Small Group Monopolistic Competition in a GTAP Model: Meeting the Markusen Challenge

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Small group monopolistic competition in a GTAP model: meeting the Markusen challenge

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Abstract:

Since the 1990s, there have been rapid increases in concentration ratios in many industries in the U.S., Australia and, we suspect, in other countries.

Despite this, applications of GTAP (the world's most widely used global economic model) continue to be based on pure competition or Melitz-style Large-Group Monopolistic Competition (LGMC). In either case, all firms are small, there is free entry, and industries make zero pure profits.

Markusen challenges modellers to move to Small-Group Monopolistic Competition (SGMC) in which industries have high levels of concentration and firms are aware of the likely behaviour of their rivals.

We create a version of GTAP in which some industries are modelled as SGMC. We make two generalization of earlier Melitz-LGMC specifications.

First, we treat the perceived elasticity of demand by firms in SGMC industries as a variable. In our SGMC specification, mark-ups over marginal costs, which depend on perceived elasticities, fall when these elasticities are reduced by pro-competition policies.

Second, we allow for sticky adjustment of the number of firms in an industry, and simulate situations in which entry is blocked and incumbent firms make excess profits.

JEL codes: D43; D33; D58; C68

Key Words: Small-group monopolistic competition; GTAP; Melitz and Markusen; Wage rates and pure profits

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1. Introduction

Industries dominated by a few large firms are now a common feature of many economies. Statistica lists 20 industries in the U.S. in which the top 4 firms account for more than 88% of sales. These include industries supplying medical equipment, financial intermediation, air traffic control, aircraft manufacturing, courier services and computer storage devices. Grullon *et al.* (2019) document a rapid increase in the concentration of U.S. industries since the 1990s. They show that industries with the largest increases in product-market concentration show higher profit margins than other industries. They find no evidence that increased concentration has been accompanied by productivity-enhancing scale economies.

Despite these developments, all applications of GTAP models of which we are aware assume that industries are composed of large numbers of small firms. In most cases, it is assumed that the industries are perfectly competitive. In some cases, Melitz-style large-group monopolistic competition (LGMC) is assumed, see for example Akgul *et al.* (2016), Balistreri & Rutherford (2013) , Bekkers & Francois (2018) and Dixon *et al.* (2019a & b). LGMC allows for economies of scale, but with either perfect competition or LGMC, there are zero pure profits and free entry. In setting their prices and quantities, firms take no account of likely reactions by their rivals.

In his recent JGEA article, Markusen (2023) attacks the LGMC setup. He says:

> *"It is bafflingly inconsistent to assume that firms produce with increasing returns to scale, yet have no mass. This has remained true in almost all papers modeling heterogeneous firms, where the most productive firms are very large relative to their industry average."*

Markusen advocates for the adoption of small group monopolistic competition (SGMC) in which industries have high levels of concentration and firms make decisions taking account of the likely reactions of their rivals. Markusen uses a theoretical model with stylized numbers to illustrate the potential importance for trade and welfare results in CGE models of switching from LGMC to SGMC. Nevertheless, Markusen continues to assume free entry.

In this paper, we describe a version of GTAP in which some industries are modeled as SGMC. Unlike Markusen, we will allow for barriers to entry and pure profits. We think these are potentially important explanators of inflation in some countries, and reductions in many countries in the labor-share of GDP. We also suspect that recognition in a CGE model of SGMC will lead to larger and more realistic estimates of the benefits of freer trade and relaxed restrictions on FDI.

In the SGMC specification that we embed in a version of GTAP, we make two generalization of earlier Melitz-LGMC specifications.

First, we treat the perceived elasticity of demand by firms in SGMC industries as a variable. In Melitz, the perceived elasticities are parameters. In our SGMC specification, mark-ups over marginal costs, which depend on perceived elasticities, fall when these elasticities are reduced by pro-competition policies. This mechanism is not part of the Melitz model.

Second, we allow for sticky adjustment of the number of firms in an industry. In Melitz, with free entry, the number of firms in an industry adjusts continuously and fully to ensure zero pure profits. In our SGMC specification, we simulate situations in which entry is blocked and incumbent firms can make excess profits.

With these generalizations, we refer to the resulting model as GTAP-MM (or GTAP-Melitz-Markusen).

The paper is set out as follows. In the rest of this section, we provide a brief refresher on the Melitz model and mention contrasts with the MM model. Section 2 describes the equations for a Melitz-Markusen industry. Section 3 contains illustrative simulations under Armington, and MM assumptions. Concluding remarks are in Section 4. We provide a long appendix that details all of the mathematics underlying our MM specification and its representation in the GTAP model.

1.1. Refresher on Melitz and contrasts with MM

Melitz (2003) sets out a model of an industry, which we will refer to as the Widget industry. This industry has four key features.

(a) Firms and varieties

A Melitz industry contains many firms and each firm produces a single Widget variety. For Widget users, these varieties are imperfect substitutes.

In the MM model, we envisage an industry with only a few firms. Nevertheless, in common with Melitz we assume that there are many varieties: each firm can produce multiple varieties.

(b) Setting up new firms

In Melitz, entrepreneurs look at current profits in the Widget industry in deciding whether to produce a new variety, which is the same as setting up a new firm. To set up a new firm, a Melitz entrepreneur must incur a fixed setup cost before knowing whether the new firm will be profitable. Melitz encapsulates this prior uncertainty by assuming that an intending Widget entrepreneur pays for a draw from a distribution of productivity levels. Equivalently, he could have assumed that the producer draws a demand-side variable or attractiveness variable from a probability distribution. Whether it is a supply-side variable or a demand-side variable doesn't matter. The point is that a favourable draw means that the new variety (firm) will be profitable. An unfavourable draw means that the new variety may never reach production stage.

In the MM model, we retain the idea that current profits determine entry to the Widget industry, that is creation of new firms. Although appealing, we don't think the Melitz idea of prior uncertainty in setting up a firm is necessary in the MM model. We assume that an intending Widget entrepreneur incurs a fixed cost to buy the ability to produce an array of Widget varieties with a known distribution of productivity levels.

(c) Link-specific fixed costs

Widget firms in Melitz incur a fixed cost to set up sales of each variety to their domestic market and to each foreign market. We refer to these as link-specific fixed costs. For any given variety, incurring these fixed costs may be worthwhile for only a selection of potential markets. For low-productivity varieties, there may be no market for which it is profitable to incur the link-specific setup cost. In this case, the variety will not be produced.

In MM we retain this story. However, the determination of what varieties to send on each link is more complicated in MM than in Melitz. In MM, firms must take account of the effect of the sales of each of their varieties on the sales of their other varieties, and also the effects on the sales of varieties produced by other firms. These inter-variety effects are absent in Melitz: each firm in Melitz produces just one variety and each firm is too small to have worry about the effects of its decisions on other firms.

(d) Reducing the model to relationships between variables for typical varieties

Although the Widget industry contains a large number of varieties, Melitz is able to reduce his model to a system of equations that connect variables only for typical varieties. Melitz does this by adopting the Pareto form for the distribution from which Widget entrepreneurs make their productivity draws. It is the reduction of the variety dimension to just typical varieties that makes Melitz theory practical for CGE modelling. It also means that the Melitz model can be well understood at an intuitive level by working through a manageably small number of equations such as those in Table 1.

We use the Pareto distribution to describe the distribution of productivity levels across the varieties producible by a firm in country s. Then, as set out in the appendix, we apply Melitz' method to reduce the MM model to typical varieties.

2. A Melitz-Markusen model: theory

Table 1 lists equations describing a generic industry, the Widget industry under MM assumptions. To a large extent, Table 1 is Melitz plus additional equations to allow the transition from LGMC to SGMC. This section explains Table 1.

Preliminary comment

In interpreting the table, the simplest picture to have in mind is that the Widget industry in country s consists of a small number of identical firms, each of which produces its own distinctive varieties. With this interpretation, the minimum productivity for a variety to justify sales from s to d is the same for all firms in s.

The price of Widgets sent from s to d, equations (T1.1a) and (T1.1b)

Equation (T1.1a) specifies the price in region d of the typical variety of Widget sent from s as marginal cost *times* a markup factor (M_d, same for all s). In common with Melitz, the marginal cost of supplying the typical variety on the sd-link is specified in the MM model as:

> *the cost* of the input bundle (W_s) used in Widget production in region s;
> *deflated* by marginal productivity ($\Phi_{\bullet sd}$, which is the increase in the number of units of the typical sd variety that are produced in s from an extra input bundle);
> *grossed up* by the tariff and transport factor (T_{sd}) applying to all Widget flows from s to d.

Table 1. The Widget industry in the Melitz-Markusen model

(T1.1a)	$P_{\bullet sd} = \left(\frac{W_s T_{sd}}{\Phi_{\bullet sd}}\right) * M_d$
(T1.1b)	$\Phi_{\bullet sd} = \beta * \Phi_{\min(s,d)}$
(T1.2a)	$P_d = \left(\sum_s N_{sd}\delta_{sd}^{\sigma} P_{\bullet sd}^{1-\sigma}\right)^{\frac{1}{(1-\sigma)}}$
(T1.2b)	$N_{sd} = N_s * B_s * \left(\Phi_{\min(s,d)}\right)^{-\alpha}$
(T1.3a)	$Q_{\bullet sd} = Q_d \delta_{sd}^{\sigma}\left(\frac{P_d}{P_{\bullet sd}}\right)^{\sigma}$
(T1.3b)	$V_{sd} = P_{\bullet sd} N_{sd} Q_{\bullet sd}$
(T1.3c)	$Q_{sd} = N_{sd} Q_{\bullet sd}$
(T1.4a)	$\left(M_d - 1\right)\left(\frac{Q_{\min(s,d)}}{\Phi_{\min(s,d)}}\right) - F_{sd} * Z_{sd} = 0$
(T1.4b)	$Q_{\min(s,d)} = Q_{\bullet sd} / \beta^{\sigma}$
(T1.5)	$\Pi tot_s = \sum_d N_{sd}\left[\frac{W_s}{\Phi_{\bullet sd}} * Q_{\bullet sd} * \left(M_d - 1\right) - W_s * F_{sd}\right] - N_s H_s W_s$
(T1.6)	$L_s = \sum_d \frac{N_{sd} Q_{\bullet sd}}{\Phi_{\bullet sd}} + \sum_d N_{sd} F_{sd} + N_s H_s$

Add-ons for small group monopolistic competition

(T1.7a)	$M_d = \frac{\Gamma_d}{\Gamma_d - 1}$
(T1.7b)	$\Gamma_d = \frac{1}{\frac{1}{Ntot_d} + \left(1 - \frac{1}{Ntot_d}\right) * \frac{1}{\sigma}}$
(T1.7c)	$Ntot_d = \bar{N}tot_d * \sum_s \bar{S}_{sd} * N_s / \sum_s \bar{S}_{sd} * \bar{N}_s$
(T1.7d)	$S_{sd} = \frac{V_{sd}}{P_d Q_d}$
(T1.7e)	$Z_{sd} = 1 \Big/ \left(1 - S_{sd} * \left(\frac{\sigma - \Gamma_d}{\sigma - 1}\right)\right)$
(T1.7f)	$N_s = \bar{N}_s * \exp\left(\Psi_{1s}\left(\frac{\Pi tot_s}{W_s L_s} - \Psi_{0s}\right)\right)$

Notation follows

Notation for Table 1

$\mathbf{P_{\bullet sd}}$ is the price paid by Widget users in d for Widgets set from s.

$\mathbf{W_s}$ is the cost of an input bundle used in Widget production in s. To simplify the exposition, we assume that labor is the only input so that W_s is the wage rate. In our implementation of MM in GTAP, we allow for other primary factors and intermediate inputs.

$\mathbf{\Phi_{\bullet sd}}$ is the marginal productivity of an input bundle in the production of a typical Widget variety sent on the sd link.

$\mathbf{T_{sd}}$ is the power (1 plus rate) of the tariff and transport costs applying to flows of Widgets from s and d.

$\mathbf{M_d}$ is the markup factor (price/marginal cost) which all Widget producers apply in pricing to customers in country d.

$\boldsymbol{\beta}$ in a parameter with value greater than 1, see equation (A2.10) in section A2 of the appendix.

$\mathbf{\Phi_{min(s,d)}}$ is the minimum marginal productivity of an import bundle over all varieties sent on the sd link.

$\mathbf{P_d}$ is the cost to Widget users and of satisfying a unit demand for Widgets.

$\boldsymbol{\sigma}$ is the elasticity of substitution by Widget users between Widget varieties . This is assumed to be greater than 1 (e.g. 5) and is the same for Widget users in all countries.

$\boldsymbol{\delta_{sd}}$ is a preference parameter in the CES function that specifies the creation of composite Widgets for use in d.

$\mathbf{N_{sd}}$ is the number of Widget varieties supplied by s for use in d.

$\mathbf{N_s}$ is the numbers of Widget firms located in s.

$\mathbf{B_s}$ in a parameter and can be interpreted as the number of potentially producible varieties per Widget firm in s.

$\boldsymbol{\alpha}$ is a parameter in the Pareto to distribution used to describe the distribution of productivities over Widget varieties in region s, see section A2 in the appendix.

$\mathbf{Q_{\bullet sd}}$ is the quantity used in d of the typical Widget variety sent on the sd link.

$\mathbf{Q_d}$ is quantity of composite Widgets used in d.

$\mathbf{V_{sd}}$ is expenditure in d on Widgets sent from s ro d.

$\mathbf{Q_{sd}}$ is a measure of the total quantity of Widgets sent from stod.

$\mathbf{P_{min(s,d)}}$ is the price to users in d of the lowest-productivity variety of Widgets on the sd link.

$\mathbf{Q_{min(s,d)}}$ is the quantity of the lowest-productivity variety of Widgets sent on the sd link.

$\mathbf{F_{sd}}$ is the number of input bundles required up-front to make it possible to sell Widgets from s to d.

$\mathbf{Z_{sd}}$ is a variable whose value is greater than 1 and which acts as a markup on the sd set-up requirement (F_{sd}) in the determination of the minimum productivity level required for a variety to be viable on the sd link, see section A3 of the appendix.

$\mathbf{\Pi tot_s}$ is excess profits in the Widget industry in country s. These are earnings beyond what is required to cover costs, including normal rates-of-return on capital.

$\mathbf{H_s}$ is the number of inputs bundles required to set up a Widget firm in country s.

$\mathbf{L_s}$ is the number of input bundles used by Widget firms in s. This covers production, set up on links and the initial set up of firms.

$\mathbf{\Gamma_d}$, which we assume is greater than 1, is the elasticity of demand for their products perceived by all suppliers of Widgets to country d.

$\mathbf{Ntot_d}$ is literally the number of domestic and foreign Widget producers competing for sales in d. In implementing our MM model, we may ignore small firms and set the initial value of $Ntot_d$ by counting firms in descending order of sales in d until we have reached 75% of total sales in d.

$\mathbf{S_{sd}}$ is the share of firms from s in total Widget sales in d.

$\mathbf{\overline{Ntot}_d}$, $\mathbf{\overline{S}_{sd}}$ and $\mathbf{\overline{N}_s}$ are initial values of $Ntot_d$, S_{sd} and N_s.

$\boldsymbol{\Psi_{1s}}$ and $\boldsymbol{\Psi_{0s}}$ are exogenous variables that control the sensitivity of movements in the number of Widget firms in s to profits in s.

Different from Melitz, M_d in the MM model is a destination specific endogenous variable. In Melitz it is a parameter with the same value for all destinations. As described below, in the MM model, M_d is determined by the elasticity of demand for their products perceived by all Widget suppliers to region d. The perceived elasticity for region d (and hence M_d) depends on the amount of competition in d's market. This is determined endogenously in an MM industry by the number of firms.

