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THE THEORY OF TARIFF RATE QUOTAS:

AN APPLICATION TO THE U.S. SUGAR PROGRAM USING MONASH-USA

by

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The Centre of Policy Studies (COPS) is a research centre at Monash University devoted to quantitative analysis of issues relevant to Australian economic policy.

The Theory of Tariff Rate Quotas: an Application to the U.S. Sugar Program using MONASH-USA

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Abstract

MONASH-USA (also known as USAGE-ITC) is a detailed dynamic general equilibrium model of the U.S. developed by the Centre of Policy Studies in collaboration with the U.S. International Trade Commission. This paper reports on the theoretical developments completed for a project intended to (a) add detail to the industry and commodity classification of the relevant sectors and (b) create a detailed modelling structure for the U.S. trade and industry-support policies that affect these sectors. A secondary theme of the research is the development and application of methods for modelling complementarity relationships in a large-scale general equilibrium framework. Data issues and simulation results are discussed in a second paper.

JEL Classifications: C61, C63, C68, D58, F13, F14, Q13, Q17, Q18.

Keywords: international trade, agricultural policy, sugar, commercial policy, tariff-rate quotas, complementarity relationships, dynamic general equilibrium modelling.

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1 Introduction

This paper addresses the nature of, and interactions between, U.S. sugar and sweetener industry support programs. A theoretical analysis is undertaken, and then used to inform a modelling structure for a large scale general equilibrium model of the United States.

MONASH-USA, also known as USAGE-ITC, is a highly disaggregated, dynamic, computable general equilibrium (CGE) model of the United States developed at the Centre of Policy Studies (CoPS) in collaboration with the U.S. International Trade Commission (USITC). The model distinguishes over 500 industries and commodities, 51 regions (the 50 states plus the District of Columbia), over 700 occupational categories, multiple household categories and disaggregates international trade by the destinations and sources of exports and imports respectively. MONASH-USA is able to run dynamically with either backward-looking (recursive) or forward-looking expectations [or more detail on MONASH-style models, see Dixon and Rimmer (2002)]

In early applications of MONASH at the USITC, concerns were raised about the model's treatment of the sugar industry. The most significant areas of concern were (a) the level of detail captured in the industry and commodity classifications and (b) the theoretical structures underpinning the modelling of industry and trade policies. A program of development and model modification was undertaken to address these issues, the results of which are reported in this paper.

In the first part of the paper, the structure of the U.S. sweetener sector is discussed, as well as the trade and domestic support policies applied to these sectors.

Next, there is a theoretical analysis of the U.S. sugar program, placed in the context of conventional trade analysis under tariff rate quota (TRQ) regimes. This discussion suggests that care is needed in applying broadly defined theoretical norms to real-world policy regimes, and that regime-specific approaches are often required.

Thirdly, a description is provided of the various adjustments made to the model's database and dimensional structure. Some existing dimensions of the database are disaggregated to identify the various stages of sweetener-related agriculture and down-stream milling and refining, as well as the transformation possibilities available at the various stages of these processes (for example, corn-based stock feeds, corn starches and ethanol production as alternatives to wet corn-milling operations). Sugar imports into the U.S. are also disaggregated by source.

In the final section of the paper, a description is provided of the modelling techniques used to capture the various components of the trade and support policies directed at these industries.

2 U.S. Sugar and Corn Industry Policy

2.1 The U.S. Sweetener Sector

2.1.1 Sugar

The U.S. sugar industry is made up of the cane sugar and beet sugar industries. Unlike most sugar-producing nations, the U.S. has the geographical scale, climatic variation and domestic market size to support both types of sugar manufacturing solely for the purpose of supplying domestic consumption. The U.S. is not a direct exporter of sugar, although it does indirectly export sugar through trade in sugar-containing products.

The cane sugar sector can be characterised as comprising three broad sub-sectors,

1. sugar cane farming,
2. sugar cane milling, and
3. cane sugar refining.

Each of these sub-sectors produces a distinct product:

1. Sugar cane farming is an agricultural activity that produces sugar cane;
2. Sugar cane milling is an industrial activity that uses sugar cane as an input and produces raw cane sugar, as well as by-products such as molasses and sugar syrups;
3. Cane sugar refining takes raw cane sugar as an input and produces refined cane sugar.

Sugar cane is grown in Florida, Hawaii, Louisiana and Texas. The U.S. sugar cane crop currently totals around 33 million metric tons per annum, of which about 90 percent is grown in Florida and Louisiana.

The beet sugar sector can be characterised as involving two distinct activities,

1. sugar beet farming, and
2. beet sugar refining,

and two distinct products,

1. sugar beets, and
2. refined beet sugar.

Sugar beet farming regions are categorised by the USDA[1] according to a cost-of-production metric. In no particular order, these regions are

1. Great Lakes (Michigan, Ohio),
2. Upper Midwest (Minnesota and North Dakota),
3. Great Plains (Colorado, Montana, Nebraska, New Mexico, Texas, Wyoming) and
4. Far West (California, Idaho, Oregon, Washington State).

U.S. sugar production in 2004 totalled approximately 7.83 million metric tons raw value (MTRV[2]). This was comprised of 4.25 million MTRV of beet sugar and 3.58 million MTRV of cane sugar. The U.S. sugar industry typically ranks around 4th or 5th in the world by tonnage, depending on the season in question – for example, 2005 is expected to be an unusually low crop year due to the spate of hurricanes that hit Florida in 2004. The U.S. sugar industry generates a variety of products, but the bulk of its revenues are derived from sugar milling and refining. Other production possibilities for the mills and refineries, mostly by-products of sugar milling and refining, include bagasse, molasses, ethyl alcohol, rum, animal feeds, particle board and paper board.

U.S. imports of all sugar products in 2004 totalled 1.56 million MTRV, comprised mostly of raw sugar imports under the TRQ and NAFTA programs of approximately 1.17 million MTRV, rendering the U.S. as the worlds 4th largest importer of raw sugar by tonnage for that year. The balance of the managed import volume is divided between refined sugar, sugar syrups and the indirect importation of sugar in sugar containing products. The management of sugar-containing

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[1] See, for example, any recent issue of '*Sugar and Sweetener Situation and Outlook*', USDA, ERS.

[2] A short ton is 2000 pounds, and a metric ton is 1000kg – so, 1 metric ton equals 1.102311 short tons. "Raw value" refers to a standard measure for sugar that takes into account the two levels of processing in cane sugar compared to the single level in beet sugar. One ton of refined sugar is equivalent to 1.07 tons of sugar, *raw value*.

product importing is also regulated by a TRQ policy, using a complicated set of formulae to calculate the sugar content of imported products, so as to apply quotas on the sugar content itself.

The U.S. sources its imported sugar from 40 countries under the TRQ system, of which the largest suppliers in 2004 were the Dominican Republic, Brazil, the Philippines and Australia.

Sugar cane must be milled soon after harvesting (usually within 72 hours), or the sugar yield decreases as the moist core dries. Similarly, beets must be processed very soon after harvesting in order to avoid a loss of extractable fructose. As a consequence, the agricultural and industrial components of the sugar industry (cane farms and sugar mills, and beet farms and beet-sugar refineries) must be located in relatively close proximity. As a consequence, regional sugar cane and sugar beet markets in the U.S. tend to face low competition from other regions, and cane and beet prices can vary substantially between sugar producing locales - even between districts within states.

Refined cane and beet sugar are chemically indistinct forms of fructose, and in this sense enter the market as a single homogenous product. At the end of the production chain, therefore, refined sugars from the two sectors compete almost purely on price.

The intermediate sugar milling sector of the cane sugar industry is the focus of the sugar program. The transportability of this product makes it most vulnerable to import competition. Raw sugar prices in the U.S. tend to be around 46 cents per kilogram, with the domestic support price under the agricultural loans program for sugar at around 39.6 cents per kilogram. The world sugar price, although historically volatile and variable through a wide range, is currently around 17 cents per kilogram.

2.1.2 Corn

The U.S. corn industry is a major agricultural producer and exporter for the US, with total production in 2004 in excess of 10 billion bushels (around 254 million metric tons[3]). This level of production ranks the U.S. as far-and-away the largest producer of corn in the world, producing around 100 million tons more than the next largest producer (China). Around 50 million metric

[3] A bushel of yellow corn weighs 56 pounds.

tons of U.S. corn is exported annually to a range of countries, with the major destinations for U.S. corn being Japan, Mexico, Taiwan and Egypt.

