural variation parameters, and I set up a model for the US for the empirical analysis. The numerical model shows that, as a consequence of a fall in trade costs, the results obtained under the HRT approach are very similar to those obtained by using the suggested methodology, if key conditions are satisfied.

I also suggest using these types of models to study the impact of competition policies against anti-competitive collaborations among firms by varying the conjectural variation parameters. The scenarios suggest that if competition policies are introduced to break the collusive behaviour in the US market among either domestic firms or foreign firms, then large welfare gains can be generated because resources are more efficiently used and economies of scale are exploited considerably. However, if these policies are brought in to weaken the collusive behaviour among exporting firms, then a welfare loss can be generated due to a large negative terms of trade effect.

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# Appendix

***Derivation of (18)**

Given (10)

$$\frac{\partial D_i}{\partial \tilde{d}_{is}} = D_i^{1/\varsigma_i} \tilde{d}_{is}^{-1/\varsigma_i} \left[ 1 + \frac{\sum_{t \neq s} (\tilde{d}_{it}^{-1/\varsigma_i})}{\tilde{d}_{is}^{-1/\varsigma_i}} \lambda \right] \tag{A1}$$

Since from (12) $D_i^{1/\varsigma_i}\tilde{d}_{is}^{-1/\varsigma_i} = \tilde{p}_{is}^d / p_i^d$, then

$$\frac{d\ ln\ D_i}{d\ ln\ \tilde{d}_{is}} = \frac{\tilde{p}_{is}^d / \tilde{d}_{is}}{p_i^d D_i}\left[1 + \frac{\sum_{t \neq s}(\tilde{d}_{it}^{-1/\varsigma_i})}{\tilde{d}_{is}^{-1/\varsigma_i}}\lambda\right] \tag{A2}$$

Since, by using the chain rule, $\frac{\partial p_i^d}{\partial \tilde{d}_{is}} = \frac{\partial p_i^d}{\partial D_i}\frac{\partial \Delta_i}{\partial \tilde{d}_{is}^e}$, then

$$\frac{d\ ln\ p_i^d}{d\ ln\ \tilde{d}_{is}} = \frac{\tilde{p}_{is}^d \tilde{d}_{is}}{p_i^d D_i}\frac{D_i}{p_i^d}\frac{\partial p_i^d}{\partial D_i}\left[1 + \frac{\sum_{t \neq s}(\tilde{d}_{it}^{-1/\varsigma_i})}{\tilde{d}_{is}^{-1/\varsigma_i}}\lambda\right]. \tag{A3}$$

Given the symmetry assumption, (A3) and (A2) into (17) yield

$$\frac{1}{\tau_i} = -\frac{1}{\varsigma_i} + \frac{1}{n_i}\left(\frac{1}{\varsigma_i} + \frac{D_i}{p_i^d}\frac{\partial p_i^d}{\partial D_i}\right)[1 + (n_i^d - 1)\lambda] \tag{A4}$$

By applying similar steps at the second stage of the demand tree, then

$$\frac{D_i}{p_i^d}\frac{\partial p_i^d}{\partial D_i} = -\frac{1}{\varepsilon_i} + \Psi_i\left(\frac{1}{\varepsilon_i} - \frac{1}{\chi_i}\right) \tag{A5}$$

where $\chi_i = -(p_i/Q_i)(\partial Q_i/\partial p_i)$. Equation (A5) into (A4) yields expression (18).

## • Derivation of the Price Elasticity of Aggregate Demand

The price elasticity of aggregate demand can be derived by using (4)-(6), as follows:

$$\chi_i = -\frac{\partial Q_i}{\partial p_i}\frac{p_i}{Q_i} = -\frac{p_i}{Q_i}\left(\frac{\partial X_i}{\partial p_i} + \frac{\partial C_i}{\partial p_i}\right) = -\frac{p_i}{Q_i}\frac{\partial X_i}{\partial p_i} + \frac{C_i}{Q_i}.$$