Equation (T1.1b) specifies the marginal productivity ($\Phi_{\bullet sd}$) of the typical sd variety in terms of the minimum marginal productivity $\Phi_{min(s,d)}$ over all varieties sent on the sd-link. In (T1.1b), β is a parameter with value greater than 1. The determination of $\Phi_{min(s,d)}$ is explained later in Table 1. The maths underlying (T1.1b) and the evaluation of β are set out in the appendix.

The cost of satisfying a unit of demand and love of variety: equations (T1.2a) and (T1.2b)

These equations are straight from Melitz.

Equation (T1.2a) specifies the cost (P_d) in region d of satisfying a unit demand for Widgets. This is a CES combination of the prices ($P_{\bullet sd}$) of the supplies of typical varieties to d. The parameters of the CES function are the elasticity of substitution between Widget varieties (σ, assumed to be greater than 1 and the same in all markets) and the preference parameters (δ_{sd}).

Love of variety is introduced in (T1.2a) through the variable N_{sd}, which is the number of varieties sent from s to d. If N_{sd} increases, then at given prices, P_d falls: an increase in varieties allows Widget users in d to choose varieties that more closely match their requirements thereby reducing the cost of meeting any given level of demand.

Equation (T1.2b) determines N_{sd}. In this equation, B_s is a parameter, a factor of proportionality.[1] N_s is the number of Widget firms in country s and $\Phi_{min(s,d)}$ is, as defined earlier, is the minimum productivity (maximum cost) over all varieties sent on the sd-link. α is the parameter in the Pareto distribution used to describe the distribution of productivities over the varieties in region s. If a higher level of productivity is required to justify the set-up costs of sending a variety from s to d [an increase in $\Phi_{min(sd)}$], then via (T1.2b) there is a decline in the number of varieties per firm sent from s to d (a decline in N_{sd}/N_s).

This still leaves $\Phi_{min(s,d)}$ and N_s to be explained by later equations.

Demands: equations (T1.3a) to (T1.3c)

Again, these equations are the same as those in Melitz.

Equation (T1.3a) is region d's demand function for typical-variety Widgets from s. Consistent with a CES optimizing problem (set out in the appendix), region d's source-specific demands ($Q_{\bullet sd}$) depend on d's overall requirement for Widgets (Q_d, determined predominantly by income and other CGE variables outside the Widget

[1] B_s turns out to be the number of potentially producible varieties per firm in country s. It appears in MM, but not in Melitz, because we don't use the Melitz assumption of one variety per firm.

industry) and the price of a typical Widget variety from s ($P_{\bullet sd}$) relative to Widget costs averaged over all sources [P_d, see (T1.2a)].

Equation (T1.3b) calculates the value in d of Widgets sent from s to d (V_{sd}) as the quantity for the typical variety *times* the number of varieties times the price. Equation (T1.3c) calculates the quantity of the s-to-d flow (Q_{sd}) by dividing the value by the price of a typical variety ($P_{\bullet sd}$).

A confusing aspect of the demand equations is the role of love of variety and the concept of effective quantities. We think it is easiest to interpret $Q_{\bullet sd}$ and Q_{sd} (=N_{sd}* $Q_{\bullet sd}$) as normal quantities such as number of Widgets or tonnes of Widgets. However, Q_d cannot be interpreted in this way. It is a CES combination of Widgets sent to d from all sources, and is not simply the sum over s of Q_{sd}. As discussed in the appendix,

$$Q_d = \left(\sum_s \delta_{sd} N_{sd} Q_{\bullet sd}^{(\sigma-1)/\sigma} \right)^{\sigma/(\sigma-1)} \tag{2.1}$$

This means that the effective quantity of Widgets supplied to d increases if $Q_{\bullet sd}$ halves and N_{sd} doubles even though there is no change in the s-to-d quantity (Q_{sd}). This is the "quantity-side" of love of variety corresponding to the reduction in P_d associated with increased variety discussed in the previous sub-section.

Unlike quantities, there is no interpretive difficulty with values. (T1.2a) together with (T1.3a) – (T1.3c) imply that the value of Widget expenditure in d equals the value of supplies to d:

$$P_d Q_d = \sum_s P_{\bullet sd} N_{sd} Q_{\bullet sd} = \sum_s P_{\bullet sd} Q_{sd} = \sum_s V_{sd} \tag{2.2}$$

Minimum productivity to justify sending a variety on the s-to-d link: equations (T1.4a) and (T1.4b)

These equations tie down one of the loose ends from the discussion of (T1.2a) and (T1.2b), namely the determination of the marginal productivity ($\Phi_{min(sd)}$) for the lowest productivity variety on the sd-link.

For understanding (T1.4a) we start by assuming temporarily that the variable Z_{sd} is fixed on 1 and can be ignored. Then (T1.4a) can be derived by assuming, as Melitz does, that the contribution to the profits of Widget producers in s from the lowest productivity (highest cost) variety sent on the sd-link is zero. As shown in the appendix, under our MM assumption that the mark-up factor (M_d) is the same for all varieties sent to d, varieties with lower productivity are not sent because they would not earn sufficient revenue to cover their costs of production, transport and tariffs, and the fixed costs of establishing the variety on the link. With zero profits assumed for the lowest productivity variety, we obtain:

$$0 = \frac{P_{min(sd)}}{T_{sd}} * Q_{min(sd)} - \frac{W_s}{\Phi_{min(sd)}} * Q_{min(sd)} - W_s * F_{sd} \tag{2.3}$$

where

$\Phi_{min(s,d)}$ is the lowest productivity over all varieties sent on the sd-link;
$P_{min(sd)}$ and $Q_{min(sd)}$ are the price and sales volume on the sd-link of the minimum productivity variety sent on the link; and
F_{sd} is the number of input bundles required to setup sales of a variety on the sd-link.

With the M_d factor for the typical variety also applying to the minimum productivity variety,

$$P_{min(sd)} = \frac{W_s T_{sd}}{\Phi_{min(sd)}} * M_d \tag{2.4}$$

Substituting from (2.4) into (2.3) gives (T1.4a) with Z_{sd} equal to 1. This is a Melitz equation.

Z_{sd} comes to life when we move to SGMC. We assume that suppliers on the sd-link understand that supplying extra varieties affects the sales of all varieties sold into d. This leads to the conclusion that the range of varieties supplied on the sd-link will not be pushed to the point where the lowest productivity variety on the sd-link makes zero contributions to the profits of Widget producers in s. In our modelling of SGMC, Z_{sd} is a variable whose value is greater than or equal to 1 and which responds to changes in the perceptions of Widget producers in s regarding the level of competition that they face in market d. Our specification of Z_{sd} is given in (T1.7e) and discussed later in this section. Mathematical details are in the appendix.

The value of Z_{sd} affects the values of $Q_{min(sd)}$ and $Q_{\bullet sd}$. However, irrespective of Z_{sd}, $Q_{min(sd)}$ and $Q_{\bullet sd}$ are related by the parameter β^{σ} in equation (T1.4b). This parameter is more than 1, implying that sales of minimum-productivity varieties are less than those of typical varieties. The derivation of (T1.4b) is in the appendix.

Total profits in the Widget industry of country s: equation (T1.5)

The contribution ($\Pi_{\bullet sd}$) to profits in s's Widget industry from selling a typical variety on the sd-link is:

$$\Pi_{\bullet sd} = \frac{P_{\bullet sd}}{T_{sd}} * Q_{\bullet sd} - \frac{W_s}{\Phi_{\bullet sd}} * Q_{\bullet sd} - F_{sd} * W_s \tag{2.5}$$

This is revenue net of transport costs and tariffs *less* production costs *less* the fixed costs of setting up sales of a variety on the sd-link. These fixed costs are calculated as the number of input bundles (F_{sd}) required to commence sales of a variety on the sd-link *times* the cost of a bundle (W_s). Using (T1.1a), we can write (2.5) as

$$\Pi_{\bullet sd} = \frac{W_s}{\Phi_{\bullet sd}} * Q_{\bullet sd} * \left(M_d - 1\right) - F_{sd} * W_s \tag{2.6}$$

(T1.5) calculates total profits (Πtot_s) for the Widget industry in s as the sum over all destinations d of the profit contribution of a typical variety on the sd-link [$\Pi_{\bullet sd}$ given by (2.6)] *times* the number of varieties on the sd-link (N_{sd}) *less* the fixed cost over all firms of setting up to start production. The start-up cost for a firm is the number of input bundles required per firm (H_s) *times* the cost of a bundle. This gives the total production start-up cost for the Widget industry in s as $N_sH_sW_s$ where N_s is the number of firms.

Total input to the Widget industry in country s: equation (T1.6)

Total input to the Widget industry in s (L_s) has three parts. The first is input to production. This is the sum over all links d of the input required for production of the typical variety on the sd-link ($Q_{\bullet sd}/\Phi_{\bullet sd}$) *times* the number of varieties on the sd-link (N_{sd}). The second part is the input required to set up sales on the links. This is the sum over all links d of the link setup cost per variety on the sd-link (F_{sd}) *times* the number of varieties on the sd-link. The third part is the input required for setting up firms. This is the input requirement for start-up per firm (H_s) *times* the number of firms in s (N_s).

Add-ons for SGMC: equations (T1.7a) to (T1.7f)

Equation (T1.7a) is an application of Lerner's rule. In stripped-down notation, omitting subscripts, it can be derived from the following profit-maximizing problem:

choose P

to maximize P*Q – MC*Q

subject to $Q = P^{-\Gamma}$ (2.7)

where

P and Q are the price and quantity set by a supplier to market d;
MC, assumed constant, is the marginal cost of supplying market d; and
Γ, assumed greater than 1, is the elasticity of demand perceived by all suppliers of Widgets to market d.

Optimization problem (2.7) implies that P/MC, that is the markup factor is $\Gamma/(\Gamma-1)$.

Equation (T1.7b) is adapted from Markusen (2023). It relates the perceived elasticity of demand (Γ_d) in market d to the users' substitution elasticity (σ) between Widget varieties and to the number of firms ($Ntot_d$) supplying market d. If the number of firms is large, then Γ_d in (T1.7b) is close to σ, and M_d is close to $\sigma/(\sigma-1)$, which is the mark-up value used by Melitz in his LGMC model. When we move to SGMC and assume that there are a small number of competing firms, each of which anticipates reactions by its competitors, then Γ_d can be considerably less than σ and M_d can be considerably greater than $\sigma/(\sigma-1)$. Assume for example, that $\sigma = 5$ and $Ntot_d = 4$. Then the LGMC values of Γ_d and M_d are 5 and 1.25 whereas the SGMC values are 2.5 and 1.67. As explained in the appendix, Markusen derives (T1.7b) under the Cournot conjecture: each firm anticipates that a change in the prices of its own varieties in market d will generate responses from its competitors aimed at maintaining the quantities of their sales.

In equation (T1.7c), we set the initial number of firms that compete in d's Widget market as $\overline{N}tot_d$. This is the number of firms located in d that sell Widgets in d and foreign firms that export to d. In simulations, the model moves $Ntot_d$ away from its initial value in response to changes in the number of producing firms in all countries, N_s for all s. If N_s doubles for all s, then in (T1.7c) $Ntot_d$ doubles. However, in determining the amount of competition in d, indicated by $Ntot_d$, we give different weights to movements in the number of firms in different countries. The weight given to movements in N_s in determining movements in $Ntot_d$ is the initial share [$\bar{S}_{sd}$] of firms from s in the value of Widgets supplied to d. S_{sd} is defined in (T1.7d).

Equation (T1.7e) determines Z_{sd}. The role of this variable was explained in the discussion of (T1.4a). In the appendix, we derive (T1.7e) by assuming that in choosing the lowest productivity (lowest profitability) variety for the sd-link, producers in country s maximize total profits generated on the link, taking account of the effect of their choice on sales of all varieties. In this optimization problem, the elasticity of demand perceived by suppliers to d's market (Γ_d) reappears. This is because suppliers perceive that changes in the array of varieties in d's market affect the cost in d of satisfying a unit of demand (P_d).

Looking more closely at (T1.7e), we see that Z_{sd} is always greater than 1 provided that $1<\Gamma_d < \sigma$. Z_{sd} equals 1 if $\Gamma_d = \sigma$, which is the implicit LGMC assumption in Melitz. Z_{sd} will be close to 1 if country s is a minor supplier to d (S_{sd} is close to zero).

Equation (T1.7f) relates the number of Widget-producing firms in country s (N_s) to industry profits per unit of resource input cost ($\Pi tot_s / W_s L_s$). To ensure that (T1.7f) is consistent with the initial situation in which $N_s = \bar{N}_s$, the initial value of ψ_{0s} is the initial value of the profit ratio (that is $\Psi_{0s} = \bar{\Pi}tot_s / \bar{W}_s \bar{L}_s$). If profits are initially zero, so that Ψ_{0s} is zero, and Ψ_{1s} is given a very large value, then (T1.7f) will closely mimic Melitz and Markusen's assumption of free entry and zero profits. With a large value for Ψ_{1s}, $\Pi tot_s / W_s L_s$ cannot move far from its initial value, implying that adjustments in N_s almost entirely eliminate disturbances to the profit ratio. At the other extreme, we could set Ψ_{1s} at zero. This would be appropriate for investigating the implications of blocked entry to s's Widget industry: with $\Psi_{1s} = 0$, N_s is unresponsive to profitability. Cases between free and blocked entry can be simulated with intermediate values for Ψ_{1s}.

In implementing the MM model, we treat Ψ_{0s} and Ψ_{1s} as exogenous variables rather than parameters. This extends the range of the model's applications. For example, we can apply a negative shock to Ψ_{0s}, possibly combined with a positive shock to Ψ_{1s}, to simulate a pro-competition policy for s's Widget industry.

Overview of the SGMC equations and a numerical example

While we refer to $Ntot_d$ as the number of firms competing in d and N_s as the number of firms set up in s, these definitions cannot be interpreted literally. We have to accept the idea of fractional firms and interpret $Ntot_d$ as an indicator of competition in supplying d's Widget requirements and N_s as one of the determinants of $Ntot_d$. For clarifying what this means and for understanding more generally how the SGMC add-on equations interact with each other and the rest of the CGE equation system, it is useful to work through a numerical example.

Our example is concerned with the effects in country d of competition policy applied to the Widget industry in country s, where s and d could be different countries or the same country. We assume in the initial equilibrium that:

- the number of firms competing in d is 4, that is $\bar{N}tot_d = 4$. This setting might be backed out from (T1.7a) and T(1.7b) after imposing data or judgements suggesting that $M_d = 1.667$ and $\sigma = 5$ implying that $\Gamma_d = 2.5$ and $Ntot_d = 4$.
- the number of firms producing in s is 10, that is $\bar{N}_s = 10$. This might be informed by data on concentration ratios showing that the top 10 firms in country s account for almost all of s's Widget production.
- country s accounts for 40 per cent of Widget sales in d ($\bar{S}_{sd} = 0.40$).
- the level of profitability per unit of resource cost in s's Widget industry ($\bar{\Pi}tot_s / \bar{W}_s\bar{L}$) is 0.10 (requiring that the initial value of Ψ_{0s} is 0.10), and the initial value of Ψ_{1s} is zero. The picture we have in mind for s's Widget industry is a highly profitable cartel in which entry is effectively blocked.

How will the equilibrium be affected by a pro-competitive policy that causes new firms to chase the excess profits in s's Widget industry? Imagine that to answer this question, we set up a simulation in which Ψ_{0s} is shocked from 0.1 to zero and Ψ_{1s} is shocked from zero to 2.2314. [2] The shock to Ψ_{0s} introduces an incentive for new firms to enter Widget production in s, and the shock to Ψ_{1s} makes entry possible.

The first round effects of the shocks to Ψ_{0s} and Ψ_{1s} can be traced out as follows.