Most corn grown in the U.S. is yellow corn, a variety not typically grown for direct human consumption purposes (unlike sweet corn). Around 80 percent of the corn crop is used for stock feeds, with the rest going mainly to the production of wet and dry corn-milling products like corn-based sweeteners, corn starches and ethanol. In 2004, the use of corn in the U.S. wet corn-milling sector was divided between these three uses in the following proportions: 45.1 percent to sweeteners, 17.1 percent to starches and 37.8 percent to ethyl/methyl alcohols (mostly ethanol). When dry milling is included, ethyl/methyl alcohol production becomes the major milling product of corn, with total proportions being: 30.1 percent to sweeteners, 10.8 percent to starches, 51.7 percent to alcohols, and 7.4 percent to cereals. The dry corn-milling industry is the largest producer of ethanol in the U.S. – currently, only very small quantities of sugar based ethanol are produced or imported.

The U.S. corn sweetener industry, a sub-sector of the wet corn-milling industry, produces mainly high fructose corn syrups (HFCS), glucose syrups and dextrose. Around 70 percent of corn-sweetener industrial activity is accounted for by HFCS production. Corn sweetener production has expanded rapidly in recent years, and these products now account for around 56 percent of the total sweetener deliveries by-weight to U.S industrial demand and final consumption, having overtaken sugar as the major supplier of sweeteners in recent years. Notably, the U.S. beverage industry has almost entirely moved into using HFCS, while, to a lesser extent, manufacturers of baked goods like breads and cookies have increasingly switched to corn sweeteners for their baking properties.

2.2 The U.S. Sugar Support Program

2.2.1 Background

The current U.S. sugar program is built on the foundation of the Jones-Costigan Act of 1934. This act initiated a program of planned management for the U.S. domestic sugar market that (basically) involved (1) the forecasting of U.S. domestic demand on an annual basis, (2) the use of quotas as a means to formally allocate a proportion of the U.S. market to domestic and foreign suppliers, (3) the creation of marketing allotments (domestic production quotas) and (4) a formal program of acreage management designed to facilitate (3). This policy "template" has formed the basis of U.S. sugar policy ever since, with various revisions and modifications.

The Jones-Costigan Act was replaced with the Sugar Acts of 1937 and 1948, both of which carried the underlying principles of the original legislation right through to the early 1970's. In 1974, the U.S. Congress repealed the Sugar Act of 1948, which lead almost immediately to large spikes in sugar production and a plummeting domestic sugar price. In 1977, Congress passed the Food and Agriculture Act, re-instigating a program of sugar industry support and supply controls, and introducing the first sugar loan program. The Agriculture Act of 1979 added a system of price supports to sugar processors, operating via the loan scheme, and authorising purchases of portions of the sugar supply by federal agencies, aimed at maintaining a stable producer-price and the management of U.S. consumer prices. In application, this was essentially a typical agricultural buffer-stock scheme aimed at price stability and support.

The passing of the Food and Agriculture Act of 1981 saw the loan scheme modified to provide credit on a nonrecourse basis (that is, loans without penalties for delinquency), and was grandfathered essentially unchanged into the Farm Act of 1990. The 1996 Farm act again extended the sugar program, but limited the ability of federal agricultural authorities to intervene in markets and maintain prices above the loan rate (due largely to number of policy developments including U.S. commitments to the WTO and the NAFTA agreement). The 1996 Act also changed the nature of the loans from nonrecourse to recourse subject to the proviso that total sugar imports didn't exceed 1.336 million MTRV. The penalties instigated under the recourse loans scheme were 1 cent per pound for raw cane sugar and 1.072 cents per pound for refined sugar on any forfeiture (see below). Most recently, the 2001 Agricultural Appropriations Act eliminated the TRQ trigger for nonrecourse loans and removed all provision for loans to be granted on a recourse basis.

The two most important components of the current U.S. sugar support program are the loan scheme and the TRQ program.

2.2.2 The Loan Scheme

Under the sugar industry support program, loans are taken out against raw sugar production at the "loan rate" (essentially a support price) with the sugar committed as collateral, *ex ante*, for a maximum term of 9 months. Initially, this loan rate was set at 16.75 cents per pound for raw sugar and 19.7 cents per pound for refined beet sugar, but has since been increased to 18 cents and 22.9 cents per pound, respectively. Loans must be repaid with any interest charges by September 30 in any given year. While cane mills are able to share the interest expense with their growers, beet refineries cannot and, so, must recover the entire interest expense from revenues generated by sugar sales – this in part explains the differences in the loan rates, along with the fact that beet sugar is typically sold at a 2 percent cash discount, as such.

The Commodity Credit Corporation (CCC) administers the loans directly to sugar cane mills and beet sugar refineries, which qualify for the scheme by agreeing to offer sugar cane and sugar beet growers a minimum price for their produce of around 60 percent of the loan rate. As U.S. trade commitments under the WTO and NAFTA guidelines are autonomous to this decision making process, the marketing allotments effectively become the “free variable” in the hands of domestic authorities used as the policy tool, at least in the first instance, to limit the supply of sugar and maintain a target “minimum” price. The intent of the minimum price is to avoid sugar forfeitures, achieved by setting the price sufficiently high to cover the loan rate plus a small margin to account for mill-to-refinery transport costs and other distribution costs (plus, in some instances, location discounts imposed by refiners on mills) in the case of sugar mills, and exactly the loan rate in the case of beet refiners (as there is no second stage to processing and no additional costs are incurred by refiners post-production). Thus, the intention is make it more profitable for sugar mills and beet refineries to sell their output onto the market and repay the loans, rather than to forfeit the crop and retain the funds as a "compensation". Haley (2001) estimates that minimum prices required in 2000 to forestall sugar forfeitures were 19.86 cents per pound for raw cane sugar and 24.78 cents per pound for beet sugar, compared to the loan rates of 18 and 22.9 cents per pound respectively.

2.2.3 The TRQ Program

Under its obligations to the WTO set down in the Uruguay Round Agreement on Agriculture (URAA) of 1994, the U.S. agreed to import a minimum of 1.139 million MTRV of sugar in each marketing year (October to September). This is mostly comprised of raw sugar quotas, but does include a specific allocation of 24,251 MTRV of refined sugar. The allocation of TRQs to the 40 recipient countries occurs on a historical-allocation basis, calculated against the share of each country’s supply to the U.S. during the period 1975-81 when trade in sugar was deemed to be relatively free.

In chapter 17 (heading 1701) of the U.S. Harmonized Tariff Schedule (HTS), the in-quota and over-quota rates applied to sugar, as negotiated under the URAA, are *excise* rates set (in general) at 1.4606 and 33.87 cents per kilogram respectively. The U.S. HTS allows for different rates for special cases, including zero in-quota tariff rates for nations annexed under the Caribbean Basin Economic Recovery Act (CBERA) and those covered by the Generalized System of Preferences

(GSP). These exemptions, in practice, have lead to a situation where most of the 40 nations holding TRQ rights are supplying sugar to the U.S. market free of U.S. duties on in-quota amounts.

Additional quotas over-and-above any allotments under the TRQ program are allocated to Canada and Mexico under NAFTA. Canada supplies small quantities of beet sugar to the U.S. market, while Mexico supplies both refined and raw cane sugar. These quotas are discussed further below.

3 Changing the MONASH-USA Theory to Model Tariff Rate Quotas

3.1 Introduction

The microeconomic foundations of TRQ policies have been well-covered in the literature. However, this literature typically relies on simple, generic frameworks that suppress important details like those evident in the United States sweetener sector policies. Furthermore, generic approaches don't lend themselves readily to welfare analysis. This section addresses and expands the standard approach, with particular reference to the U.S. sugar policy.

3.2 The Microeconomic Foundations of Tariff Rate Quota Policies

In application to agricultural policies, imposed on industries with annual production/cropping cycles and significant lags between production decisions and revenue receipts, industry supply response and the implications of the resulting shifts in market power are important factors. The nature of U.S. sugar supply in a given period differs from that of a 'generic' commodity. A series of diagrammatical analyses is developed below that begin with, and then extend and refine, the conventional approach to TRQs to incorporate the detail of U.S. sugar programs. In the diagrams discussed below, applied tariff rates are *ad-valorem* equivalent unless otherwise noted.

Denote the in-quota and over-quota *ad-valorem* equivalent (see below) tariff rates by t_i and t_o respectively; the quota by Q; imports by M; the world price (in U.S. dollars) by P_w; the U.S. customs-insurance-freight (CIF) price by P_{CIF}; the U.S. landed-duty-paid (LDP) price by P_{LDP} or P_{US}; and the rent per unit (or premium) generated by the quantitative constraint at the sugar quota boundary by ϕ .