Under a Leontief specification $\partial X_i/\partial p_i = 0$. To show this assume that production is undertaken by using intermediate inputs only, which are substitutes. Then, the intermediate demand can be written as $X = a^b p^{-b} q^b Y$, where $q = [a^b p^{1-b} + (1-a)^b \bar{p}^{1-b}]^{1/(1-b)}$, $p$ is the price of intermediate goods $X$, $\bar{p}$ the price of other intermediate goods, $a$ a share parameter, and $b$ the elasticity of substitution among inputs. In this case, $\partial X/\partial p = -ba^b Y p^{-1-b} q^b [1 - a^b (p/q)^{1-b}]$, which means that $\lim_{b \to 0}(\partial X/\partial p) = 0$. Since I assume a Leontief specification between value added and intermediate inputs, which are in turn assumed to be net complements, then $\partial X_i / \partial p_i = 0$. Given the Cobb-Douglas utility function, the absolute value of the price elasticity of aggregate demand reduces to $0 \le \chi_i = C_i / Q_i \le 1$.

**• The Algebraic Model with Transport Costs and Nonzero Conjectures**

The three-sector DES model is characterised by 54 endogenous variables and 54 equations. Note that the consumer income $I = w\bar{L} + r\bar{K} - T$, which by Walras's law is subtracted from the system of equations, because it is determined by the trade balance equilibrium condition. I wish to stress that the zero profit conditions for all sectors and the Walras's law have been accurately checked in all simulation exercises. Note that $i$ denotes the IRS sectors (i.e. industry), $c$ the CRS sectors (i.e. agriculture and services) and $j = i \cup c$.

| Price equations | Determined variables |
|---|---|
| $p_c Q_c = [\bar{p}_c^m (1 + z_c) + t_c] M_c + p_c^d D_c$ | $p_c$ |
| $p_i Q_i = (\tilde{p}_i^m - t_i)(1 + z_i) n_i^m m_i + \tilde{p}_i^d n_i^d d_i$ | $p_i$ |
| $\tilde{p}_i^d = \dfrac{c_i}{1 + 1/\tau_i^d}$ | $\tilde{p}_i^d$ |
| $\tilde{p}_i^e = \dfrac{c_i + \tau_i}{1 + \dfrac{1}{\gamma_i^e}}$ | $\tilde{p}_i^e$ |
| $\tilde{p}_i^m = \dfrac{\bar{c}_i^m + t_i}{1 + 1/\tau_i^m}$ | $\tilde{p}_i^m$ |
| $p_j^f = \Delta_j^{-1} [\delta_j^{\sigma_j} w^{(1-\sigma_j)} + (1 - \delta_j)^{\sigma_j} r^{(1-\sigma_j)}]^{1/(1-\sigma_j)}$ | $p_j^f$ |
| $p_c^y = p_c^f + \sum_j a_{jc} p_j$ | $p_c^y$ |

Perceived price elasticities equations

$$\frac{1}{\tau_i^d} = -\frac{1}{\varsigma_i^d} - \frac{1}{n_i^d}\left[\frac{1}{\varepsilon_i^d} - \frac{1}{\varsigma_i^d} + \frac{\tilde{p}_i^d n_i^d d_i}{p_i Q_i}\left(\frac{Q_i}{C_i} - \frac{1}{\varepsilon_i^d}\right)\right][1 + (n_i^d - 1)\lambda_i^d] \qquad \tau_i^d$$

$$\frac{1}{\tau_i^e} = -\frac{1}{\varsigma_i^e} - \frac{1}{n_i^d}\left[\frac{1}{\varepsilon_i^e} - \frac{1}{\varsigma_i^e} + \frac{\tilde{p}_i^e n_i^d e_i}{\bar{D}_i^e + \tilde{p}_i^e n_i^d e_i}\left(1 - \frac{1}{\varepsilon_i^e}\right)\right][1 + (n_i^d - 1)\lambda_i^e] \qquad \tau_i^e$$

$$\frac{1}{\tau_i^m} = -\frac{1}{\varsigma_i^m} - \frac{1}{n_i^m}\left[\frac{1}{\varepsilon_i^d} - \frac{1}{\varsigma_i^m} + \frac{[(\tilde{p}_i^m - t_i)(1+z_i) + t_i]n_i^m m_i}{p_i Q_i}\left(\frac{Q_i}{C_i} - \frac{1}{\varepsilon_i^d}\right)\right][1 + (n_i^m - 1)\lambda_i^m] \qquad \tau_i^m$$