- In (T1.7f), N_s increases by 25%. This is a first-round affect calculated with the profit rate in s's Widget industry left at its initial value of 0.1.
- In (T1.7c), the 25% increase in N_s causes a first-round increase in $Ntot_d$ of 10 per cent (= 25 per cent of 40 per cent), that is form 4 to 4.4.
- In (T1.7b), the 10 per cent increase in $Ntot_d$ causes the demand elasticity perceived by suppliers to d's market, Γ_d, to increase from 2.5 to 2.619.
- In (T1.7a), the increase in the perceived elasticity causes the mark-up factor M_d to fall from 1.667 to 1.618.
- In (T1.7e), increased competition in d's market (the increase in Γ_d), moves Z_{sd} from its initial value of 1.333 to 1.3125, taking it closer to the LGMC value of 1.
- In (T1.4a), the ratio $[Q_{min(sd)}/\Phi_{min(sd)}]$ of the sd sales volume to productivity for the minimum productivity variety on the link is proportional to $Z_{sd}/(M_d\text{-}1)$. When M_d falls, $Q_{min(sd)}/\Phi_{min(sd)}$ rises. This, perhaps surprisingly, requires an increase in $\Phi_{min(sd)}$[3] and a consequent reduction in varieties on the sd link. On

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[2] This is ln(1.25)/0.1. Why this number? Simply because it leads to a round number (25%) for the first-round effect on N_s.

[3] Using (T1.4b), (T1.3a), (T1.1a) and (T1.1b), we obtain $\frac{Q_{min(s,d)}}{\Phi_{min(s,d)}} = \left[\frac{Q_d \delta_{sd}^{\sigma} P_d^{\sigma}}{(W_s T_{sd})^{\sigma}}\right] * \Phi_{min(s,d)}^{\sigma-1}$. The value of σ is greater than 1 and we can assume that the terms in the square bracket are no more than mildly sensitive to variations in $\Phi_{min(s,d)}$. Hence we can assume that an increase in $Q_{min(s,d)} / \Phi_{min(s,d)}$ requires an increase in $\Phi_{min(s,d)}$.

the other hand, a reduction in Z_{sd} reduces $Q_{min(sd)}/\Phi_{min(sd)}$ and increases the number of varieties on the sd link: the perception of more competition in d's market (a higher Γ_d giving a lower Z_{sd}) leads s's producers to anticipate less damage to the sales of varieties already established in d from the introduction of additional varieties. In our numerical example, the M_d effect dominates. In combination, the movements in M_d and Z_{sd} generate an increase in $Q_{min(sd)}/\Phi_{min(sd)}$ of 6.2 per cent (from 1.333/0.667 to 1.3135/0.618). This implies a first-round reduction in the number of varieties on the sd-link: all varieties on the link whose ratio of sales volume to productivity was less than 6.2 per cent above minimum are now eliminated.

All of these first-round effects have implications for demands and supplies throughout the general equilibrium system. In the next section, we look at simulation results from a version of GTAP that includes MM industries. Our aim is to move beyond first round effects and to trace out general equilibrium repercussions.

3. Illustrative simulations under Armington and Melitz-Markusen assumptions

In this section, we describe three GTAP simulations showing the effects of:

(1) an increase of 10 per cent in the power of the tariffs applying to imports of all commodities to all countries under Armington assumptions;

(2) an increase of 10 per cent in the power of the tariffs applying to imports of all commodities to all countries under Melitz-Markusen (MM) assumption for 13 selected commodities and under Armington assumptions for the remaining 44 commodities;

(3) a movement in the equilibrium pure profit rate for selected industries from 1 per cent to 10 per cent in all countries/regions for the 13 selected industries.

We chose the first two simulations to illustrate the effects of shrinkage in world trade as countries attempt to improve their supply chain security and to provide a comparison between Armington and MM assumptions. . Results for these simulations are in Table 3.1, marked A for Armington and MM for Melitz-Markusen. We also attempted to compute a solution under Melitz assumptions. But we failed to find a legitimate solution because under Melitz assumptions there is too much instability in the commodity composition of exports in some regions.[4]

We chose the third simulation to illustrate the possible deadening effects on wage growth of reduced competition and the emergence of pure profits. This is only possible under MM assumptions: under Armington and Melitz there are no pure profits. The results for this simulation are in Table 3.2.

The 13 selected MM industries in simulations (2) and (3) are: Oil extraction (oil); Gas extraction (gas); Other mining (omn); Wearing apparel (wap); Motor vehicles (mvh); Other transport equipment (otn); Electronic equipment (ele); Other machinery (ome); Construction (cns); Communications (cmn); Other financial intermediation (ofi);

[4] The introduction of Markusen features helps to give a positive slope to output supply curves in MM industries. This aids stability.

Insurance (isr); and Other business services (obs). These 13 industries account for 36 per cent of world GDP.

We should emphasise that the simulations are purely illustrative. They are conducted with an old database (version 7, from 2008) and with only 10 regions. We also use a simple but crude closure, the main features of which are as follows:

- Real investment, real public consumption and the balance of trade[5] in each region are exogenous, unaffected by the shocks. Real GDP and private consumption are endogenous, with private consumption being determined as a residual in the identity

  $$GDP = C + I + G + X - M.$$

  With this set up, C can be used as a measure of welfare.

- The employment of each of the 5 primary factors in the GTAP database (land, unskilled labor, skilled labor, capital and natural resources) is exogenous, unaffected by the shocks.

- The government in each region achieves revenue neutrality by varying in a uniform manner the power of the income taxes applying to all primary factors and production taxes applying to all industries. Revenue neutrality is important in tariff simulations. The damage of tariff increases to real factor incomes would be overestimated if we failed to have an offsetting tax reduction.

The purpose of the simulations to facilitate our understanding of the underlying models and to iron out glitches. In future research, we hope to implement versions of imperfect competition in policy-relevant, dynamic models.

3.1. The effects of worldwide tariff increases (Table 3.1)

3.1a. Armington results

Armington: Real GDP

In an Armington model, we can usually explain the effects of tariff changes on GDP using a dead-weight-loss (DWL) diagram, see Figure 3.1. On this basis, we made a back-of-the-envelope (BoTE) calculation of the percentage effects on GDP of the 10 percent worldwide tariff changes in the Armington simulation according to the formula:

$$BoTE\_gdp(r) = \left[TR_{initial}(r) + 0.5 * 0.10\right] * \frac{Imports(r)}{GDP(r)} * m(r) \text{ for all r} \qquad (3.1)$$

Calculations using this formula are shown in the supplementary section of Table 3.1 together with simulation results for percentage changes in import quantities [m(r)], data for import shares in GDP [Imports(r)/GDP(r)], and data for initial tariff rates averaged over commodities [$TR_{initial}(r)$]. Regressing the Armington GDP simulation results for percentage changes in real GDP against BoTE_gdp generates

[5] In the Armington tariff simulation, the exogenous variable was literally the balance of trade. In the MM simulations we exogenized the ratio of the balance of trade to GDP. This change was necessary because in MM there are significant changes in the world price level. This caused changes in real trade balances when the balance of trade was exogenous. Changes in real trade balances had unintended consequences for real consumption in each regions.

Table 3.1 Percentage effects of 10 per cent tariffs imposed on all trade by all countries/regions

	Oceania	East Asia	SE Asia	South Asia	N America	Latin America	EU_25	MENA	SSA	Rest of World
Real private consumption (welfare)										
A	-1.07	-0.82	-3.56	-0.84	0.23	-1.33	-0.15	-4.24	-2.09	-2.37
MM	-0.28	-0.99	-5.65	-0.69	0.24	-0.78	-0.05	-4.12	-1.09	-1.85
Real post-tax wage rate										
A	0.21	-0.51	-1.98	-0.37	0.45	-0.22	0.15	-0.37	0.15	-0.71
MM	0.41	-0.66	-2.65	-0.60	0.40	-0.12	0.11	-0.43	0.51	-0.66
Terms of trade										
A	-1.40	-0.43	-2.11	0.32	3.32	-1.83	1.60	-3.54	-1.68	-2.13
M										
MM	0.03	0.82	-1.78	-0.82	0.06	0.35	1.73	-2.61	-0.18	-0.78
Real GDP										
A	-0.35	-0.34	-1.20	-0.56	-0.11	-0.46	-0.21	-0.68	-0.73	-0.73
MM	-0.19	-0.42	-2.40	-0.39	-0.06	-0.34	-0.17	-0.81	-0.47	-0.65
Pure profits as a per cent of GDP										
A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MM	0.29	0.04	-0.72	0.14	0.03	0.24	0.07	0.03	0.31	0.19
Supplementary information: deadweight loss explanation of Armington GDP results										
Imports/GDP, data	0.19	0.14	0.55	0.21	0.11	0.17	0.13	0.37	0.30	0.19
Initial tariff rates, data	0.036	0.039	0.046	0.127	0.023	0.071	0.020	0.067	0.091	0.050
Import vol, % change, A sim	-16.34	-22.51	-21.60	-13.99	-14.93	-21.87	-19.32	-14.91	-16.35	-19.87
100*DWL/GDP	0.27	0.28	1.14	0.53	0.12	0.44	0.18	0.64	0.69	0.56

Sim A13 and R13 run with GTAPMM59.tab

$$A\_rgdp(r) = -1.04 * BoTE\_gdp(r) - 0.03 \quad \text{for all r} \tag{3.2}$$

Standard errors: *(0.06)* *(0.03)*

R^2: 0.98

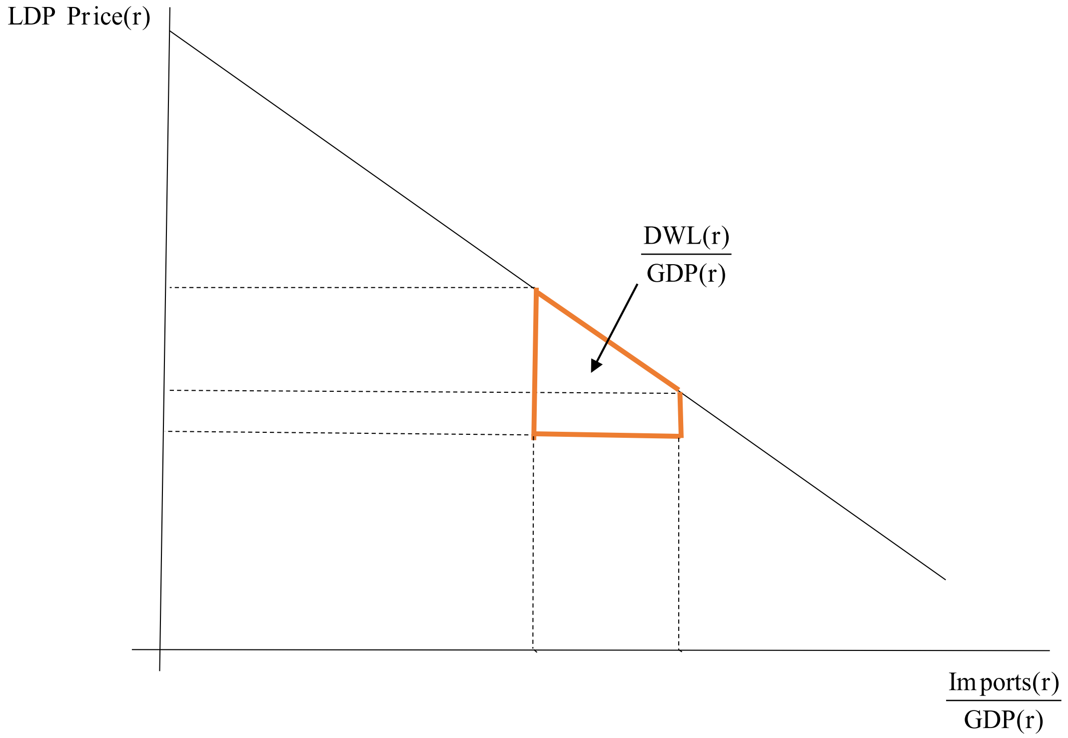
The regression equation supports the DWL explanation of the Armington GDP results. It gives a high R^2 and the coefficient on BoTE_gdp is close to -1 with a small standard error.

Armington: Real private consumption

With real government consumption, real investment and the balance of trade held constant for each country, the Armington consumption results in Table 3.1 can be explained by the BoTE variable [A_Bote_cons(r)]:

$$A\_BoTE\_cons(r) = \left[rgdp(r) + TradSH(r) * tot(r)\right] * \frac{GDP(r)}{CONS(r)} \tag{3.3}$$

Figure 3.1. Back of the envelope calculation of the effect on GDP of 10% worldwide tariff increases: Armington



where rgdp(r) and tot(r) are simulation results for percentage effects on real GDP and the terms of trade for country r and CONS(r) and TradSH(r) are data for country r on aggregate private consumption and the average of imports and exports as a share of GDP. The term in square brackets on the RHS of (3.3) is the increase in consumption expressed as a percentage of GDP made possible by the tariff-induced increase in real GDP and by the percentage change in the terms of trade. The multiplying factor, GDP/CONS, converts the increase in consumption from a percentage of GDP to a percentage of consumption.

$$A\_rgdp(r) = -1.04 * BoTE\_gdp(r) - 0.03 \quad \text{for all r} \qquad (3.2)$$

Standard errors: *(0.06)* *(0.03)*

R^2: 0.98

The regression equation supports the DWL explanation of the Armington GDP results. It gives a high R^2 and the coefficient on BoTE_gdp is close to -1 with a small standard error.

Armington: Real private consumption

With real government consumption, real investment and the balance of trade held constant for each country, the Armington consumption results in Table 3.1 can be explained by the BoTE variable [A_Bote_cons(r)]:

$$A\_BoTE\_cons(r) = \left[rgdp(r) + TradSH(r) * tot(r)\right] * \frac{GDP(r)}{CONS(r)} \qquad (3.3)$$

where rgdp(r) and tot(r) are simulation results for percentage effects on real GDP and the terms of trade for country r and CONS(r) and TradSH(r) are data for country r on aggregate private consumption and the average of imports and exports as a share of GDP. The term in square brackets on the RHS of (3.3) is the increase in consumption expressed as a percentage of GDP made possible by the tariff-induced increase in real GDP and by the percentage change in the terms of trade. The multiplying factor, GDP/CONS, converts the increase in consumption from a percentage of GDP to a percentage of consumption.

Regressing the Armington simulation results for real private consumption [A_cons(r)] against A_BoTE_cons(r) generates:

$$A\_cons(r) = 0.90 * A\_BoTE\_cons(r) - 0.15 \quad \text{for all } r \qquad (3.4)$$

Standard errors: (0.04) (0.09)

R^2: 0.98

With a small standard error and a coefficient value close to 1 on the explaining variable, together with a high R^2, (3.4) supports A_BoTE_cons as an explanation for the Armington results for real consumption.

Armington: Real post-tax wage rate

Our BoTE variable for percentage effects on real post-tax wage rates is

$$BoTE\_rpostwage(r) = \left[A\_rgdp(r) + pgdp(r) - ppriv(r)\right] \qquad (3.5)$$

Why this specification?

BoTE_rpostwage is based on the aggregate production function:

$$RealGDP(r) = A * F(K, Lab, Lnd, NatRes) \qquad (3.6)$$

All of the primary-factor inputs on the RHS of (3.6) are held constant. Consequently, rgdp(r) can be thought of as the percentage change in total factor productivity, that is the percentage change in A in (3.6). On the assumption that labor is paid the value of its marginal product, we would expect the pre-tax nominal wage rate to move in line with total factor productivity (A) and the price of GDP [pgdp(r)]. Given that we are concerned with post-tax wage rates, we also considered the role of taxes. We concluded that under our tax neutrality assumption, tax rates can be excluded from a back-of-the-envelope explanation of movements in post-tax wage rates. To convert from movements in nominal wage rates to movements in real wage rates, we deflated by movements in consumer prices [ppriv(r)].

Regressing the Armington simulation results for real post-tax wage rates against BoTE_rpostwage gave a relatively poor fit ($R^2 = 0.43$).