Denoting the excise rate (using the in-quota value for this example) by t_i^e, the *ad-valorem* equivalent is determined by recognising that any level of revenue generated by an excise tax has an equivalent value-based rate implied by the equality

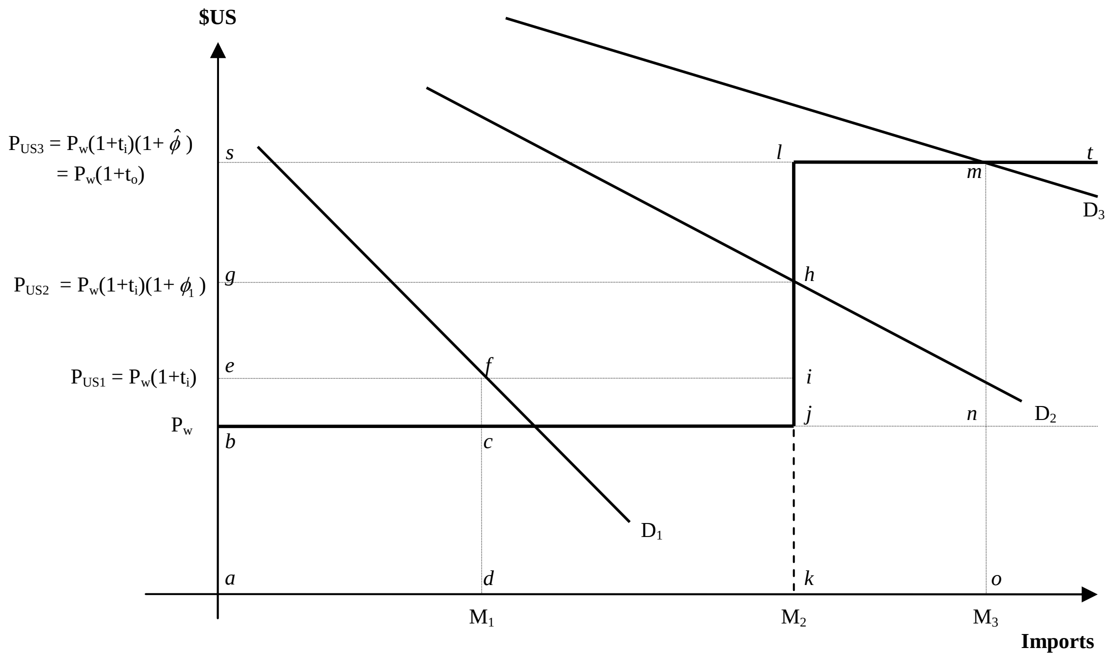
$$t_i^e M = t_i P_{CIF} M \ ,$$

which implies

$$t_i = \frac{t_i^e}{P_{CIF}} \ . \qquad (1)$$

When the ‘powers’ of the tariffs (i.e. the *ad-valorem* tariff rate plus 1) are applied in this paper, this allows the multiplier to be inserted either below or above the rent rectangle in the diagrams when the appropriate price variable - P_{CIF} - is applied in the denominator. The CIF price is equal to the world price plus rents, or from an alternative perspective, the LDP price minus the tariff. Diagrammatically, the tariff-revenue rectangle remains a constant absolute size as either of these prices varies, which is particularly useful in the case of the rent-inclusive CIF price when analysing on-quota imports, or when plotting multiple demand schedules on a single diagram.

Figure 1



Hereafter, the variable $\hat{\phi}$ denotes the maximum value of ϕ. Representing a fairly simple approach to TRQ analysis, figure 1 highlights the important underlying features of this type of trade policy. Three different levels of demand for sugar are plotted in figure 1, given the values of the two *ad-valorem* tariff rates and the sugar quota, to represent in-quota (D_1), on-quota (D_2) and over-quota (D_3) import volumes.

Demand schedule D_1 captures sugar imports occurring at an in-quota level M_1, attracting the in-quota tariff and generating zero rents as the quantity constraint imposed by the quota is not binding. The US CIF price is equal to the U.S-dollar world price, the total CIF value of imports is *abcd*, the LDP value is *aefd*, and tariff revenue is represented by area *befc*. The LDP price – the *basic* price to U.S. agents represented along schedule D_1 - is P_{US1} in this case.

Demand schedule D_2 generates an on-quota level of imports, M_2, equal to the quota Q. As the quantity constraint is binding, a rent accrues to the foreign exporter and the CIF price rises accordingly. Under these circumstances, the CIF value of imports increases to *aghk* minus tariff revenue *eijb*, and now involving a rent captured by area *ghie*. These values are generated by the on-quota level of imports Q, the LDP price P_{US2} (inclusive of a rent and tariff wedge) and a CIF price equal to $P_{US2}/(1+t_i)$. As demand expands, the tariff revenue remains constant and the rents generated by the quantitative restriction expand proportionately with the CIF price - that is, *not* proportionately with the LDP price as the tariff is an excise tax. In this example, excess demand at P_{US1} is generating a per-unit rent of ϕ_1, which is assumed to accrue to the foreign supplier who holds the quota "licence", as is the case in the U.S. sugar program.

In the case of demand schedule D_3, the import volume increases to an over-quota level M_3, the LDP price increases to P_{US3}, the CIF price at the margin *falls* to $P_{US3}/(1+t_o)$ - again equal to P_w – on the over-quota import quantity (M_3-Q). Tariff revenue now comes in two parts – a fixed component given by the in-quota tariff rate t_i and the quota Q (area *eijb*), and a second component determined by the over-quota tariff rate t_o and the level of over-quota imports (M_3-Q) (area *lmnj*). As demand drives the LDP price to reach P_{US3}, the per-unit rent reaches a maximum value of $\hat{\phi}$, but this is only applicable to sugar imported under the quota. Thus, as the volume of imported sugar goes over-quota, the total value of rents has reached a maximum also, given by area *slie*.

How complete is this analysis? Ignore the specific characteristics of sugar production and assume a generic commodity. If the imported good is determined to be readily substitutable for a U.S. variety, the three demand schedules in figure 1 must be interpreted as excess demand schedules. As such, a diagram like figure 1 cannot be used for analysing the affect of trade policies on domestic economic welfare under such circumstances, as it entirely ignores the implications of policy for (a) domestic production of the substitute and (b) overall consumption behaviour. It seems unlikely that a trade policy would be applied to a good that had no domestic substitutes in need of protection and thus, logically, the diagram is incomplete. Figure 2 below addresses some of these issues.

Figure 2

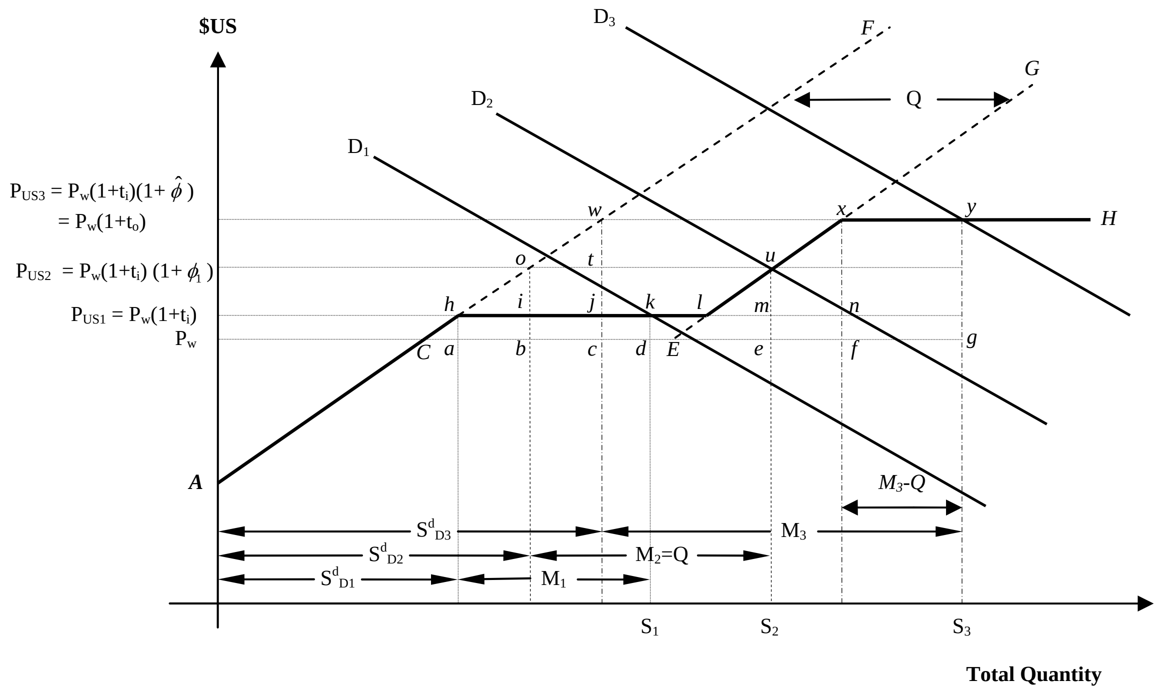


Figure 2 is the underlying market diagram that generates figure 1, drawn using the assumption that a close domestic substitute for the imported good exists.