Production costs equations

$$c_i = \Delta_i^{-1}[\delta_i^{\sigma_i} w^{(1-\sigma_i)} + (1-\delta_i)^{\sigma_i} r^{(1-\sigma_i)}]^{1/(1-\sigma_i)} + \sum_j a_{ji} p_j \qquad c_i$$

$$f_i = w\bar{l}_i^f + r\bar{k}_i^f \qquad f_i$$

Production and factor inputs equations

$$p_c^y Y_c = p_c^d D_c + (\bar{p}_c^e - t_c)E_c \qquad Y_c$$

$$L_c = \Delta_c^{(\sigma_c - 1)}\left(\delta_c \frac{p_c^f}{w}\right)^{\sigma_c} Y_c \qquad L_c$$

$$K_c = \Delta_c^{(\sigma_c - 1)}\left((1-\delta_c)\frac{p_c^f}{r}\right)^{\sigma_c} Y_c \qquad K_c$$

$$y_i = d_i + e_i \qquad y_i$$

$$l_i = \Delta_i^{(\sigma_i - 1)}\left(\delta_i \frac{p_i^f}{r}\right)^{\sigma_c} y_i \qquad l_i$$

$$k_i = \Delta_i^{(\sigma_i - 1)}\left((1-\delta_i)\frac{p_i^f}{r}\right)^{\sigma_i} y_i \qquad k_i$$

Zero profits equations

$$(\tilde{p}_i^d - c_i)d_i + (\tilde{p}_i^e - c_i - t_i)e_i = f_i \qquad n_i^d$$

$$(\tilde{p}_i^m - \bar{c}_i^m - t_i)m_i = \bar{f}_i^m \qquad n_i^m$$

Domestic and international trade equations

$$Q_j = A_j[\varphi_j D_j^{(\varepsilon_j^d - 1)/\varepsilon_j^d} + (1-\varphi_j)M_j^{(\varepsilon_j^d - 1)/\varepsilon_j^d}]^{\varepsilon_j^d/(\varepsilon_j^d - 1)} \qquad D_j$$

$$\frac{M_c}{D_c} = \left[\frac{p_c^d}{\bar{p}_c^m(1+z_c) + t_c}\frac{(1-\varphi_c)}{\varphi_c}\right]^{\varepsilon_c^d} \qquad M_c$$

$$\frac{M_i}{D_i} = \left[ \frac{n_i^{d(1/1-\varsigma_i^d)} \tilde{p}_i^{\,d}}{n_i^{m/(1-\varsigma_i^m)} [(\bar{p}_i^m - t_i)(1 + z_c) + t_i]} \frac{(1-\varphi_i)}{\varphi_i} \right]^{\varepsilon_c^d} \qquad M_i$$

$$D_i = A_i^d n_i^{d\varsigma_i^e/(\varsigma_i^e - 1)} d_i \qquad d_i$$

$$E_i = A_i^e n_i^{d\varsigma_i^e/(\varsigma_i^e - 1)} e_i \qquad e_i$$

$$M_i = A_i^m n_i^{m\varsigma_i^m/(\varsigma_i^m - 1)} m_i \qquad m_i$$

$$Y_c = B_c [\theta_c D_c^{(\eta_c^d + 1)/\eta_c^d} + (1-\theta_c) E_c^{(\eta_c^d + 1)/\eta_c^d}]^{\eta_c^d/(\eta_c^d + 1)} \qquad E_c$$

$$\frac{E_c}{D_c} = \left[ \frac{\bar{p}_c^e - t_c}{p_c^d} \frac{\varphi_c}{(1-\varphi_c)} \right]^{\eta_c^d} \qquad p_c^d$$

$$E_i = B_i^e \left[ \frac{n_i^{m\,1/\left(1-\varsigma_i^m\right)}}{n_i^{d\,1/\left(1-\varsigma_i^d\right)} \tilde{p}_i^e} \right]^{\varepsilon_c^e} \qquad E_i$$