Looking in more detail at the simulation results, we found that the tariff-induced changes in the industrial composition of output in each country cause changes in the relative returns to primary factors. For example in SEAsia, the simulation shows sharp increases in the prices of natural resources and land relative to labor. We traced this to a contraction in the output of SEAsia's major export industry, Electronic equipment (ele), and expansions in SEAsia's outputs of mining and agricultural industries. In SEAsia, Electronic equipment has average labor intensity whereas most of the mining and agricultural industries have low labor intensity and high natural resource and land intensity.

Changes in relative factor prices were ignored in our initial BoTE regression based purely on (3.5). To obtain a more satisfactory explanation of the simulation results for real post-tax wage rates, we added a variable that captures the effects on wage rates of tariff-induced changes in the industrial structure of the economy, dem4l_impact(r). This is the effect on the demand for labor in country r of tariff-induced changes in the outputs of r's industries holding constant the costs to industries of primary factors. In other words, dem4l_impact(r) is the impact effect on the demand for labor before the adjustment in primary-factor prices necessary to leave the usage of each primary factor unchanged. With the inclusion of dem4l_impact(r) we obtain a satisfactory explanation of movements in real post-tax wage rates:

$$\mathrm{A\_rpostwage(r)} = 1.54 * \mathrm{BoTE\_rpostwage(r)} + 3.31 * \mathrm{dem4l\_impact(r)} + 0.40 \quad (3.7)$$

Standard errors: *(0.14)* *(0.40)* *(0.09)*

R^2: 0.95

Armington: terms of trade

We explain the terms-of-trade movements by the regression equation[6]:

$$\mathrm{A\_tot(r)} = -0.091 * \mathrm{ShCX(r)} + 0.047 * \mathrm{ShNR\_MX(r)} - 0.28 * \mathrm{Trade\_bal(r)} + 1.71 \quad (3.8)$$

Stand. errors:

(0.026) *(0.011)* *(0.054)* *(0.542)*

R^2: 0.91

In this equation,

A_tot(r) is the percentage terms-of-trade movement in the Armington simulation in Table 3.1.

ShCX(r) is the percentage of country r's exports that we classify as consumer commodities. As can be seen in Table 3.1, a world-wide increase in tariffs causes shrinkage in private consumption for almost all countries. With investment and government consumption held constant in each country, we expected reliance in this simulation on exports of consumption goods to be associated with terms of trade decline. The negative sign on ShCX(r) in the regression confirms this expectation.

ShNR_MX(r) is the difference between the percentage of country r's exports accounted for by natural resource commodities and the percentage of r's imports accounted for by these commodities. Natural resource commodities are those that use natural resources as inputs. They include Forestry, Fishing and the mining commodities. With shrinkage in the world economy and with natural resource

[6] Done on the Trade data sheet of Solutions190624.xlsx in directory C:\Dixon\presentations\GTAP2024\MelitzChap7\Sim.

inputs treated as fixed and immobile between industries, our simulation showed sharp declines in returns to natural resources and corresponding declines in the prices of natural resource commodities. Consequently, we expected terms-of-trade benefits for countries whose imports are heavily weighted towards natural resource products and whose exports are only lightly weighted towards these products. The positive sign on ShNR_MX(r) in the regression confirms this expectation.

Trade_bal(r) is country r's balance of trade expressed as a percentage of initial GDP. To understand the relevance of this variable to the terms of trade, we start by assuming that the initial impact of world-wide increases in tariffs is to reduce each country's exports and imports by x per cent. For countries with a trade surplus, this moves their trade balance towards deficit. Moving their trade balance back to its original level requires export stimulation via reduced export prices with negative consequences for the terms of trade. Similarly, for countries with an initial trade deficit, maintaining the deficit has positive consequences for the terms of trade. Consistent with this argument, (3.8) shows a negative coefficient on Trade_bal(r).

3.1b. MM results

MM: Real GDP

The MM results for real GDP in Table 3.1 differ from the corresponding Armington results for two reasons. First, the MM and A simulations produce different results for percentage changes in aggregate imports in each country [m(r)]. Consequently, the dead-weight losses are different, see equation (3.1). However, the import results are quite similar, so differences in dead-weight losses are not the major reason for differences between the simulations in their GDP results.

The second, and the major explanator of the differences in the GDP results, is scale economies. Relative to Armington, there are GDP gains in MM for regions in which the tariff increases lead to expansions in the outputs of the 13 MM industries. These industries reap economies of scale. Similarly, there are GDP loses for regions in which the tariff increases lead to contractions in the outputs of the 13 MM industries.

To demonstrate these assertions, we create two variables to explain the differences between the Armington and MM results. The first is the change in BoTE_gdp(r) in going from Armington to MM computed by comparing the values of the RHS of (3.1) using MM results for m(r) with the values obtained using Armington results.

The second, we refer to as Scale(r)[7], is computed according to:

$$\text{Scale}(r) = \sum_{i \in S13} \text{VOMsh}(i,r) * [\text{qMM}(i,r) - \text{qA}(i,r)] \tag{3.9}$$

where

VOMsh(i,r) is the initial value of output of industry i in region r as a share in the value of output in region r added over all industries;

[7] Done in the eqn 3.9 sheet of Solutions210624.xlsx in directory C:\Dixon\presentations\GTAP2024\MelitzChap7\Sim.

qMM(i,r) and qA(i,r) are the percentage changes in the output of industry i in region r in the MM and Armington simulations; and

S13 refers to the 13 industries in which there are economies of scale.

Scale(r) is positive for region r if industries in S13 do well in the region in MM relative to Armington [qMM(i,r) > qA(i,r)]. It is large if these industries are an important part of r's economy [large values for VOMsh(i,r), $i \in S13$]. Scale(r) is negative for regions in which S13 industries do poorly in MM relative to Armington and is a large negative if these industries are an important part of r's economy.

Regressing the changes in the GDP results as we go from Armington to MM, against Scale(r) and the changes in BoTE_gdp(r) gives[8]:

$$\Delta A2MM\_gdp(r) = 1.49 * Scale(r) + 0.12 * \Delta Bote\_gdp(r) + 0.023 \quad \text{for all r} \quad (3.10)$$

Standard errors: (0.14) (0.13) (0.08)

R^2: 0.94

This regression equation shows that the two factors we have identified largely explain the changes in GDP results.

MM: Real private consumption

As in the Armington simulation, we use equation (3.3) to explain the MM results in Table 3.1 for real private consumption. Evaluating BoTE_cons(r) with MM results for rgdp(r) and tot(r) and using the resulting values in a regression explaining the MM consumption results we obtain[9]:

$$MM\_cons(r) = 0.96 * MM\_BoTE\_cons(r) - 0.16 \quad \text{for all r} \quad (3.11)$$

Standard errors: (0.05) (0.12)

R^2: 0.98

MM: real post-tax wage

We use MM results to form MM versions of BoTE_rpostwage and dem4l_impact. We also recognize that in MM simulations real wages are reduced by increases in pure profits. This led us to the regression equation[10]:

[8] Done on the Ch in DWL A2MM eqn 3.10 sheet of Solutions210624.xlsx in directory C:\Dixon\presentations\GTAP2024\MelitzChap7\Sim (uses Sim A13 and R13).

[9] Done on the Ch in DWL A2MM eqn 3.10 sheet of Solutions210624.xlsx in directory C:\Dixon\presentations\GTAP2024\MelitzChap7\Sim (uses Sim A13 and R13)

[10] Done on the Ch in DWL A2MM eqn 3.10 sheet of Solutions210624.xlsx in directory C:\Dixon\presentations\GTAP2024\MelitzChap7\Sim (uses Sim A13 and R13)

$$MM\_rpostwage(r) = 1.18 * MM\_BoTE\_rpostwage(r) + 2.62 * MM\_dem4l\_impact(r) - 1.21 * profit2GDP(r) + 0.28 \quad (3.12)$$

Stand.errors:

(0.15) *(0.39)* *(0.53)* *(0.11)*

R^2: 0.98

In this equation, MM_rpostwage and MM_dem4l_impact are the MM versions of rpostwage and dem4l_impact, and profit2GDP(r) is the change in pure profits in r expressed as a percentage of r's GDP.

MM: terms of trade

In trying to explain the terms of trade results in Table 3.1 for the MM simulation, we adopted a similar approach to that used for the Armington terms of trade results. However, as can be seen from equation (3.13) we included an extra variable, MX13. This is the percentage of a country's imports accounted for by the 13 MM commodities less the percentage of the country's exports accounted for by these commodities. We included MX13 because we noticed for each of the 10 countries that the cif import prices and the fob export prices of the MM commodities fall relative to the prices of other commodities. Consequently, having a high MM-13 import share and a low MM-13 export share is favourable for a country's terms of trade.

All of the coefficients in (3.13) have the expected sign, but relative to our other regression equations, (3.13) gives a poor fit. The standard errors on the coefficients are large relative to the absolute size of the coefficients[11].

$$MM\_tot(r) = 0.036 * MX13(r) - 0.057 * ShCX(r) + 0.019 * ShNR\_MX(r) - 0.078 * Trade\_bal(r) + 0.792 \quad (3.13)$$

Stand. errors:

(0.052) *(0.055)* *(0.019)* *(0.101)* *(0.909)*

R^2: 0.49

We spent a considerable amount of time trying to produce a better explanation of the MM terms-of-trade results than that given by (3.13). We used as explanatory variables the average for each country over the MM-13 commodities for the profit rate and total factor productivity [d_profrate(r) and aoMel(r)]. We looked closely at the differences for each country in their import and export prices for each MM commodity. We studied the trade patterns for the MM commodity Electronic equipment (ele). Despite these efforts, we did not find a better explanation than (3.13).

The next step, which we plan to conduct in future research, is to use Table A2 to derive an expression for $p_{\bullet sd} - t_{sd}$ in terms of exogenous variables. To keep this

[11] Done on the tot sheet of Solutions210624.xlsx in directory C:\Dixon\presentations\GTAP2024\MelitzChap7\Sim.

manageable we might start with Melitz specification. This would allow us to assume that $m_d = z_{sd} = 0$.

3.2. The effects of worldwide deterioration in competition (Table 3.2)

Average results for the MM industries

The simulation in Table 3.2 is designed to show the effects of a reduction in competition. In the simulation, we apply shocks to ψ_{0s} in equation (T1.7f) in Table 1. Specifically, we raise ψ_{0s} from an initial value of 0.01, in all regions and the 13 MM industries, to a final value of 0.10. Figure 3.2 helps to explain what this means.

The figure is a stylized representation of relationships between the number of firms (N_s) in an MM industry in region s and the profitability of the industry. Profitability is represented by the ratio of pure profits (Π) to the total costs of inputs (WL).

The downward-sloping M_0 line marked "Market", represents the idea that when the number of firms increases, industry output increases and market forces reduce profitability by reducing prices. The upward-sloping E_0 line marked "Entry incentive" is a diagrammatic representation of (T1.7f) with the values of the ψ variables set at their initial values. The E_0 line shows that the emergence of higher profits induces entry of new firms. The initial equilibrium occurs at point A where the M_0 and E_0 lines intersect. As shown in the figure, we assume that this occurs with the profit ratio equal to the initial setting for ψ_{0s}, which is 0.01, and with the number of firms equal to $N_s^{initial}$ [denoted as $\overline{N}_s$ in (T1.7f)].

In the simulation, the entry-incentive line moves upward from E_0 to E_1. For any given number of firm, the profit ratio compatible with zero entry or exit is increased by 0.09. We have in mind a situation in which competition is reduced via mergers and anti-competitive practices, facilitated by, for example, government regulations, loyalty schemes and computer systems that make shifting between service providers difficult.

With the upward shift in the Entry-incentive line, the equilibrium shifts from A to B.

We describe the effects shown in Table 3.2 of the upward shifts in the entry-incentive lines in a sequence, similar to that at the end of section 2, but in the opposite direction. The results for all regions are quite similar. It will be sufficient to focus on just one region, N America.

Consistent with Figure 3.2, the movement from the initial equilibrium to the final equilibrium (A to B in Figure 3.2) increases profits in N America (by 3.71 per cent of GDP) and reduces the number of firms in MM industries (by 7.03 per cent).

With similar reductions in the number of MM firms in other regions, there is a decrease in the number of effective competitors in N America's domestic markets for MM commodities (-6.97 per cent).

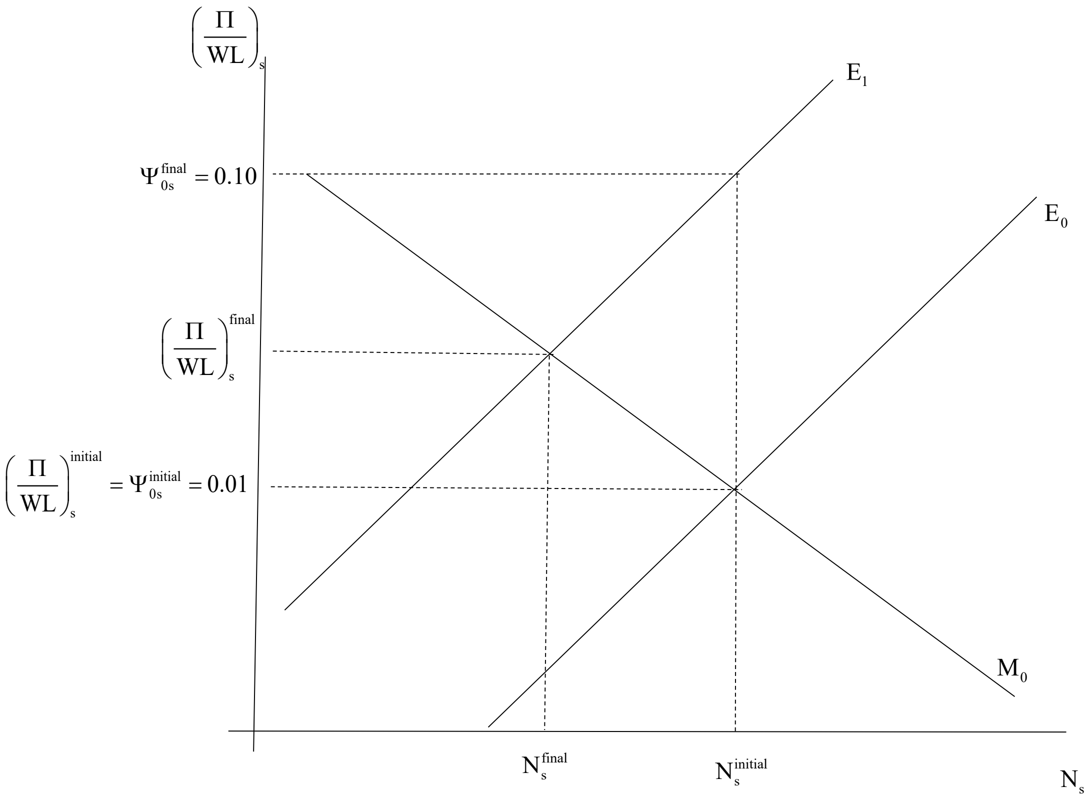
Consequently, domestic and foreign suppliers of MM products to N America perceive a decrease in the elasticity of demand for their products in N America (-2.62 per cent).