The demand curves in figure 2 plot the underlying demand schedules that (along with the domestic supply schedule *AF*) generate the excess demand curves plotted in figure 1. It is helpful in reconciling these two diagrams to recognise the following: (1) the curve S^d in figure 2 is equivalent to the vertical axis plotted in figure 1; and (2) the curve *hlxH* in figure 2 is equivalent to curve *bjlt* in figure 1. The "total" supply schedule – the horizontal sum of domestic and foreign supply at every price - is given by line *ACg* in the absence of any trade policies. With the TRQ system in place, line *AhlxH* describes the supply curve, with segment *hlxH* being equivalent to the import-supply curve plotted in figure 1. As a demand schedule is moved to the right and passes through point *l*, imports are restricted by the quota and domestic production responds to the increase in price as excess demand materialises. The increase in the domestic price at the quota boundary is also passed to the foreign supplier of the import quota as a rent, and the supply curve changes as the line segment *hl* slides up the underlying domestic supply curve *AF*. Once demand is sufficient to generate the LDP price P_{US3} at point *x*, buyers are able to purchase as many units of the good as desired from foreign suppliers at this price, equal to the world price P_w plus the over-quota tariff.

As such, a further positive shock to demand must be met by an increase in imports as domestic production has reached a ‘maximum’ at that price. At point *x* and beyond, the line segment that previously represented the quota ceases to “slide” along *AF* and, instead, attaches to point *w* and extends out to the right of the diagram.

Figure 2 lacks the simplicity of figure 1, but therefore includes detail that is subsumed in a figure 1 style diagram that focuses on excess (domestic) demand and imports. A comprehensive welfare analysis using a diagram like figure 2 will be conducted later in the paper. A complete welfare analysis is not possible in figure 1 unless, as mentioned, there is no substitutability between the imported good and a domestic commodity, in which case there would be no “figure 2”. Of most importance, in the event that substitutability *does* exist, is that the domestic supply response is included so that it becomes possible to examine how consumer and (total) producer surplus areas are redistributed by changes in policy variables. For now, a brief interpretation of figure 2 that enables comparisons with figure 1 is provided.

With demand schedule D_1, total supply is found at S_1, comprised of domestic production S^d_{D1} and in-quota imports M_1, and generating tariff revenue *ahkd*. As this level of imports lies below the quota (*hl*) by the amount *kl*, there are no rents generated for the foreign exporter. This was assumed implicitly in figure 1 also. It should be noted that this is not always true – the discussion of the U.S. sugar program below will highlight the circumstances under which this assumption does not hold. For now, keep in mind that the quotas in figure 2 are not interpreted as import commitments by the importer, and that domestic supply is responsive to current market conditions.

Under demand conditions represented by curve D_2, imports have reached the quota boundary and rents are being generated. In this case, the equilibrium levels of total demand and supply occur at S_2, where supply is composed of domestic production S^d_{D2} and imports M_2, equal to the quota (also represented by line segment *ou* in this case). Tariff revenue is given by area *bime*, and rents by *ioum.* Compared to the previous case, this higher level of demand stimulates an increase in domestic output by *hi*, and an increase in (domestic) producer surplus of area *hio* - this is absent from figure 1, as is the change in consumer surplus due to increased consumption of the domestic variety and the transfer of surplus from consumers to domestic producers caused by the price increase (both of which we ignore for now in figure 2).

Demand curve D_3 generates an equilibrium total level of demand and supply at S_3, comprised of domestic output S^d_{D3}, and imports $M_{3,}$ equal to the quota plus over-quota imports (M_3-Q) along line segment *xy*. Total tariff revenue is now a function of two components, (1) imports at the in-quota tariff rate generating revenue *cjnf* on quantity *wx* (i.e. the quota) plus (2) imports at the over-quota tariff rate generating revenue *fxyg* on quantity *xy*. Once the LDP price has reached P_{US3} and the level of imports has exceeded the quota, the total value of rents reaches a maximum value of $r_{max}Q$, captured in figure 2 by area *jwxn*. Compared to the outcome generated by demand schedule D_1, curve D_3 has generated an increase the domestic price from P_{US1} to P_{US3}, and stimulated (1) an increase in domestic output *hj* and (2) domestic producer surplus *hjw*, larger than the case of curve D_2 by *ij* and *ijwo* respectively.

3.3 Tariff Rate Quotas under the U.S. Support Programs

3.3.1 Supply in the U.S. Sugar Industry

The ‘current’ spot price and quantity are measured along the vertical and horizontal axes, respectively, of figures 1 and 2. The implication is that an immediate supply response is possible from all sectors of the market in all situations where the quota is not binding. This assumption is not defendable in the U.S. sugar market.

At the time that sugar enters the market and prices are determined in any given year, that year's level of sugar production is highly inelastic with regard to that year’s sugar price. As discussed in section 2.2 above, the U.S. sugar program involves domestic production quotas – known as “marketing allotments” – and a commodity loan scheme in order to maintain an implicit price floor of approximately 39.6 cents per kilogram (plus a small margin, as discussed above). The program aims to avoid loan default and sugar forfeitures. Given this aim, and in light of the empirical evidence found in historical stock-accumulation data, it seems reasonable to assume that sugar stocks do not systematically accumulate. In administering the program and managing market supply in pursuit of the price floor (i.e. the ‘loan rate’), a forecast is generated for the U.S. total demand for sugar at about this price floor plus a margin for error. The import commitments under WTO obligations are subtracted from this forecast, and the residual determines the level of domestic output required to bring total sugar supply to the level required to achieve and maintain the price floor. The domestic component of total U.S. sugar supply is allocated to the domestic industry in the form of production quotas (i.e. ‘marketing allotments’).

As is the case for many tradable agricultural commodities, sugar production is characterised by long lags between decision making and outcomes. Production decisions are made on the basis of expected prices well before the output is released onto the market and revenue streams are generated. Therefore, other than for the real possibility of over-quota imports from Mexico at the lower NAFTA over-quota tariff rate, sugar supply above the price floor at the time of harvesting is highly inelastic. Supply is also very inelastic below the price floor at this time, as costs are sunk at the time of harvesting and the beginning of the marketing cycle. If the variable costs of growers and millers cannot be covered in the event of extremely low prices, crops may be abandoned and mills run at less than full capacity utilisation or, indeed, left idle – the equivalent of the "shutdown" point of undergraduate microeconomics classes. Some limited supply response is afforded the authorities through the loans scheme, as it is within their power to withhold forfeited sugar from the market if demand forecasts have been too optimistic. A further small degree of supply responsiveness flows from any sugar stock held over from previous years, but the change in these stocks is small on average, implying that their role in the behavioural outcomes that determine the total sugar supply is marginal.