Expenditure equations

$$C_j = \alpha_j \frac{I}{p_j} \qquad C_j$$

$$X_j = \sum_c a_{jc} Y_c + \sum_i a_{ji} n_i^d y_i \qquad X_j$$

Market clearing conditions

$$Q_j = C_j + X_j + \bar{G}_j \qquad Q_j$$

$$\sum_c (\bar{p}_c^e - t_c) E_c + \sum_i (\tilde{p}_i^e - t_i) n_i^d e_i + \bar{W} = \sum_c (\bar{p}_c^m - t_c) M_c + \sum_i \tilde{p}_i^m n_i^m m_i \qquad I$$

$$\bar{W} + T + \sum_c z_c \bar{p}_c^m M_c = \sum_i z_i (\tilde{p}_i^m - t_i) n_i^m m_i = \sum_j p_j \bar{G}_j \qquad T$$

$$\bar{L} = \sum_c L_c + \sum_i n_i^d (l_i + \bar{l}_i^f) \qquad w$$

$$\bar{K} = \sum_c K_c + \sum_i n_i^d (k_i + \bar{k}_i^f) \qquad r$$

Definition of endogenous variables

$c_i$ Domestic firm's marginal cost
$C_j$ Consumer consumption
$d_i$ Domestic firm's domestic output
$D_j$ Domestic sales
$e_j$ Domestic firm's exports
$E_j$ Exports
$f_i$ fixed costs
$I$ Consumer income
$k_i$ Domestic firm's capital
$K_c$ Capital
$l_i$ Domestic firm's labour
$L_c$ Labour
$m_i$ Foreign firm's exports
$M_j$ Imports
$n_i^d$ Number of domestic firms
$n_i^m$ Number of foreign firms
$p_c^y$ Output price
$p_c^d$ Domestic price
$\tilde{p}_i^d$ Domestic price
$\tilde{p}_i^e$ Domestic export price
$\tilde{p}_i^m$ Import price groos of transport costs
$p_j$ Price of final and intermediate goods
$p_j^f$ Value added price
$Q_j$ Aggregate demand
$r$ Rental rate
$T$ Lump sum transfer
$w$ Wage rate
$X_j$ Intermediate demand
$y_i$ Domestic firm's output
$Y_c$ Output
$\tau_i^d$ Price elasticities of domestic demand perceived by domestic firms
$\tau_i^e$ Price elasticities of export demand perceived by domestic firms
$\tau_i^m$ Price elasticities of import demand perceived by foreign firms

Definition of parameters and exogenous variables
$a_{jj}$ Input output coefficients

$\bar{c}_i^m$ Foreign firm's marginal cost
$\bar{f}_i^m$ Foreign firm's fixed cost
$\bar{G}_g$ Government consumption
$\bar{k}_i^f$ Fixed amount of capital used by the domestic firm
$\bar{K}$ Capital stock
$\bar{l}_i^f$ Fixed amount of labour used by the domestic firm
$\bar{L}$ Total employment
$\bar{p}_c^e$ World price of exports
$\bar{p}_c^m$ World price of imports
$t_j$ Specific transport cost
$\bar{W}$ Foreign transfers (i.e. current account deficit)
$z_j$ Ad valorem tariff rate
$\alpha_j$ Consumer budget shares
$\delta_j$ Share parameter of the production function
$\varepsilon_j^d$ Elasticity of substitution between imports and domestic goods in the home market
$\varepsilon_i^e$ Elasticity of substitution between imports and domestic goods in the foreign market
$\varphi_j$ Share parameter of the Armington function.
$\eta_c^d$ Elasticity of transformation among exports and domestic goods
$\lambda_i^d$ Conjectured reaction of rival domestic firms in the home market
$\lambda_i^e$ Conjectured reaction of rival domestic firms in the foreign market
$\lambda_i^m$ Conjectured reaction of rival foreign firms in the home market
$\theta_c$ Share parameter of the CET function
$\sigma_j$ Elasticity of substitution between labour and capital
$\varsigma_i^d$ Elasticity of substitution among domestic varieties in the home market
$\varsigma_i^e$ Elasticity of substitution among domestic varieties in the foreign market
$\varsigma_i^m$ Elasticity of substitution among imported varieties in the home market
$A_j$ Shift parameter of the Armington function
$A_i^d$ Shift parameter of the domestic firms's domestic supply function
$A_i^e$ Shift parameter of the domestic firm's export supply function
$A_i^m$ Shift parameter of the foreign firm's export supply function
$B_c$ Shift parameter of the CET function
$B_i^e$ Shift parameter of the foreign Armington function
$\Delta_j$ Shift parameter of the production function