Table 3.2. Effects of a reduction in competition: a 9 percentage point upward shift in the entry-incentive line for MM industries in all regions

		Oceania	East Asia	SE Asia	South Asia	N America	Latin America	EU_25	MENA	SSA	Rest of World
(1)	*Pure profits as a per cent of GDP: change in 100*Π/GDP*	3.72	4.74	4.54	2.38	3.71	3.37	4.44	3.90	3.51	3.91
(2)	*Number of firms in MM industries in s: ave over c in % Δ in NUM(c,s)*	-6.33	-7.03	-6.57	-6.43	-7.03	-6.51	-6.89	-6.07	-6.36	-6.49
(3)	*Number of effective competitors in markets for MM coms: ave over c in % Δ in Ntot(c,d)*	-6.88	-6.91	-6.85	-6.90	-6.97	-6.84	-6.90	-6.90	-6.79	-6.82
(4)	*Perceived elasticities by suppliers to MM markets in d: ave over c in % Δ in Γ(c,d)*	-2.59	-2.60	-2.59	-2.60	-2.62	-2.58	-2.59	-2.60	-2.55	-2.56
(5)	*Markup applied by suppliers to MM markets in d: ave over c in % Δ in M(c,d)*	2.52	2.53	2.51	2.53	2.56	2.51	2.53	2.53	2.49	2.50
(6)	*Modification of min. productivity of varieties supplied to d: ave over c and s in % Δ in Z(c,s,d)*	3.26	3.71	1.95	2.82	3.64	3.20	3.64	2.93	2.54	3.09
(7)	*Minimum productivities for supplies to d: ave over c and s in % Δ in Φmin(c,s,d)*	-4.33	-4.04	-4.10	-4.20	-4.04	-4.25	-4.16	-4.20	-4.52	-4.22
(8)	*Varieties delivered to MM markets in d: ave over c and s in % Δ in NUML(c,s,d)*	3.38	3.01	4.49	4.28	2.79	3.79	2.96	4.24	4.18	3.75
(9)	*Price to users in d of MM coms: ave over c in % Δ in P(c,d) relative to general price level in d*	4.19	4.48	3.97	3.85	4.27	3.95	4.56	4.11	4.26	4.19
(10)	*Real GDP: percentage change*	0.45	0.45	0.23	0.36	0.40	0.48	0.52	0.62	0.41	0.50
(11)	*Real private consumption (welfare): percentage change*	-0.09	1.43	0.94	0.37	0.39	0.52	0.87	0.55	0.03	0.43
(13)	*Real post-tax wage rate: percentage change*	-3.69	-3.32	-3.35	-1.26	-3.74	-2.62	-4.39	-2.44	-3.11	-3.17

Sim R03 run with GTAPMM59.tab.

Figure 3.2. Simulating a reduction in competition by an upward shift in the Entry-incentive curve



The reduction in the perceived elasticity leads suppliers of MM products to N America to adopt higher mark-up factors on marginal costs in setting their prices for N America (2.56 per cent). As we saw at the end of section 2, higher mark-ups increase the number of varieties. On the other hand, the reduction in the perceived elasticity reduces the number of varieties by leading to a perception of increased damage to profitability from extra varieties. This is encapsulated in the 3.64 per cent increase in the average Z-factor on sales of MM commodities to N America.

The increase in mark-ups on sales to N America dominate the increase in the Z-factor, leaving the average minimum productivity reduced on the trade links to N America (-4.04 per cent). Correspondingly, the number of varieties sold in the N American market is increased (2.79 per cent).

An increase in mark-ups generates higher prices for MM commodities in N America. On the other hand, the cost to N American users of MM commodities of satisfying any given level of demand is reduced by an increase in varieties. In our simulation, the mark-up effect dominates. On average, the unit cost to N American consumers of MM commodities increases by 4.27 per cent.

Macro results

The reduction in competition in MM industries causes GDP to increase in all regions (0.40 per cent in N America). With increases in GDP, there are increases in private consumption in all regions except Oceania. The small decrease in private consumption in Oceania was caused an unfavorable terms-of-trade movement.

The positive movements in GDP reflect economies of scale for firms in MM industries. As shown in row 2 of Table 3.2, there are sharp declines in the numbers of these firms. This saves on set up costs, increasing output per unit of input in the MM industries in all regions. The saving on input costs is equivalent to a GDP-increasing technological improvement [an increase in A in (3.6)].

With increases in GDP and consumption, what is not to like about a deterioration in competition?

The answer is negative effects on real wage rates (-3.47 per cent for N America). This is the most important result from our simulation. Deterioration in competition can lead to inequitable changes in the distribution of income.

4. Concluding remark

Melitz introduced an attractive theoretical model of trade based on the assumptions of LGMC, in particular the assumptions that all firms in an industry are small and that pure profits in an industry are zero. Inspired by Markusen, we reformulated the Melitz model as SGMC, allowing for large firms and non-zero pure profits at the industry level.

Melitz and Markusen focus primarily on trade. With Melitz-Markusen (MM) features embedded in GTAP, we obtained results in an illustrative tariff simulation that are distinctly different from those generated by a standard Armington model. Nevertheless, we wonder about the significance of these differences. We don't see that they lead to different policy prescriptions.

By contrast, we think that the MM formulation may give new perspectives on competition policy. In an illustrative simulation under MM assumptions, we showed that deterioration in competitiveness in industries can increase pure profits as a share of GDP and reduce real post-tax wage rates. Deterioration in competitiveness has been documented by Grullon *et al.* (2019) for the U.S. and by Fels (2024) for Australia. With pure profits accruing mainly to top managers in large corporation and to well-off, old people holding large retirements funds, could a deterioration in competitiveness be part of the explanation of public discontent with the performance of economies despite high rates of employment and satisfactory growth in macro variables such as GDP and private consumption? Could lack of competition be part of the explanation of intergenerational inequity in which young people relying on declining or sluggishly growing wage income struggle to achieve an acceptable standard of living, while older people enjoy a prosperous lifestyle?

Relative to Armington and LGMC versions of Melitz, the MM model is a step in the right direction towards answering these questions. It contains necessary ingredients: pure-profits and non-competitive oligopolistic behaviour. However, much more research is necessary. We will need to analyse data on industry concentration ratios (e.g. shares of industry outputs accounted for by the top 4 firms) and on profit shares in GDP. We will need to move from the relatively crude comparative-static modelling in this paper to dynamic modelling.

Appendix. The mathematics behind the MM model and its implementation in GEMPACK

A1. Introduction

The aim of this appendix is to provide the technical details underlying the theory and implementation of an MM specification in a standard GTAP model.

We start in section A2 by describing a set of encompassing equations. These equations identify all Widget varieties, not just typical varieties. Following Melitz we show how the variety dimension can be reduced to typical varieties.

Section A3 is a description and solution of the optimization problems that lead to the specification in (T1.7b) of the perceived elasticity of demand (Γ_d) and the specification in (T1.7e) of the modifying factor (Z_{sd}) in the SGMC determination of the minimum-productivity variety on the sd-link.

In section A4, we derive a percentage change version of MM. The coefficients in the percentage-change equations are readily interpretable in terms of cost shares, sales shares, substitution elasticities and parameters of the Pareto distribution of variety productivities. The percentage change equations, with their relatively easily evaluated coefficients are the basis for implementing MM in GEMPACK software.

The final section of the appendix describes our method for creating an MM industry in the GTAP model with minimal changes to standard GTAP. The method relies mainly on reinterpretation of changes in selected tax variables in standard GTAP as changes in mark-ups and profits, and changes in selected technology variables as changes in average costs associated with economies of scale.

A2. Deriving MM equations from encompassing equations

The first column of Table A1 repeats the first 6 groups of MM equations from Table 1 in section 2. These are either straight Melitz or slightly adapted from Melitz. The second column is an encompassing or more general specification of a Widget industry. Notational notes on the encompassing equations are at the end of the table. Notation for the MM equations was given at the end of Table 1.

In this section we derive the MM equations in the first column of Table A1 as special cases of the encompassing equations in the second column.

Commentary on the encompassing equations (second column in Table A1)

Encompassing equation (T1.1a) determines the prices of the varieties on the sd-link by marking up their marginal costs. We could give the mark-up factor k and s subscripts in addition to the d subscript. However, we don't have any implementable theory to suggest differences in mark-ups across varieties in d's market. Consequently, even in the encompassing equations we assume that the mark-up factor (M_d) is the same for all varieties used in d.

Encompassing equation (T1.3a) determines the demand in country d for each k-class variety from s. By k-class varieties, we mean varieties with marginal productivity of Φ_k. Encompassing equation (T1.2a) determines the cost to Widget users in s of an extra unit of

Widgets (a unit increase in Q_d). These two equations follow from a CES cost-minimizing problem of the form:

choose Q_{ksd} for all s and $k \in S(s,d)$

$$\text{to minimize } \sum_{s} \sum_{k \in S(s,d)} Q_{ksd} P_{ksd} \tag{A2.1}$$

subject to

$$Q_d = \left(\sum_{s} \sum_{k \in S(s,d)} \delta_{sd} N_s B_s g(\Phi_k) Q_{ksd}^{(\sigma-1)/\sigma} \right)^{\sigma/(\sigma-1)} \tag{A2.2}$$

In interpreting (A2.2) it is useful to note that $N_s B_s g_s(\Phi_k)$ is the number of k-class varieties sent on the sd-link, that is the number of firms *times* the number of potentially producible varieties per firm *times* the proportion of varieties with productivity Φ_k,

Encompassing equation (T1.3b) is an accounting relationship determining the value of the sd-flow.

Encompassing equation (T1.4b) defines profits for a k-class variety in s from its sales to d as: revenue (net of tariffs and transport costs) *less* variable costs of production *less* the fixed costs required to set up sales of a variety on the sd-link. Then via encompassing equation (T1.4a) we assume that for a variety to be sent on the sd-link, sending it on that link must contribute non-negatively to the profits of Widget-producers in s. As explained in section 2 in the discussion of MM equation (T1.4a), the Z_{sd} factor, which is greater than or equal to 1, takes account of the perceived effect on the profitability of established varieties on the sd-link of an extra variety. In the encompassing equations, we leave the determination of Z_{sd} open.

Encompassing equation (T1.5) defines total profits in the Widget industry of s as the sum of profit contributions over all classes and links *less* the fixed costs of setting up Widget firms in s.

Encompassing equation (T1.6) defines total input bundles (employment) in the Widget industry in s as the sum of bundles used as variable inputs and fixed inputs.

Introducing the Pareto distribution and defining the typical variety

Melitz assumed that the productivity distribution from which intending Widget entrepreneurs make their productivity draw has the Pareto form:

$$g_s(\Phi) = \alpha \Phi^{-\alpha-1}, \ \Phi \geq 1 \tag{A2.3}$$

where α is a positive parameter. Under (A2.3), the lowest potential productivity value is 1. This assumption can be made without loss of generality through a suitable choice of units for the input bundle.

We adopt (A2.3) to describe the distribution of productivities across varieties producible be a firm in s, where $g_s(\Phi)$ is, as defined earlier, the proportion of the firm's varieties that has productivity Φ.

Next, following Melitz, we define the typical variety sent on the sd-link as one that has productivity level given by

$$\Phi_{\bullet sd} = \left[\sum_{k \in S(s,d)} \frac{N_s B_s g_s(\Phi_k)}{N_{sd}} \Phi_k^{\sigma-1} \right]^{\frac{1}{\sigma-1}} \quad , \tag{A2.4}$$

that is, the typical variety on the sd-link is a CES average of the productivities of all the varieties k on the sd-link, $k \in S(s,d)$. As shown by Dixon *et al.* (2019, chapter 2), the definition in (A2.4) can be reduced to a statement about the "size" of the typical variety. It turns out that the typical variety on the sd-link is one which uses the average number of input bundles over varieties on the sd-link to generate output for the link. For example, if production for the sd-link (not link or firm set-up costs) uses 300 input bundles and there are 15 varieties sent on the sd-link, then the typical variety on the link is one whose production for the link requires 20 input bundles.

With the definition of the typical variety for the sd-link in place, we can move to the derivation of the MM equations in the first column of Table A1.

Deriving MM equation (T1.1a)

MM equation (T1.1a) is the encompassing equations written for the typical variety on the sd-link.

Deriving MM equation (T1.2b)

From (A2.3) we obtain

$$\int_{\Phi_{min}}^{\infty} g_s(\Phi)\, d\Phi = \Phi_{min}^{-\alpha} \tag{A2.5}$$

(A2.5) means that the proportion of productivity values in country s that are greater than any given level, Φ_{min}, is $\Phi_{min}^{-\alpha}$. Thus the proportion of varieties in country s with productivity of at least $\Phi_{min(s,d)}$, i.e. the proportion of varieties $[N_{sd}/(N_s B_s)]$ that can be sent on the sd-link is $\Phi_{min(s,d)}^{-\alpha}$. This justifies the MM equation (T1.2b).

Deriving MM equation (T1.1b)

Next, we apply (A2.3) and (T1.2b) in a continuous version of (A2.4). This gives

$$\Phi_{\bullet sd}^{\sigma-1} = \int_{\Phi_{min(s,d)}}^{\infty} \Phi_{min(s,d)}^{\alpha} \alpha\, \Phi^{-\alpha-1} \Phi^{\sigma-1} d\Phi \tag{A2.6}$$

that is

$$\Phi_{\bullet sd}^{\sigma-1} = \left(\frac{\alpha}{\alpha - (\sigma-1)} \right) \Phi_{min(s,d)}^{\sigma-1} \quad . \tag{A2.7}$$

In deriving (A2.7), we assume that

$$\alpha > (\sigma\text{-}1) \tag{A2.8}$$

This doesn't have an obvious economic interpretation. However, without it, the integral on the RHS of (A2.6) is unbounded. From (A2.7) we get

$$\Phi_{\bullet sd} = \beta \Phi_{\min(s,d)} \quad . \tag{A2.9}$$

where

$$\beta = \left(\frac{\alpha}{\alpha - (\sigma - 1)} \right)^{1/(\sigma-1)} \quad . \tag{A2.10}$$

This justifies (T1.1b).

Deriving MM equation (T1.2a)

Encompassing equation (T1.1a), implies that

$$P_{ksd} = P_{\bullet sd} * \frac{\Phi_{\bullet sd}}{\Phi_{ksd}} \tag{A2.11}$$

Substituting from (A2.11) into the encompassing version of (T1.2a) and using (A2.3), we obtain:

$$P_d^{1-\sigma} = \sum_s N_s B_s \delta_{sd}^{\sigma} (P_{\bullet sd} \Phi_{\bullet sd})^{1-\sigma} \int_{\Phi \min(s,d)}^{\infty} \alpha \Phi^{-\alpha-1} \Phi^{\sigma-1} d\Phi \tag{A2.12}$$

leading to

$$P_d^{1-\sigma} = \sum_s N_s B_s \delta_{sd}^{\sigma} (P_{\bullet sd} \Phi_{\bullet sd})^{1-\sigma} \frac{\alpha}{\alpha - (\sigma - 1)} * \Phi_{\min(s.d)}^{\sigma-\alpha-1} \tag{A2.13}$$

Via MM equations (T1.1b) and (T1.2b) together with (A2.10), we can reduce (A2.13) to

$$P_d^{1-\sigma} = \sum_s N_{sd} \delta_{sd}^{\sigma} (P_{\bullet sd})^{1-\sigma} \tag{A2.14}$$

which establishes MM equation (T1.2a).

Deriving MM equation (T1.3a)

This is the encompassing equation written for the typical variety on the sd-link.

Deriving MM equations (T1.3b) and (T1.3c)

From encompassing equations (T1.3a) and (T1.1a), we have

$$Q_{ksd} = Q_{\bullet sd} * \left(\frac{P_{ksd}}{P_{\bullet sd}} \right)^{-\sigma} \tag{A2.15}$$

and

$$P_{ksd} = P_{\bullet sd} * \left(\frac{\Phi_{\bullet sd}}{\Phi_{ksd}} \right) \tag{A2.16}$$

Then substituting into the continuous version of encompassing equation (T1.3b) and using MM equation (T1.2b) and (A2.3), we obtain

$$V_{sd} = \int_{\Phi_{min(s,d)}}^{\infty} P_{\bullet sd} * \left(\frac{\Phi_{\bullet sd}}{\Phi}\right) * N_{sd} * \left(\Phi_{min(s,d)}\right)^{\alpha} \alpha\Phi^{-\alpha-1} * Q_{\bullet sd} * \left(\frac{\Phi_{\bullet sd}}{\Phi}\right)^{-\sigma} d\Phi \qquad \text{(A2.17)}$$

Rearranging (A2.17) and using (T1.1b) to eliminate $\Phi_{\bullet sd}$ gives

$$V_{sd} = P_{\bullet sd} * N_{sd} * Q_{\bullet sd} * \beta^{1-\sigma} * \left(\Phi_{min(s,d)}\right)^{1+\alpha-\sigma} \alpha \int_{\Phi_{min(s,d)}}^{\infty} \Phi^{-\alpha-1+\sigma-1} d\Phi \qquad \text{(A2.18)}$$

By performing the integration and noting the definition of β in (A2.10), we can reduce (A2.18) to (T1.3b).