Figure 3

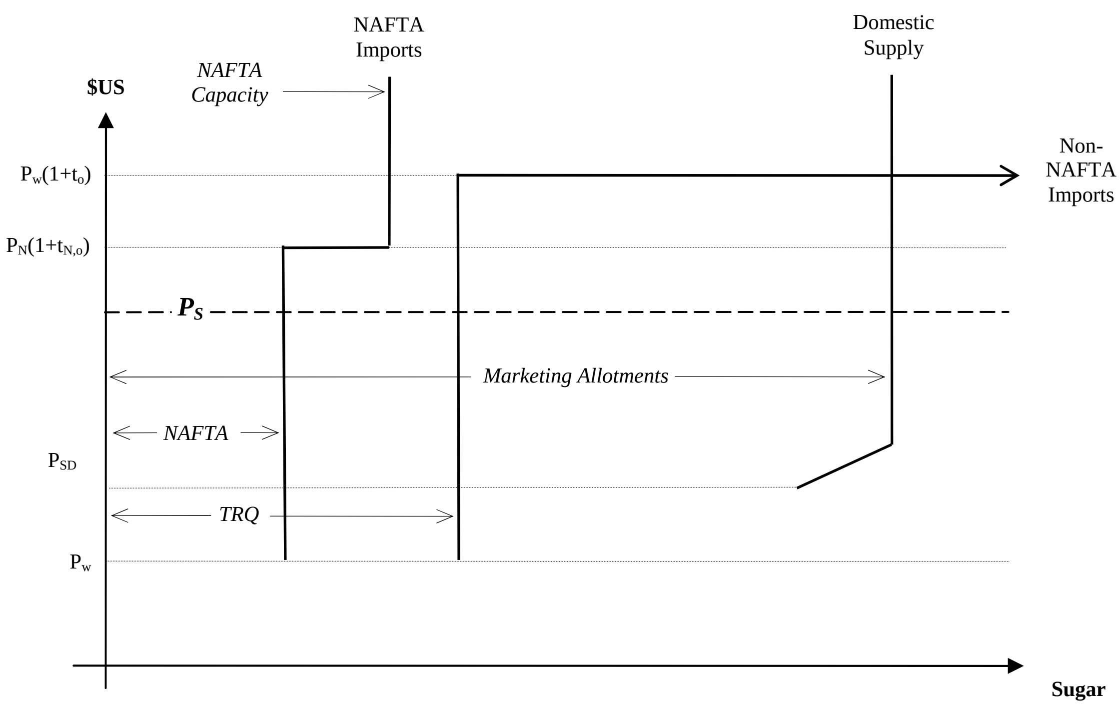


Figure 3 plots the components of total U.S. sugar supply at the time that the marketing cycle begins. As the U.S. WTO commitments are binding at this time, and as the sugarcane has been harvested and sugar mills are processing sugar, domestic supply is rendered highly inelastic at a level equal to the sum of the marketing allotments. As mentioned, very low prices may stimulate crop abandonment and create excess capacity in sugar mills, and therefore - at the limit - supply could potentially fall to zero. This is a situation unlikely to eventuate in reality, as it would require the convergence of large and unlikely errors in the expectations of cane growers, sugar processors and the federal authorities who set the marketing allotments. The domestic supply schedule in figure 3 is drawn to show that U.S. sugar production costs are higher than both the world price (inclusive of the in-quota tariff) and the NAFTA duty-free price. The diagram defines a "shutdown" price P_{SD} for domestic production – at prices slightly higher than this, profits are likely to be negative but some fixed costs can be covered after variable costs have been met, while below it a cane grower or milling firm cannot even cover variable costs.

The TRQ curve plots the U.S. WTO commitments for imported sugar. This amount must be imported under these WTO commitments, and so is autonomous with respect to market spot prices during the marketing cycle. At a domestic price below the tariff inclusive world price, no sugar would be offered for sale by foreign exporters, although, again, WTO commitments in effect oblige the U.S. to purchase this amount at a price no less than the world price.

The NAFTA supply schedule is also drawn as relatively inelastic. Under the NAFTA agreement, Mexico receives an additional quota allocation over-and-above the U.S. WTO obligations. This amount is calculated, on a year-by-year basis, as a function of the estimated Mexican sugar surplus (of production over consumption) up to a maximum amount of 250 thousand metric tons. In practice, the allocation is usually set at a level far below this. The NAFTA curve becomes perfectly elastic at the Mexican over-quota tariff rate (reflecting that Mexican sugar production costs are significantly less than this implied price) and again becomes inelastic at the point that Mexican supply capacity is reached for a given season. The Mexican quota can be filled with any combination of raw and refined sugar: this sugar enters the U.S. market duty-free within the quota allocation and at a relatively low over-quota tariff rate of around 10 cents per kilogram in the event that the quota allocation is exceeded. In most recent years, Mexico has imported more sugar at world prices than it has exported to the U.S. at the U.S. price, effectively making a healthy arbitrage profit on its quota allocation. As the quotas and duties are to be removed in 2008 under NAFTA, this highlights an issue of concern for U.S. trade policy makers. Rules of origin apply currently to combat this type of behaviour, but these rules do not effectively limit the ability of a country to export its own product while consuming imported sugar.

Combining these functions generates the effective U.S. supply curve for sugar in any given year, relating current prices and production, and is plotted in figure 4 below. Note that the two axes in each of figures 3 and 4 are not drawn to scale.

Figure 4

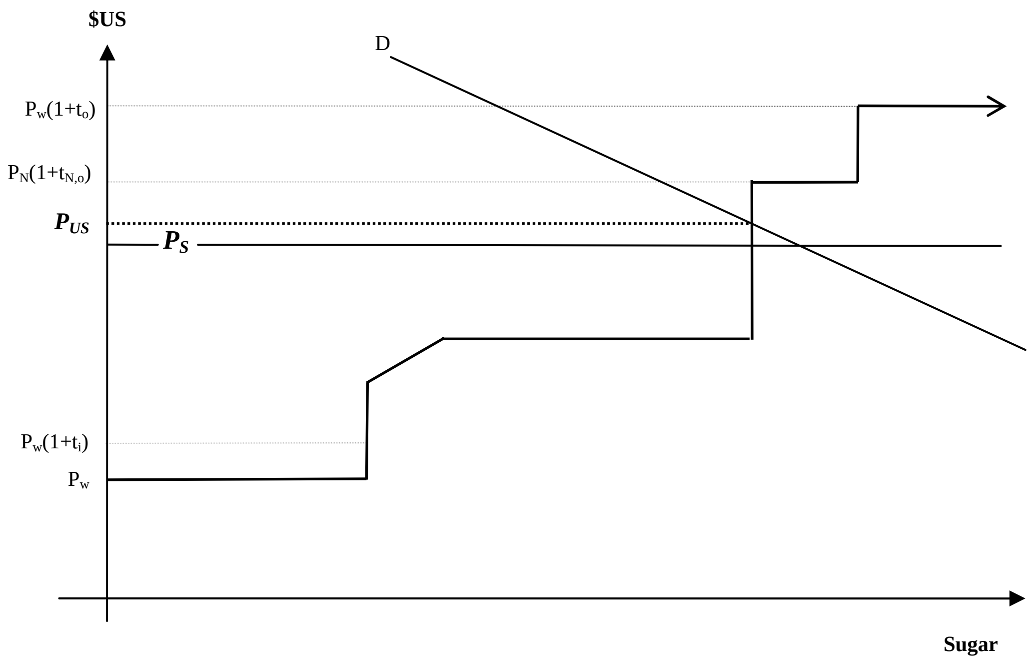


Figure 4 indicates that the supply of sugar in the U.S. during the marketing cycle is highly inelastic throughout a wide range of prices, and only involves some price-responsiveness at very low prices (due to crop abandonment, etc) and at prices sufficiently high to stimulate over-quota imports from Mexico or the rest of the world. This supply curve indicates the opportunity cost of sugar to the various supply-side agents only once the commitment has been made to supply the various quantities, and in this sense is not truly a "supply" function, telling us little or nothing about the underlying resource allocation decisions.

Due to these limitations, it is not possible to conduct a complete behavioural analysis with figure 4. As our interest in economic policy analysis rests on concepts such as allocative-efficiency, redistributive effects, and the behavioural and welfare outcomes of production decisions in the sugar industry (both domestic and foreign), we need to relate the expected market price of sugar to the underlying production functions and the opportunity cost of resources allocated to this use.

Figure 5

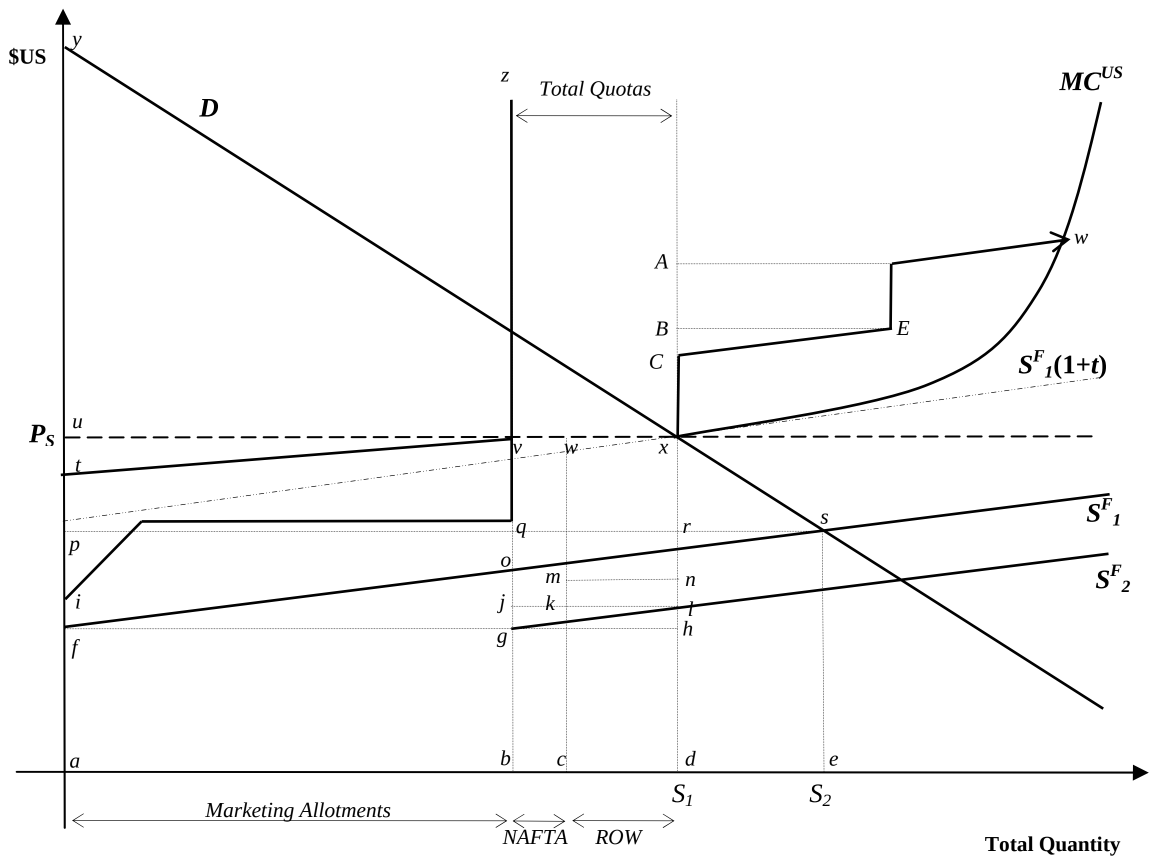


Figure 5 takes some components from figures 2 and 4, along with some pertinent characteristics of the U.S. sugar industry, and combines them to generate a more comprehensive diagram representative of the U.S. market for raw sugar. Domestic production is limited by quotas (marketing allotments) to *ab*, NAFTA (Mexico) is allocated a duty free quota *bc*, and the "rest-of-world" (ROW) is allocated quotas summing *cd*[4]. ROW imports are subject to an in-quota *ad valorem* equivalent tariff rate of *mk*/*kc*, and an over-quota rate of *Al*/*kc*. NAFTA raw sugar can be imported over-quota at an *ad valorem* equivalent rate of *Cl*/*kc*, up to a maximum amount (determined by net capacity in any given year) of *BE*. The diagram assumes that NAFTA and ROW imports are (on average) produced according to the same production function – this is clearly not a defendable assumption, but a relaxation of the assumption changes none of the qualitative

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[4] Note that these quantities are not drawn to scale.

outcomes of the analysis represented here. The foreign supply curve $S^F{}_1$ plots a price-responsive supply of foreign sugar (including NAFTA sugar), reflecting (a) that the U.S. is a major importer of raw sugar and (b) the global capacity constraint in agricultural production in any given year. In order to divert sugar from other buyers on the world market, the U.S. would need to offer a higher price. Foreign supply curve $S^F{}_2$ is simply a horizontal shift of $S^F{}_1$ by the amount of the domestic marketing allotments, and indicates that a CIF price of *ld* would be charged on the quota volume in the absence of the domestic support program. Domestic supply is plotted by curves *iqv* and *xw* (involving a discontinuity across *vx*), produced at a marginal cost determined by the curve *tvx*$\mathrm{MC}^{\mathrm{US}}$ (also with a discontinuity along *vx*).

The diagram is drawn to represent a situation of perfect foresight – the marketing allotments have successfully filled the gap between domestic raw sugar demand and the U.S. import obligations such that the cost of the marginal unit of domestic production is just covered, and there are no incentives for domestic producers to expand output (if they could). This ignores the margin required to cover additional expenses that was discussed above, and so assumes that the loan rate is equal to the trigger price for forfeitures.

Figure 5 suggests that no domestic raw sugar would produced under a free trade regime. Equilibrium output and consumption is determined at S_2 at a price of *se*, generating total expenditure *apse*. Total welfare is given by area *ysf*, of which consumer surplus *xsp* accrues to domestic agents and producer surplus *psf* to foreign producers. This outcome has obvious consequences for 'upstream' cane growers that are not captured in this diagram - however, offsetting this to some degree, it is likely that cheaper raw sugar would induce a demand response from downstream users, and sugar refineries and other end users of raw and refined sugar should see an expansion in their activity in response to lower input costs. This is an example of the type of general equilibrium linkage that MONASH-USA is designed to account for.

Under the current U.S. support program, the supply of sugar S_1 at the support price P_S generates total expenditure *auxd,* a change of *drse* minus *puxr*. Which of these expenditure-change areas is the larger depends on the arc elasticity of demand around line segment *xs*: however, based on the econometric evidence of relatively inelastic raw sugar demand in the U.S, this is likely to stimulate an increase in expenditure[5]. Total economic welfare derived from production and consumption in

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[5] See, for example, Haley (1998).

this market is represented by area *yxlgvt*, comprising consumer surplus *yxu* to domestic consumers, *uvt* in producer surplus to domestic producers, tariff revenue *kmnl* accruing to the domestic government, and some foreign surplus areas. These foreign surplus areas can be divided into *mwxn* in rents to ROW producers, *jvwk* in rents to NAFTA producers, and producer surplus area *jlg* going to both in proportions determined by their share in the total quota, *bc*/*bd* for NAFTA and *cd*/*bc* for ROW (assuming identical production functions). The outcome for foreign producers depends on the relative sizes of (1) the loss in producer surplus from the decrease in volume and (2) the various rent rectangles, while for the U.S. the outcome is an unambiguous loss of total welfare equal to *ptvxs* minus the tariff revenue *kmnl*. The overall welfare loss to the U.S. is a function of the deadweight production-side loss *ptvq* (due to the increased cost of domestic production over foreign acquisition) a deadweight demand-side loss equal to *rxs* (due to the increase in price and reduction in consumption) and a transfer of consumer surplus to foreigners as rents equal to *qvxr*.

The efficacy of a TRQ and support price program can be addressed by a comparison with a tariff-equivalent policy that involves an *ad valorem* tariff sufficient to generate the same price and total volume outcomes. This has been made possible on figure 5 with the addition of a dashed foreign supply curve $S^F_1(1+t)$. The equivalent-tariff case enables the domestic government to internalise all rents available under the TRQ policy in the form of tariff revenue, and in doing so (as the diagram is drawn in this case) stimulate no domestic production increase and associated production-side deadweight losses. Of course, underlying this analysis is the assumption that factor markets will clear and that the domestic resources freed up by import substitution are utilised in more valuable alternative uses. In the presence of wage floors and market frictions (e.g. search costs, information asymmetries, etc) this assumption might be questioned, but it is a well-accepted tenet of economic theory and empirics that trade policy is a poor substitute for labour market programs in pursuing full employment over the medium to long term.

Figure 5 generates some outcomes from the TRQ policy that are not typical of this type of trade analysis. Of significant influence in this matter is that sufficient quantities of foreign-sourced sugar to clear the U.S. market can be supplied at a lower cost than the first unit of domestic production, implying that the domestic industry ceases to exist without trade restrictions. However, this is partly generated by some simplifications, perhaps most importantly the assumption of low price elasticities for import supply across the relevant range. The U.S. is committed to around 1.5 million metric tons of sugar imports out of total global trade in sugar of around 35 million metric tons. This is a relatively small, but not insignificant, part of the total. In the event that the U.S. chose to increase sugar imports significantly, it is likely that capacity constraints (generated by the nature of sugar production) applying to global supply in a given year would see the world spot-price move to divert significant quantities of sugar from other destinations. It is clear, in any case, that the U.S. cane growers and raw sugar milling installations would be adversely affected by a free and open sugar market in the United States. This is not the end of the story for total U.S. economic welfare however, as general equilibrium analyses of such trade policies tend to show.