MM equation (T1.3c) defines the quantity (Q_{sd}) of Widgets on the sd-link as the value (V_{sd}) divided by the price of the typical variety ($P_{\bullet sd}$). Whereas V_{sd} feeds into other parts of the general equilibrium model, Q_{sd} does not. It is simply a convenient variable in reporting results. Consequently, we do not need to derive MM equation (T1.3c) from an encompassing version, or even to specify an encompassing version.

Deriving MM equations (T1.4a) and (T1.4b)

Encompassing equation (T1.4b) calculates the contribution to the profits of Widget producers in s from sending a k-class variety on the sd-link as:

revenue net of transport costs and tariffs,

less production costs,

less set-up costs for a variety on the sd-link.

By substituting from encompassing equation (T1.1a) into encompassing equation (T1.4b) we find that

$$\Pi_{ksd} = \left[M_d - 1\right] * \frac{W_s}{\Phi_k} * Q_{ksd} - F_{sd} W_s \qquad \text{(A2.19)}$$

Using encompassing equations (T1.3a) and (T1.1a) we can write (A2.19) as

$$\Pi_{ksd} = \Phi_k^{\sigma-1} * \left(M_d - 1\right) * W_s * Q_d \delta_{sd}^{\sigma} P_d^{\sigma} \left(W_s T_{sd} M_d\right)^{-\sigma} - F_{sd} W_s \qquad \text{(A2.20)}$$

Recall that M_d and σ are greater than 1. Hence, (A2.20) shows that Π_{ksd} is as an increasing function of Φ_k. This means that a variety with minimum profitability over all those sent on the sd-link also has the minimum productivity level, $\Phi_{min(s,d)}$. Now using (A2.19), we see that encompassing equation (T1.4a) implies that

$$\left(M_d - 1\right) W_s \left(\frac{Q_{min(s,d)}}{\Phi_{min(s,d)}}\right) - F_{sd} * W_s - F_{sd} * W_s * (Z_{sd} - 1) = 0 \qquad \text{(A2.21)}$$

where $Q_{min(s,d)}$ is the sales volume on the sd-link of a variety with minimum productivity for the link. (A2.21) reduces to MM equation (T1.4a).

MM equation (T1.4b) can be derived from (A2.15), (A2.16) and (T1.1b):

$$\frac{Q_{min(s,d)}}{Q_{\bullet sd}} = \left(\frac{P_{min(s,d)}}{P_{\bullet sd}}\right)^{-\sigma} = \left(\frac{\Phi_{min(s,d)}}{\Phi_{\bullet sd}}\right)^{\sigma} = \frac{1}{\beta^{\sigma}} \tag{A2.22}$$

Deriving MM equations (T1.5)

Substituting from (A2.19) into encompassing equation (T1.5) and then using (T1.2b), (A2.3), (A2.15) and (A2.16) we obtain

$$\Pi tot_s = \sum_d \sum_{k \in S(s,d)} N_{sd} \Phi^{\alpha}_{min(sd)} \alpha \Phi_k^{-\alpha-1} \left[(M_d - 1) * \frac{W_s}{\Phi_k} Q_{\bullet sd} \left(\frac{\Phi_k}{\Phi_{\bullet sd}}\right)^{\sigma} - F_{sd} W_s \right] \quad - N_s H_s W_s \tag{A2.23}$$

Converting to continuous form gives

$$\begin{aligned} \Pi tot_s = & \sum_d N_{sd} \Phi^{\alpha}_{min(sd)} \alpha (M_d - 1) W_s Q_{\bullet sd} \Phi_{\bullet sd}^{-\sigma} \int_{\Phi_{min(sd)}}^{\infty} \Phi^{-\alpha-1+\sigma-1} \, d\Phi \\ & - \sum_d N_{sd} F_{sd} W_s \Phi^{\alpha}_{min(sd)} \alpha \int_{\Phi_{min(sd)}}^{\infty} \Phi^{-\alpha-1} \, d\Phi \quad - N_s H_s W_s \end{aligned} \tag{A2.24}$$

Performing the integrations and using (A2.10) and (T1.1b), we can reduce (A2.24) to MM equation (T1.5).

Deriving MM equations (T1.6)

Substituting from (T1.2b), (A2.3), (A2.15) and (A2.16) into encompassing equation (T1.6) we obtain

$$L_s = \sum_d \sum_{k \in S(s,d)} N_{sd} \Phi^{\alpha}_{min(sd)} \alpha \Phi_k^{-\alpha-1} \frac{Q_{\bullet sd}}{\Phi_k} \left(\frac{\Phi_k}{\Phi_{\bullet sd}}\right)^{\sigma} + \sum_d \sum_{k \in S(s,d)} N_{sd} \Phi^{\alpha}_{min(sd)} \alpha \Phi_k^{-\alpha-1} F_{sd} \quad + N_s H_s \tag{A2.25}$$

Converting to continuous form gives

$$L_s = \sum_d N_{sd} \Phi^{\alpha}_{min(sd)} \alpha Q_{\bullet sd} \Phi_{\bullet sd}^{-\sigma} \int_{\Phi_{min(sd)}}^{\infty} \Phi^{-\alpha-1+\sigma-1} \, d\Phi \quad + \sum_d N_{sd} \Phi^{\alpha}_{min(sd)} \alpha F_{sd} \int_{\Phi_{min(sd)}}^{\infty} \Phi^{-\alpha-1} \, d\Phi \quad + N_s H_s$$

(A2.26)

Performing the integrations and using (A2.10) and (T1.1b), we can reduce (A2.26) to MM equation (T1.6).

A3. Derivation of formulas (T1.7b) and (T1.7e) for the perceived elasticity of demand (Γ_d) and the modifying factor for minimum productivity (Z_{sd})

Unlike the first 6 groups of MM equations in Table 1 which are derived from encompassing equations specified at the variety level, the SGMC equations [the 7th group, (T1.7a) - (T1.7f)] are specified directly at the country and industry levels. Justifications for these equations were given in section 2. In this section, we provide further explanations of (T1.7b) and (T1.7e) by deriving them from micro foundations.

Deriving MM equations (T1.7b)

See Markusen (2023, section 5).

Deriving MM equations (T1.7e)

Melitz assumes that Widget firms in country s decide whether a variety k should be sent on the sd-link without considering the effects of their decisions on the profitability of other varieties on the link. This assumption is reasonable for Melitz' LGMC model in which there are many firms in country s and each firm produces only one variety. However, it is not an appropriate assumption for an SGMC model in which there are few firms and each firm produces many varieties. In such a model, we need to recognize that in making decisions on varieties, firms will take account of effects on sales of their own established varieties and those of other firms, and the likely reactions of other firms.

To introduce inter-variety dependencies into the specification of firm decision making, we assume that the minimum-productivity variety on the sd-link is chosen to maximize profits on the link. With the profit-maximizing variety decision in place for the link, each firm assumes that any movement it makes away from that decision will be matched by other firms, reducing its own sd-profits as well as those of its rivals. (Recall that we assume that Widget firms in s are identical.)

The first step towards deriving the profit-maximizing variety specification for the sd-link is to define total profits on the link:

$$\Pi_{tot(sd)} = \int_{\Phi_{min(s,d)}}^{\infty} \Pi_{ksd} N_s B_s g_s(\Phi)\, d\Phi \qquad \text{(A3.1)}$$

Substitute from (A2.3) and (A2.20):

$$\begin{aligned}\Pi_{tot(sd)} = {} & (M_d - 1) W_s Q_d \delta_{sd}^{\sigma} P_d^{\sigma} (W_s T_{sd} M_d)^{-\sigma} N_s B_s \alpha \int_{\Phi_{min(s,d)}}^{\infty} \Phi^{\sigma-1-\alpha-1}\, d\Phi \\ & - F_{sd} W_s N_s B_s \alpha \int_{\Phi_{min(s,d)}}^{\infty} \Phi^{-\alpha-1}\, d\Phi\end{aligned} \qquad \text{(A3.2)}$$

Now we start working on the evaluation of the partial derivative of $\Pi_{tot(sd)}$ with respect to $\Phi_{min(s,d)}$. In evaluating the partial derivative, Widget firms in country s assume that $\Phi_{min(s,d)}$ does not affect wage rates, mark-ups, number of firms, preferences and tariff and transport rates. Thus,

$$\begin{aligned}\frac{\partial \Pi_{tot(sd)}}{\partial \Phi_{min(s,d)}} = {} & -(M_d - 1) W_s Q_d \delta_{sd}^{\sigma} P_d^{\sigma} (W_s T_{sd} M_d)^{-\sigma} N_s B_s \alpha \Phi_{min(s,d)}^{\sigma-1-\alpha-1} + F_{sd} W_s N_s B_s \alpha \Phi_{min(s,d)}^{-\alpha-1} \\ & + (M_d - 1) W_s \delta_{sd}^{\sigma} (W_s T_{sd} M_d)^{-\sigma} N_s B_s \alpha \left(-\frac{\Phi_{min(s,d)}^{\sigma-1-\alpha}}{\sigma-1-\alpha} \right) \frac{\partial \left(P_d^{\sigma} Q_d \right)}{\partial \Phi_{min(s,d)}}\end{aligned} \qquad \text{(A3.3)}$$

If like Melitz we adopt a LGMC framework, then it is appropriate assume that $\partial\left(P_d^{\sigma} Q_d\right)/\partial \Phi_{min(s,d)}$ equals zero. Under this assumption, optimization with respect to $\Phi_{min(s,d)}$ requires that

$$0 = \left[-(M_d - 1) Q_d \delta_{sd}^{\sigma} P_d^{\sigma} (W_s T_{sd} M_d)^{-\sigma} \Phi_{min(s,d)}^{\sigma-1} + F_{sd} \right] W_s N_s B_s \alpha \Phi_{min(s,d)}^{-\alpha-1} \qquad \text{(A3.4)}$$

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Table A1. MM and Encompassing equations for a Widget industry (notation next page)

	Equations for Melitz-Markusen (MM)	**Encompassing equations**
(T1.1a)	$P_{\bullet sd} = \left(\frac{W_s T_{sd}}{\Phi_{\bullet sd}}\right) * M_d$	$P_{ksd} = \left(\frac{W_s T_{sd}}{\Phi_k}\right) * M_d \quad k \in S(s,d)$
(T1.1b)	$\Phi_{\bullet sd} = \beta * \Phi_{\min(s,d)}$	
(T1.2a)	$P_d = \left(\sum_s N_{sd} \delta_{sd}^{\sigma} P_{\bullet sd}^{1-\sigma}\right)^{\frac{1}{(1-\sigma)}}$	$P_d = \left(\sum_s \sum_{k \in S(s,d)} N_s B_s g_s(\Phi_k) \delta_{sd}^{\sigma} P_{ksd}^{1-\sigma}\right)^{1/(1-\sigma)}$
(T1.2b)	$N_{sd} = N_s * B_s * \left(\Phi_{\min(s,d)}\right)^{-\alpha}$	
(T1.3a)	$Q_{\bullet sd} = Q_d \delta_{sd}^{\sigma} \left(\frac{P_d}{P_{\bullet sd}}\right)^{\sigma}$	$Q_{ksd} = Q_d \delta_{sd}^{\sigma} \left(\frac{P_d}{P_{ksd}}\right)^{\sigma}$
(T1.3b)	$V_{sd} = P_{\bullet sd} N_{sd} Q_{\bullet sd}$	$V_{sd} = \sum_{k \in S(s,d)} P_{ksd} N_s B_s g_s(\Phi_k) Q_{ksd}$
(T1.3c)	$Q_{sd} = N_{sd} Q_{\bullet sd}$	
(T1.4a)	$\left(M_d - 1\right)\left(\frac{Q_{\min(s,d)}}{\Phi_{\min(s,d)}}\right) - F_{sd} * Z_{sd} = 0$	$\text{Min}_{k \in S(s,d)}\left[\Pi_{ksd}\right] - W_s F_{sd}\left(Z_{sd} - 1\right) = 0$
(T1.4b)	$Q_{\min(s,d)} = Q_{\bullet sd} / \beta^{\sigma}$	$\Pi_{ksd} = \frac{P_{ksd}}{T_{sd}} Q_{ksd} - \left(\frac{W_s}{\Phi_k}\right) Q_{ksd} - F_{sd} W_s$
(T1.5)	$\Pi tot_s = \sum_d N_{sd}\left[\frac{W_s}{\Phi_{\bullet sd}} * Q_{\bullet sd} * \left(M_d - 1\right) - W_s * F_{sd}\right] - N_s H_s W_s$	$\Pi tot_s = \sum_d \sum_{k \in S(s,d)} N_s B_s g_s(\Phi_k) \Pi_{ksd} - N_s H_s W_s$
(T1.6)	$L_s = \sum_d \frac{N_{sd} Q_{\bullet sd}}{\Phi_{\bullet sd}} + \sum_d N_{sd} F_{sd} + N_s H_s$	$L_s = \sum_d \sum_{k \in S(s,d)} N_s B_s g_s(\Phi_k) \frac{Q_{ksd}}{\Phi_k} + \sum_d \sum_{k \in S(s,d)} N_s B_s g_s\left(\Phi_k\right) F_{sd} + N_s H_s$

Notation for the encompassing equations [Notation for the MM equations is at the end of Table 1.]

N_s is the number of Widget-producing firms in country s.

S(s,d) is the set of all varieties k produced in s that are sent from s to d. With all varieties in s facing the same sd-link set up cost, we can assume that if any class-k variety is sent on the sd-link, then all varieties in s with productivity greater than or equal to Φ_k are sent on the sd-link.

$g_s(\Phi_k)$, assumed the same for all firms in s, is the proportion of varieties producible by an s firm that have productivity level Φ_k. This is the number of additional units of output generated per additional unit of input. In this theoretical exposition, we assume that the only input is labor but in our implementation of the theory in GTAP, Widget produces use a bundle of inputs that include labor, capital, land and intermediates. When we refer to varieties in class k in country s, we mean the set of varieties in s that have productivity Φ_k.

B_s is the number of varieties potentially producible by a firm in s. Thus, the number of k-class varieties potentially producible in country s is $N_s B_s g_s(\Phi_k)$.

P_{ksd} is the price in country d of class-k Widgets produced in country s. We assume that all class-k Widgets sent on the sd-link have the same price.

W_s is the cost of a unit of input (labor) to Widget makers in country s.

T_{sd} is the power (1 plus rate) of the tariff or possibly transport costs associated with the sale of Widgets from s to d.

M_d is the mark-up on marginal costs (≥1) applied on all varieties sent to d.

F_{sd} is the fixed cost (measured in units of input) required to set up sales of a variety from s to d. We refer to this as the sd-link set up cost.

H_s is the fixed cost (measured in units of input) to set up a firm in s.

δ_{sd} is a positive parameter reflecting d's preference for varieties in general from s relative to those from other countries.

σ (restricted to be >1) is the elasticity of substitution between varieties, assumed to be the same for all consumers in every country and for any pair of varieties wherever sourced.

Q_{ksd} is the quantity of Widgets sent from s to d of each variety in class k (this includes the s-to-s flows).

Q_d is the total requirement for Widgets in d. Q_{ksd} is a normal quantity (count or tonnes). Q_d is a CES aggregate of the Q_{ksd} s.

P_d is the cost in region d of satisfying a unit demand for Widgets, that is the cost of increasing Q_d by 1.

Π_{ksd} is the contribution to the profits of a producer in s from its sales to d of k-class Widgets.

Z_{sd} is a variable with value greater or equal to 1. As explained in section 2 in the discussion of (T1.4a), Z_{sd} takes account of the assessment of producers in s of the effect on their profits from established varieties on the sd-link of adding an extra variety. If their assessment is that there is no effect, then Z_{sd} is 1.

Πtot_s is total profits for Widget producers in s

L_s is the total number of input bundles (employment) used in the Widget industry in country s.

Using encompassing equations (T.1.1a) and (T1.3a), we can reduce (A3.4) to

$$0 = \left[-(M_d - 1)Q_{min(s,d)}\Phi_{min(s,d)}^{-1} \quad + \quad F_{sd} \right] \tag{A3.5}$$

This is the Melitz equation for determining $\Phi_{min(s,d)}$.

However, in our SGMC framework, we assume that in making their variety decision for market d, firms in country s gauge how these decisions will affect prices (P_d) and quantities (Q_d). To simplify the specification of the variety decision, we lock P_d and Q_d together by assuming, as earlier, that suppliers to country d perceive an elasticity of demand in d of Γ_d. Thus, they perceive the relationship between P_d and Q_d as

$$Q_d = P_d^{-\Gamma_d} \tag{A3.6}$$

where quantity units have been chosen so that we can omit the factor of proportionality.

Under (A3.6), we can complete the evaluation of $\partial\Pi_{tot(sd)} / \partial\Phi_{min(s,d)}$ in (A3.3) by obtaining a formula for $\partial\left(P_d^{\sigma-\Gamma_d}\right) / \partial\Phi_{min(s,d)}$.

We start the task of evaluating $\partial\left(P_d^{\sigma-\Gamma_d}\right) / \partial\Phi_{min(s,d)}$ by working on encompassing equation (T1.2a). Substituting from (A2.3) and (T1.1a) into (T1.2a) gives

$$P_d^{1-\sigma} = \sum_r \int_{\Phi_{min(r,d)}}^{\infty} N_r B_r \alpha \delta_{rd}^{\sigma} (W_r T_{rd} M_d)^{1-\sigma} \Phi^{\sigma-1-\alpha-1} \, d\Phi \tag{A3.7}$$

Performing the integration and using (A2.10) we find that

$$P_d^{1-\sigma} = \sum_r N_r B_r \beta^{\sigma-1} \delta_{rd}^{\sigma} (W_r T_{rd} M_d)^{1-\sigma} \Phi_{min(r,d)}^{\sigma-1-\alpha} \tag{A3.8}$$

Differentiating with respect to $\Phi_{min(s,d)}$ in (A3.8) leads to

$$\frac{\partial P_d}{\partial\Phi_{min(s,d)}} = P_d^{\sigma} N_s B_s \beta^{\sigma-1} \delta_{sd}^{\sigma} (W_s T_{sd} M_d)^{1-\sigma} \left(\frac{\alpha - (\sigma-1)}{\sigma-1} \right) \Phi_{min(s,d)}^{\sigma-1-\alpha-1} \tag{A3.9}$$

In deriving (A3.9) we hold constant $\Phi_{min(r,d)}$ for $r \neq s$. This is consistent with all firms supplying to the d market having reached a Nash equilibrium with respect to variety decisions.

Recalling from (A2.8) that $\alpha > \sigma$-1, and that $\sigma > 1$, we see from (A3.9) that $\partial P_d / \partial\Phi_{min(s,d)}$ is positive. An increase in $\Phi_{min(s,d)}$ reduces the varieties available to Widget users in d. Through the love-of-variety effect, this increases the cost in d of satisfying a unit of Widget demand.

Next we note that

$$\frac{\partial P_d^{\sigma-\Gamma_d}}{\partial\Phi_{min(s,d)}} = \left(\sigma - \Gamma_d\right) P_d^{\sigma-\Gamma_d-1} \frac{\partial P_d}{\partial\Phi_{min(s,d)}} \tag{A3.10}$$

Bringing in (A3.9) and using (A2.10) gives

$$\frac{\partial P_d^{\sigma-\Gamma_d}}{\partial\Phi_{min(s,d)}} = \left(\sigma - \Gamma_d\right) P_d^{2\sigma-\Gamma_d-1} * N_s B_s \delta_{sd}^{\sigma} (W_s T_{sd} M_d)^{1-\sigma} \left(\frac{\alpha}{\sigma-1} \right) \Phi_{min(s,d)}^{\sigma-1-\alpha-1} \tag{A3.11}$$

Now substitute (A3.11) into (A3.3) and assume, consistent with optimization, that $\partial\Pi_{tot(sd)} / \partial\Phi_{min(s,d)}$ is zero:

$$0 = -(M_d - 1) W_s Q_d \delta_{sd}^{\sigma} P_d^{\sigma} (W_s T_{sd} M_d)^{-\sigma} N_s B_s \alpha \Phi_{min(s,d)}^{\sigma-1-\alpha-1} + F_{sd} W_s N_s B_s \alpha \Phi_{min(s,d)}^{-\alpha-1}$$
$$+(M_d - 1) W_s \delta_{sd}^{\sigma} (W_s T_{sd} M_d)^{-\sigma} N_s B_s \alpha \left(-\frac{\Phi_{min(s,d)}^{\sigma-1-\alpha}}{\sigma - 1 - \alpha} \right) \quad \text{(A3.12)}$$
$$* \left[(\sigma - \Gamma_d) P_d^{2\sigma-\Gamma_d-1} * N_s B_s \delta_{sd}^{\sigma} (W_s T_{sd} M_d)^{1-\sigma} \left(\frac{\alpha}{\sigma - 1} \right) \Phi_{min(s,d)}^{\sigma-1-\alpha-1} \right]$$

Dividing through by $W_s N_s B_s \alpha \Phi_{min(s,d)}^{-\alpha-1}$ and using (A3.6), we arrive at

$$0 = -(M_d - 1) Q_d \delta_{sd}^{\sigma} P_d^{\sigma} (W_s T_{sd} M_d)^{-\sigma} \Phi_{min(s,d)}^{\sigma-1} + F_{sd}$$
$$+ (M_d - 1) Q_d \delta_{sd}^{\sigma} (W_s T_{sd} M_d)^{-\sigma} \left(-\frac{\Phi_{min(s,d)}^{\sigma}}{\sigma - 1 - \alpha} \right) \alpha P_d^{2\sigma-1} N_s B_s \delta_{sd}^{\sigma} (W_s T_{sd} M_d)^{1-\sigma} \left(\frac{\sigma - \Gamma_d}{\sigma - 1} \right) \Phi_{min(s,d)}^{\sigma-1-\alpha-1} \quad \text{(A3.13)}$$

Using (T1.1b) and (A2.10) we obtain

$$0 = -(M_d - 1) Q_d \delta_{sd}^{\sigma} P_d^{\sigma} \left(\frac{W_s T_{sd} M_d}{\Phi_{\bullet sd}} \right)^{-\sigma} \beta^{-\sigma} \Phi_{min(s,d)}^{-1} + F_{sd}$$
$$+ (M_d - 1) Q_d \delta_{sd}^{\sigma} \left(\frac{W_s T_{sd} M_d}{\Phi_{\bullet sd}} \right)^{-\sigma} P_d^{2\sigma-1} N_s B_s \delta_{sd}^{\sigma} \left(\frac{W_s T_{sd} M_d}{\Phi_{\bullet sd}} \right)^{1-\sigma} \left(\frac{\sigma - \Gamma_d}{\sigma - 1} \right) \beta^{-\sigma} \Phi_{min(s,d)}^{-\alpha-1} \quad \text{(A3.14)}$$

Substitute from (T1.3a) and (T1.1a):

$$0 = -(M_d - 1) Q_{\bullet sd} \beta^{-\sigma} \Phi_{min(s,d)}^{-1} + F_{sd}$$
$$+ (M_d - 1) Q_{\bullet sd} P_d^{\sigma-1} N_s B_s \delta_{sd}^{\sigma} P_{\bullet sd}^{1-\sigma} \left(\frac{\sigma - \Gamma_d}{\sigma - 1} \right) \beta^{-\sigma} \Phi_{min(s,d)}^{-\alpha-1} \quad \text{(A3.15)}$$

Use (T1.2b):

$$0 = -(M_d - 1) Q_{\bullet sd} \beta^{-\sigma} \Phi_{min(s,d)}^{-1} + F_{sd}$$
$$+ (M_d - 1) Q_{\bullet sd} P_d^{\sigma-1} N_{sd} \delta_{sd}^{\sigma} P_{\bullet sd}^{1-\sigma} \left(\frac{\sigma - \Gamma_d}{\sigma - 1} \right) \beta^{-\sigma} \Phi_{min(s,d)}^{-1} \quad \text{(A3.16)}$$

Now we start introducing values. Substituting from (T1.3b) into (A3.16) gives

$$0 = -(M_d - 1) Q_{\bullet sd} \beta^{-\sigma} \Phi_{min(s,d)}^{-1} + F_{sd} + (M_d - 1) P_d^{\sigma-1} V_{sd} \delta_{sd}^{\sigma} P_{\bullet sd}^{-\sigma} \left(\frac{\sigma - \Gamma_d}{\sigma - 1} \right) \beta^{-\sigma} \Phi_{min(s,d)}^{-1} \quad \text{(A3.17)}$$

Then via (T1.4b) and (T1.3a) we have

$$0 = -(M_d - 1) Q_{min(s,d)} \Phi_{min(s,d)}^{-1} + F_{sd} + (M_d - 1) \frac{V_{sd}}{P_d Q_d} \left(\frac{\sigma - \Gamma_d}{\sigma - 1} \right) Q_{min(s,d)} \Phi_{min(s,d)}^{-1} \quad \text{(A3.18)}$$

which can be written as

$$(M_d - 1)\frac{Q_{min(s,d)}}{\Phi_{min(s,d)}} = \frac{F_{sd}}{\left(1 - \frac{V_{sd}}{P_d Q_d}\left(\frac{\sigma - \Gamma_d}{\sigma - 1}\right)\right)} \quad \text{(A3.19)}$$

This establishes (T1.7e) as the form of the Z factor appearing in (T1.4a).

A4. Preparing the MM model for implementation in GEMPACK

The GEMPACK software[12] can accept equations presented as relationships between levels of variables. However, the software works most conveniently when the equations are presented as linear relationships between percentage-change or change variables where these are deviations from an initial equilibrium.

In this section, we start by converting the MM equations from Table 1 into linear deviation form. Then we show how MM assumptions can be embedded in a standard GEMPACK version of GTAP by closure swaps and the addition of a few equations, with minimal changes to the initial model.

A linear deviation representation of the MM equations

The left column of Table A2 repeats the MM equations from Table 1. Linear deviation versions of these equations, suitable for GEMPACK, are in the centre column. In the left column, variables are depicted as uppercase symbols. In the centre column, we use corresponding lowercase symbols for percentage deviations and "d" for ordinary changes. For example, $p_{\bullet sd}$ is the percentage deviation in $P_{\bullet sd}$, and $d\Pi tot_s$ is the ordinary change in Πtot_s.[13]

For most of the MM equations, the conversion from the left column of Table A2 to the centre column involves straightforward applications of total differentiation (what is sometimes referred to in economics as "hat" algebra).[14] Here we focus on the conversions for (T1.2a), (T1.5) and (T1.6). In the derivation of the linear deviation forms for these equations, we undertake extra steps designed to facilitate the evaluation of coefficients via easily accessed data items such as sales shares.

Derivation of the linear deviation form for (T1.2a)

From MM equation (T1.2a) in the left panel of Table A2, we obtain

$$(1-\sigma)*p_d = \sum_s \left(\frac{N_{sd}\delta_{sd}^{\sigma}P_{\bullet sd}^{1-\sigma}}{\sum_r N_{rd}\delta_{rd}^{\sigma}P_{\bullet rd}^{1-\sigma}}\right)*\left[n_{sd} + (1-\sigma)*p_{\bullet sd}\right] \quad \text{(A4.1)}$$

Using MM equation (T1.3a), we can write the complicated share coefficient on the RHS of (A4.1) as

[12] See Horridge *et al.* (2013, 2018).

[13] We prefer to work in percentage deviations. But for some variables such as profits, this is not possible because their values can pass through zero.

[14] See Jones (1965). For a brief introduction to the derivation of deviation equations for use in GEMPACK, see Dixon *et al.* (2018, box 6.1). This reference also describes how GEMPACK updates the coefficients in the linear deviation equations so that accurate solutions to the initial non-linear model are produced in a multi-step process.

Table A2. MM equations in levels and linear deviation forms

	Levels	Percentage change version suitable for GEMPACK	Role in GEMPACK implementation of MM
(T1.1a)	$P_{\bullet sd} = \left(\frac{W_s T_{sd}}{\Phi_{\bullet sd}}\right) * M_d$	$p_{\bullet sd} = \left(w_s + t_{sd} - \phi_{\bullet sd}\right) + m_d$	Omitted
(T1.1b)	$\Phi_{\bullet sd} = \beta * \Phi_{min(s,d)}$	$\phi_{\bullet sd} = \phi_{min(s,d)}$	Determines $\phi_{\bullet sd}$
(T1.2a)	$P_d = \left(\sum_s N_{sd} \delta_{sd}^{\sigma} P_{\bullet sd}^{1-\sigma}\right)^{\frac{1}{(1-\sigma)}}$	$p_d = \sum_s S_{sd} * \left[p_{\bullet sd} - \frac{1}{\sigma - 1} * n_{sd}\right]$	Omitted
(T1.2b)	$N_{sd} = N_s * B_s * \left(\Phi_{min(s,d)}\right)^{-\alpha}$	$n_{sd} = n_s - \alpha * \phi_{min(s,d)}$	Determines n_{sd}
(T1.3a)	$Q_{\bullet sd} = Q_d \delta_{sd}^{\sigma} \left(\frac{P_d}{P_{\bullet sd}}\right)^{\sigma}$	$q_{sd} - n_{sd} = q_d - \sigma * (p_{\bullet sd} - p_d)$	Omitted
(T1.3b)	$V_{sd} = P_{\bullet sd} N_{sd} Q_{\bullet sd}$	$v_{sd} = p_{\bullet sd} + n_{sd} + q_{\bullet sd}$	Omitted
(T1.3c)	$Q_{sd} = N_{sd} Q_{\bullet sd}$	$q_{sd} = n_{sd} + q_{\bullet sd}$	Determines $q_{\bullet sd}$
(T1.4a)	$\left(M_d - 1\right)\left(\frac{Q_{min(s,d)}}{\Phi_{min(s,d)}}\right) - F_{sd} * Z_{sd} = 0$	$\left(\frac{M_d}{M_d - 1}\right) * m_d + q_{min(s,d))} - \phi_{min(s,d))} = z_{sd} + f_{sd}$	Determines $\phi_{min(s,d))}$
(T1.4b)	$Q_{min(s,d)} = Q_{\bullet sd} / \beta^{\sigma}$	$q_{min(s,d)} = q_{\bullet sd}$	Determines $q_{min(s,d)}$