4 Simulating a Change in U.S. Sugar Policy

4.1 Introduction

The first part of this section provides a brief overview of changes to the structure and database of MONASH-USA. A number of new industries and commodities were added to the model, requiring that some existing industries and commodities were split and redefined. These new components also required that appropriate nesting structures be determined, but this issue is left to the discussion of the model's theory below.

To simulate the U.S. sugar program realistically, it is necessary to impose some inequality constraints (for the TRQ quotas) and apply some discontinuous (and thus non-differentiable) functions (for tariff revenue and quota rents). These relationships can be represented by complementarity functions that relate the values of two or more variables in various states. Generally speaking, applications of general equilibrium models to analyse quantity restrictions on trade such as quotas and TRQs have utilised implicit price premiums as proxies for the required inequality constraints. The GEMPACK software developed at the Centre of Policy Studies by Pearson *et al*, designed to solve very large systems of non-linear equations in general equilibrium models, has recently been enhanced with dedicated sub-routines that enable inequality constraints and discontinuous functions, like those required for complementarities, to be modelled in a theoretically rigorous way. In the second part of this section, the application of these sub-routines and some numerical methods to the modelling of the U.S. sugar market is described.

4.2 Adjustments to the Dimensions of Sets in MONASH-USA

To begin this exposition of the adjustment to MONASH-USA, it is useful to examine the changes that were made to the industry, commodity and regional dimensions of the model. After discussions with various industry groups/lobbyists and several industry analysts from the Office of Industries at the U.S. International Trade Commission, it was decided that the following adjustments would be made to the models dimensional structure.

4.2.1 Changes in Industry Sets

In MONASH-USA prior to this project, the industry dimension contained **513** elements, of which the relevant sectors were:

• I7 Feed Grains	An industry mainly engaged in growing corn, barley, sorghum, and oat crops;
• I13 Sugar Crops	An aggregation of the sugar cane and sugar beet growing industries;
• I75 Wet Corn Milling	An industry that is defined by its processes, but which mainly produces high-fructose corn syrups (HFCS), other corn sweeteners (glucose syrups and dextrose), corn starches, and corn (ethyl) alcohols;
• I79 Sugar	An aggregation of the cane and beet sugar processing industries, producing raw sugar (and by-products) at sugar mills, and refined sugar (and by-products) at sugar refineries.

These four industries have now been expanded and redefined to create **eight** sugar and corn related industries:

• I7 Corn Crops	An industry engaged in the growing of corn crops, which comprised around 80% of the output by volume of the ‘Feed Grains’ industry previously;
• I8 Other Feed Grains	Effectively the residual of the old ‘Feed Grains’ industry, engaged mainly in growing barley, sorghum, and oat crops;
• I14 Sugar Cane	The farming of sugar cane crops;
• I15 Sugar Beets	The farming of sugar beet crops;
• I77 Wet Corn Milling	Essentially as defined before, but now with explicit account taken on the output side for multiple products

		through transformation possibilities imposed by CET transformation functions in the production nests;
•	I81 Raw Sugar Milling	An industry involved mainly in milling sugar cane and producing raw cane sugar, but also by-products such as molasses, brown sugar, and sugar syrups;
•	I82 Cane Sugar Refining	An industry engaged in refining raw cane sugar into refined sugar;
•	I83 Beet Sugar Refining	Like I82, but involves the refining of sugar beets into refined sugar.

These modifications expand the MONASH-USA industry dimension to contain **517** elements.

4.2.2 Changes in Commodity Sets

A similar process is followed for the commodity dimension of MONASH-USA. Of course, the industry and commodity dimensions are closely tied together. Before modification, MONASH-USA accounted for **503** commodities, including:

•	C7 Feed Grains	Corn, barley, sorghum, and oats, produced by the feed grains industry;
•	C13 Sugar crops	Sugar cane and sugar beets, produced by the sugar crops industry;
•	C74 Wet corn milling	An aggregation of HFCS, other corn sweeteners, corn starches, and corn (ethyl) alcohols, produced by the wet milling industry;
•	C78 Sugar	Essentially a composite commodity of all output from the sugar industry other than the agricultural component of production.

These 4 commodities were split into **nine** new commodities:

•	C7 Corn	Only corn, to be produced by the new corn industry;
•	C8 Other feed grains	Barley, sorghum, and oats, to be produced by the new ‘other feed grains’ industry;
•	C14 Sugar cane	Only sugar cane, grown by the sugar cane industry;

•	C15 Sugar beets	Only Sugar beets, produced by the sugar beet industry;
•	C76 Wet milled sweeteners	Corn based sweeteners (HFCS, dextrose, glucose syrups), produced by the wet milling industry;
•	C77 Wet milled other	Corn starches, ethanol, etc produced by the wet milling industry;
•	C81 Raw cane sugar	Raw cane sugar and by products, produced by the raw sugar milling industry
•	C82 Refined cane sugar	Refined cane sugar and by-products, produced by the cane sugar refining industry;
•	C83 Refined beet sugar	Refined beet sugar and by-products, produced by the beet refining industry.

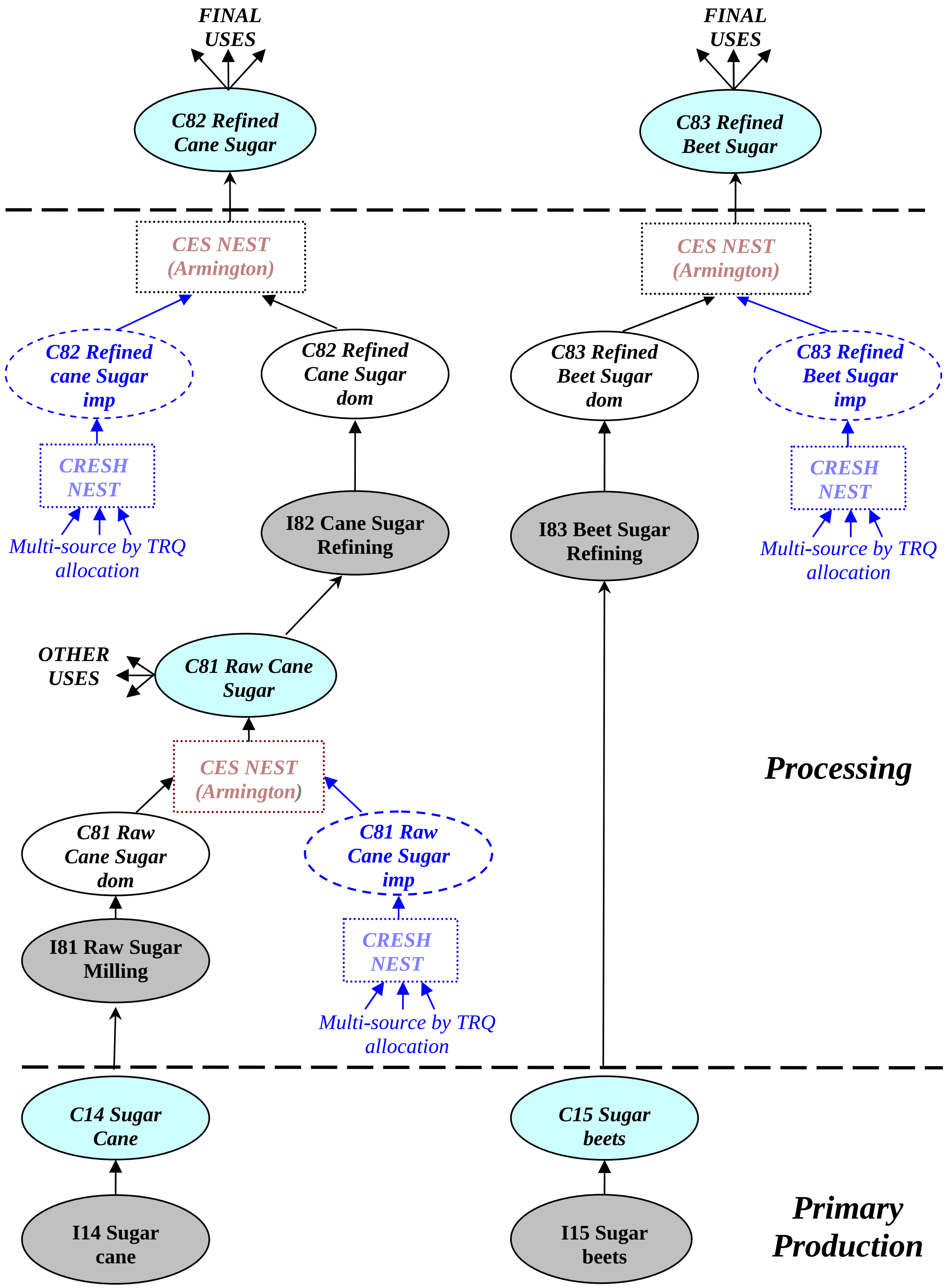
The modified MONASH-USA model now contains a total of **508** commodities.