(T1.5)	$\Pi tot_s = \sum_d N_{sd}\left[\frac{W_s}{\Phi_{\bullet sd}} * Q_{\bullet sd} * \left(M_d - 1\right) - W_s * F_{sd}\right] - N_s H_s W_s$	$100 * d\Pi tot_s = \sum_d \left[\left(1 - \frac{1}{M_d}\right)\right] * MARKETV(s,d) * \left(n_{sd} + w_s - \phi_{\bullet sd} + q_{\bullet sd}\right) + \sum_d MARKETV(s,d) * m_d - \sum_d \left(\frac{(M_d - 1)}{M_d \beta^{\sigma-1} Z_{sd}}\right) * MARKETV(s,d) * \left(w_s + n_{sd} + f_{sd}\right) - \sum_d \left[\left(1 - \frac{1}{M_d}\right) - \left(\frac{(M_d - 1)}{M_d \beta^{\sigma-1} Z_{sd}}\right)\right] * MARKETV(s,d) * \left(w_s + n_s + h_s\right) + \Pi tot_s * \left(w_s + n_s + h_s\right)$	Determines $d\Pi tot_s$
(T1.6)	$L_s = \sum_d \frac{N_{sd} Q_{\bullet sd}}{\Phi_{\bullet sd}} + \sum_d N_{sd} F_{sd} + N_s H_s$	$W_s L_s * (w_s + \ell_s) = \sum_d \frac{1}{M_d} * MARKETV(s,d) * \left(w_s + n_{sd} + q_{\bullet sd} - \phi_{\bullet sd}\right) + \sum_d \left(\frac{(M_d - 1)}{M_d \beta^{\sigma-1} Z_{sd}}\right) * MARKETV(s,d) * \left(w_s + n_{sd} + f_{sd}\right) + \sum_d \left[\left(1 - \frac{1}{M_d}\right) - \left(\frac{(M_d - 1)}{M_d \beta^{\sigma-1} Z_{sd}}\right)\right] * MARKETV(s,d) * \left(w_s + n_s + h_s\right) - \Pi tot_s * \left(w_s + n_s + h_s\right)$	Determines ao_s

Add-ons for small group monopolistic competition

(T1.7a)	$M_d = \frac{\Gamma_d}{\Gamma_d - 1}$	$m_d = \frac{-1}{\Gamma_d - 1} * \lambda_d$	Determines m_d
(T1.7b)	$\Gamma_d = \frac{1}{\frac{1}{Ntot_d} + \left(1 - \frac{1}{Ntot_d}\right) * \frac{1}{\sigma}}$	$\lambda_d = \frac{\sigma - 1}{\sigma - 1 + Ntot_d} * ntot_d$	Determines λ_d
(T1.7c)	$Ntot_d = \bar{N}tot_d * \sum_s \bar{S}_{sd} * N_s / \sum_s \bar{S}_{sd} * \bar{N}_s$	$ntot_d = \sum_s \left(\frac{\bar{S}_{sd} * N_s}{\sum_r \bar{S}_{rd} * N_r}\right) * \left(n_s\right)$	Determines $ntot_d$

(T1.7d)	$S_{sd} = \frac{V_{sd}}{P_d Q_d}$	$s_{sd} = v_{sd} - (p_d + q_d)$	Determines s_{sd}
(T1.7e)	$Z_{sd} = 1 \Big/ \left(1 - S_{sd} * \left(\frac{\sigma - \Gamma_d}{\sigma - 1}\right)\right)$	$z_{sd} = \frac{Z_{sd} S_{sd}}{\sigma - 1} * \left[\left(\sigma - \Gamma_d\right) * s_{sd} - \Gamma_d * \lambda_d\right]$	Determines z_{sd}
(T1.7f)	$N_s = \bar{N}_s * \exp\left(\Psi_{1s}\left(\frac{\Pi tot_s}{W_s L_s} - \Psi_{0s}\right)\right)$	$n_s = \frac{\Psi_{1s}}{W_s L_s} * \left[100 * d\Pi tot_s - \Pi tot_s * (w_s + \ell_s)\right] + 100 * \left(\frac{\Pi tot_s}{W_s L_s} - \Psi_{0s}\right) * d\Psi_{1s} - 100 * \Psi_{1s} * d\Psi_{0s}$	Determines n_s

$$\left(\frac{N_{sd}\delta_{sd}^{\sigma}P_{\bullet sd}^{1-\sigma}}{\sum_r N_{rd}\delta_{rd}^{\sigma}P_{\bullet rd}^{1-\sigma}}\right) = \frac{N_{sd}P_{\bullet sd}Q_{\bullet sd}\left(Q_d^{-1}\delta_{sd}^{-\sigma}P_d^{-\sigma}P_{\bullet sd}^{\sigma}\right)\delta_{sd}^{\sigma}P_{\bullet sd}^{-\sigma}}{\sum_r N_{rd}P_{\bullet rd}Q_{\bullet rd}\left(Q_d^{-1}\delta_{rd}^{-\sigma}P_d^{-\sigma}P_{\bullet rd}^{\sigma}\right)\delta_{rd}^{\sigma}P_{\bullet rd}^{-\sigma}} \qquad \text{(A4.2)}$$

Via (T1.3b), the RHS of (A4.2) reduces to $V_{sd}\Big/\sum_r V_{rd}$. From here, we quickly arrive at the linear deviation form for (T1.2a) shown in the centre column of Table A2.

Derivation of the linear deviation form for (T1.6)

We start by multiplying the MM equation (T1.6) through by W_s:

$$W_sL_s = \sum_d \frac{N_{sd}W_sQ_{\bullet sd}}{\Phi_{\bullet sd}} + \sum_d N_{sd}W_sF_{sd} \quad + N_sW_sH_s \qquad \text{(A4.3)}$$

(A4.3) can be presented in linear deviation form as:

$$\begin{aligned} W_sL_s*(w_s+\ell_s) &= \sum_d \frac{N_{sd}W_sQ_{\bullet sd}}{\Phi_{\bullet sd}}*(n_{sd}+w_s+q_{\bullet sd}-\phi_{\bullet sd}) \\ &+\sum_d N_{sd}W_sF_{sd}*(n_{sd}+w_s+f_{sd}) \quad + N_sW_sH_s*(n_s+w_s+h_s) \end{aligned} \qquad \text{(A4.4)}$$

We could stop at (A4.4). However, for setting initial values of coefficients, it is helpful to perform some additional steps.

Using (T1.1a), we see that

$$\frac{N_{sd}W_sQ_{\bullet sd}}{\Phi_{\bullet sd}} = \frac{N_{sd}\ Q_{\bullet sd}P_{\bullet sd}}{T_{\bullet sd}}*\frac{1}{M_d} \qquad \text{(A4.5)}$$

Applying (T1.3b) gives

$$\frac{N_{sd}W_sQ_{\bullet sd}}{\Phi_{\bullet sd}} = \text{MARKETV}(s,d)*\frac{1}{M_d} \qquad \text{(A4.6)}$$

where

$$\text{MARKETV}(s,d) = \frac{V_{sd}}{T_{\bullet sd}} \qquad \text{(A4.7)}$$

MARKETV(s,d) is the factory-door value of the Widget flow from s to d. It excludes transport costs and tariffs which are reflected in $T_{\bullet sd}$.

Using (T1.1a) and (T1.4a) we see that

$$N_{sd}W_sF_{sd} = \frac{N_{sd}Q_{\bullet sd}P_{\bullet sd}}{T_{sd}}*\frac{1}{M_d}*\frac{\Phi_{\bullet sd}}{Q_{\bullet sd}}*\frac{(M_d-1)}{Z_{sd}}*\frac{Q_{min(s,d)}}{\Phi_{min(s,d)}} \qquad \text{(A4.8)}$$

Via (T1.3b), (A4.7), (T1.1b) and (T1.4b), we find that

$$N_{sd}W_sF_{sd} = \text{MARKETV}(s,d)*\frac{(M_d-1)}{M_d\beta^{\sigma-1}Z_{sd}} \qquad \text{(A4.9)}$$

Using (T1.5) together with (A4.5) and (A4.9), we see that

$$N_s W_s H_s = \sum_d MARKETV(s,d) * \frac{(M_d - 1)}{M_d} - \sum_d MARKETV(s,d) * \frac{(M_d - 1)}{M_d \beta^{\sigma-1} Z_{sd}} - \Pi tot_s \qquad (A4.10)$$

Substituting from (A4.6), (A4.9) and (A4.10) into (A4.4) leads to the linear deviation form for (T1.6) given in the centre column of Table A2.

Notice that (A4.6), (A4.9) and (A4.10) reveal the split of revenue [MARKETV(s,d)] from the sd-link:

- the fraction $1/M_d$ covers the cost of producing the Widgets sent on the link;
- the fraction $\frac{(M_d - 1)}{M_d \beta^{\sigma-1} Z_{sd}}$ covers the fixed costs of setting up the link; and
- the remaining fraction, $1 - \frac{1}{M_d} - \frac{(M_d - 1)}{M_d \beta^{\sigma-1} Z_{sd}}$, contributes to covering the fixed costs of setting up Widget firms in s ($N_s H_s W_s$) and to pure profits (Πtot_s).

Understanding this split is helpful in calibrating the model. In choosing starting values (values in the initial equilibrium) for M_d and Z_{sd} and in fixing the values for the parameters underlying β, we can make sure that the implied revenue splits accord with prior judgements.

Derivation of the linear deviation form for (T1.5)

From MM equation (T1.5), we have

$$\begin{aligned} 100 * d\Pi tot_s = & \sum_d \frac{N_{sd} W_s Q_{\bullet sd}}{\Phi_{\bullet sd}} * (M_d - 1)(n_{sd} + w_s + q_{\bullet sd} - \phi_{\bullet sd}) \\ & + \sum_d \frac{N_{sd} W_s Q_{\bullet sd}}{\Phi_{\bullet sd}} * (M_d - 1) * \frac{M_d}{(M_d - 1)} * m_{sd} \\ & - \sum_d N_{sd} W_s F_{sd} * (n_{sd} + w_s + f_{sd}) - N_s W_s H_s * (n_s + w_s + h_s) \end{aligned} \qquad (A4.11)$$

Using (A4.6), (A4.9) and (A4.10), we can re-write (A4.11) in the form shown in the centre column of Table A2 for the linear deviation version of (T1.5)

A5. Making minimal alterations to standard GTAP to accommodate an MM industry

In earlier work[15], we showed how Melitz assumptions can be introduced to GTAP. Our method involves the addition of a few equations with minimal alterations to the core model. Here we describe a similar method for MM.

To simplify the exposition, we continue to assume (as in Table A2) that we are dealing with a model in which (a) labor is the only primary factor; and (b) all agents (firms, households and government) in country d use Widgets from different sources in the same proportions, thus requiring only one Widget-mixer for each country. Although these two simplifications do not apply to standard GTAP, we explain our MM method as though they do. The GEMPACK code that we can supply with this paper copes with both these complications.

[15] See Dixon *et al.* (2018 & 2019). A similar approach is described in Bekkers and Francois (2018).

Starting from standard GTAP, we can create an MM industry by adding the equations from the centre column of Table A2 to the end of the model, but excluding:

(T1.1a), which is an MM specification of the price to Widget users in s of the typical variety from d; and

(T1.2a), (T1.3a) and (T1.3b), which are MM specifications of demands and values in d for Widgets from s.

As shown in the right column of Table A2, we can think of these additional equations as determining all the new variables that are required for an MM industry but which are not part of standard GTAP. The only non-intuitive entry in the third column of Table A2 is ao_s entered against equation (T1.6). This is the percentage change in a shift variable that moves the ratio of output to input in s's Widget industry. As in standard GTAP, it is an all-input-saving technical change. If $ao_s = 10$, then the Widget industry in s can produce any given level of output with 10 per cent less of all inputs. For an MM industry, ao_s moves endogenously to reconcile the determination of total inputs to the Widget industry given by (T1.6) with the GTAP specification in which total input (L_s) is output deflated by total factor productivity (QO_s/AO_s).

But what about the omitted equations: why aren't they added to the end of the GTAP equations along with the other MM equations?

The answer to this question is that standard GTAP already has equations that determine $p_{\bullet sd}$, p_d and q_{sd}. If we simply included (T1.1a), (T1.2a) and (T1.3a) as add-ons to GTAP, they would clash with existing GTAP equations.

With (T1.1a), (T1.2a) and (T1.3a) not appearing explicitly in out model, how can we ensure that they are satisfied?

We do this by adding equations that drive naturally exogenous tax and preference variables. The equations cause the GTAP equations for $p_{\bullet sd}$, p_d and q_{sd} to generate results compatible with (T1.1a), (T1.2a) and (T1.3a). The equations we add are:

$$tx_{sd} = ao_s - \phi_{\bullet sd} + m_d \quad \text{(A5.1)}$$

and

$$aa_{sd} = \frac{1}{(\sigma - 1)} * n_{sd} \quad \text{(A5.2)}$$

In these equations:

tx_{sd} is the percentage change in the power of a tax on the flow of Widgets from s to d (includes s to s). This is charged in country s at the factory door and is included in the market value of the sd flow. tx_{sd} is not part of standard GTAP but it is easily added as a destination-specific shifter in the GTAP specification of export taxes.

ao_s is, as mentioned above, the percentage change in a shift variable that moves the ratio of output to input in s's Widget industry.

aa_{sd} is the percentage change in a shift variable that moves the preferences/technology of the Widget mixer in country s. As in standard GTAP, it is an s-saving change. If $aa_{sd} = 10$, then the mixer who provides composite Widgets to users in d can satisfy any given level of Widget requirements with 10 per cent less Widgets from s while holding Widget purchases from other sources constant.

With (A5.1) and (A5.2), together with the included equations from the centre column of Table A2, appended to the equations of standard GTAP, the excluded equations, [(T1.1a), (T1.2a), (T1.3a)and (T1.3b) are satisfied. This means that standard GTAP extended by the included equations and (A5.1) – (A5.2) produces results consistent with MM theory.

Demonstrating that (T1.1a) is satisfied

In standard GTAP, the percentage change in the price to Widget users in d of Widgets sent from s is given by

$$p_{\bullet sd} = w_s - ao_s + tx_{sd} + t_{sd} \tag{A5.3}$$

In (A5.3), $p_{\bullet sd}$ is determined by the percentage change in the cost of inputs per unit of output in s's Widget industry ($w_s - ao_s$) inflated by the percentage change in the power of the sd tax imposed by country s (tx_{sd}) and further inflated by the percentage change in the power of tariffs and transport costs applying to the sd flow (t_{sd}). With tx_{sd} specified by (A5.1), we obtain the percentage change version of (T1.1a).

Demonstrating that (T1.2a), (T1.3a) and (T1.3b) are satisfied

In standard GTAP, demands in d for Widgets from s are determined by percentage change equations consistent with:

$$q_{sd} + aa_{sd} = q_d - \sigma * \left[(p_{\bullet sd} - aa_{sd}) - p_d \right] \tag{A5.4}$$

$$p_d = \sum_t S_{td} * (p_{\bullet td} - aa_{td}) \tag{A5.5}$$

and

$$v_{sd} = p_{\bullet sd} + q_{sd} \tag{A5.6}$$

Substituting from (A5.2) into (A5.5) gives (T1.2a). Substituting from the percentage change version of (T1.3c) into (A5.6) gives (T1.3b). Substituting from (A5.2) into (A5.4) gives

$$q_{sd} + \frac{1}{(\sigma - 1)} * n_{sd} = q_d - \sigma * \left[(p_{\bullet sd} - \frac{1}{(\sigma - 1)} * n_{sd}) - p_d \right] \tag{A5.7}$$

This simplifies to the percentage change version of (T1.3a).

Who gets the revenue from the destination-specific export taxes?

The base for the artificial tax on the sd-flow that we introduce to achieve MM pricing is MARKETV(s,d)/TX_{sd} where TX_{sd} is the level of the power of the sd tax. MARKETV(s,d) is, as before, the market value of the sd flow, that is payments by Widget users in d for Widgets delivered from s, excluding tariffs and transport costs.

Total tax revenue on the Widget flows from s is given by

$$\mathrm{CollRev}(s) = \sum_d \mathrm{MARKETV}(s,d) - \sum_d \frac{\mathrm{MARKETV}(s,d)}{\mathrm{TX}(s,d)} \tag{A5.8}$$

The first term on the RHS of (A5.8) is the total value of payments to Widget producers in s at the factory door. With the equations of standard GTAP continuing to apply, the second term is the cost of inputs (including production taxes) to the Widget industry in s, that is factory-door revenue excluding factory-door destination-specific taxes. The difference between these two terms is profits (which could be positive or negative). Consequently, it turns out that the artificial destination-specific taxes are returned to Widget producers in s.

We can check the computation of profits by comparing results generated by (T1.5) with those generated by (A5.8).

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