4.2.3 The Nesting Structure

The following diagrams capture how these new industries and commodities are related in the model's theory.

Firstly, figure 6 provides an overview of the sugar industry in MONASH-USA. The abbreviations *dom* and *imp* referred to the domestic and imported varieties respectively.

Figure 6


FINAL USES
C82 Refined Cane Sugar
FINAL USES
C83 Refined Beet Sugar
CES NEST (Armington)
CES NEST (Armington)
C82 Refined cane Sugar imp
C82 Refined Cane Sugar dom
C83 Refined Beet Sugar dom
C83 Refined Beet Sugar imp
CRESH NEST
CRESH NEST
Multi-source by TRQ allocation
I82 Cane Sugar Refining
I83 Beet Sugar Refining
Multi-source by TRQ allocation
OTHER USES
C81 Raw Cane Sugar
Processing
CES NEST (Armington)
C81 Raw Cane Sugar dom
C81 Raw Cane Sugar imp
I81 Raw Sugar Milling
CRESH NEST
Multi-source by TRQ allocation
C14 Sugar Cane
C15 Sugar beets
I14 Sugar cane
I15 Sugar beets
Primary Production

At the primary production level for cane sugar, the sugar cane growers produce the cane and sell it into the intermediate stage of the sugar processing industry, cane milling. These mills crush and extract the cane juice from the cane, which is boiled and clarified to produce molasses and syrup. These are then put through a crystallization process that creates the sucrose crystals - raw cane sugar crystals. Sugar cane is not imported, as it does not travel well – after 72 hours, sugar cane begins to dry and lose its extractable fructose content. On the other hand, raw cane sugar is a highly transportable, homogenous bulk commodity, and faces significant import competition.

The main intention of the U.S. sugar program is the maintenance of the domestic raw cane sugar industry (and thus also supports the cane growers). Imports of raw sugar are sourced from around 40 countries under the U.S. TRQ program. These are firstly combined in a CRESH nest parameterised with relatively high substitution elasticities. These parameter values are set high in order (a) to ensure that different import regions are treated as supplying a relatively homogeneous and highly substitutable product and (b) to generate the right type of behaviour in the complementarity statements used to model the TRQ program (this is explained in more detail below). The composite imported sugar product that results from this nesting is then combined with the domestic variety in an Armington (CES) nest, again with high substitution elasticities to ensure that the two goods compete almost entirely on the basis of price.

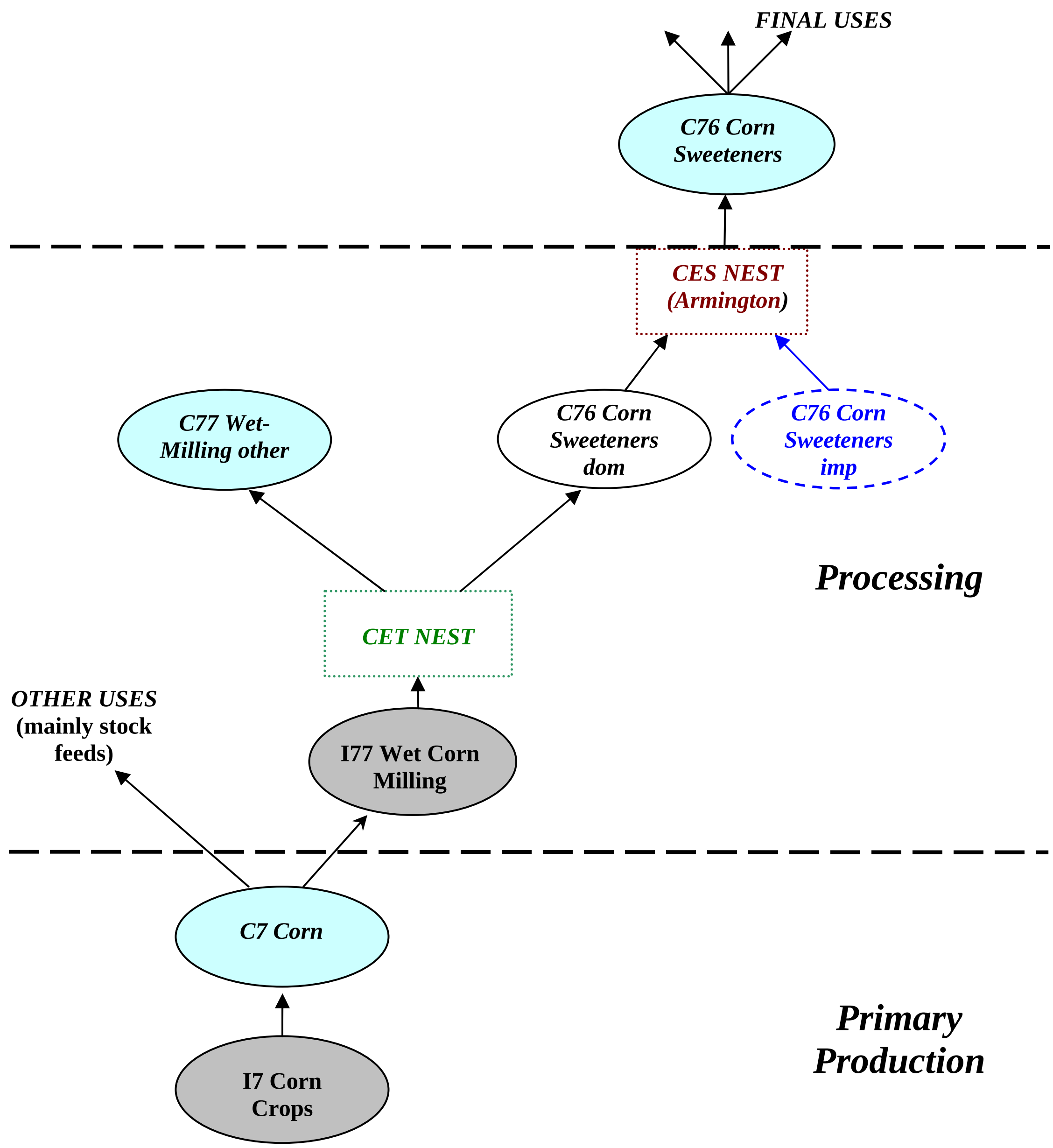
The raw cane sugar composite is sold on to the cane sugar refining industry (which produces refined sugar), to other industries (some food industries, for instance) and to final demand. Sugar refining is a process involving the addition of water to the raw sugar crystals to create a liquid, followed by repeated heating and clarifying and a crystallization process. Small quantities of refined sugar enter the U.S. under the NAFTA and TRQ programs, and these are nested in a CRESH regional nest, and then in an Armington nest with the domestic variety.

At this point it is clear, even from a qualitative perspective, that the fortunes of the refined sugar industry and downstream raw and refined sugar users are not served by the sugar program – from a refiner's or sugar-user's perspective, it simply raises the cost of an input. The lack of complaint from sugar refiners on this issue may hint at the existence of some interesting underlying industry ownership structures, or perhaps at some less formal structures involving effective vertical integration and cost shifting/transfer pricing behaviour.

Sugar beets are produced by the sugar beet growers, and sold directly to the beet sugar refineries – there is no intermediate stage for beet sugar processing. Beets are washed, sliced into ‘chips’ and soaked in water, after which the pulp is leached from the juice. The juice passes through further processing steps, including clarifying and thickening stages, and is finally subject to a crystallization process identical to that used for cane sugar. Small quantities of beet sugar are allowed to enter the U.S under the NAFTA and TRQ programs, but mainly from Canada. These import regions are nested via a CRESH regional nest into an imported composite, and then with the domestic variety in an Armington nest – both again utilising relatively high substitution elasticities.

Figure 7 outlines the structure of the corn industries in MONASH-USA.

Figure 7



The new corn cropping industry in the model grows and harvests corn. The bulk of the U.S. yellow corn crop which is sold to animal feed-stock uses, while a relatively small proportion is sold to the wet milling industry. Wet corn milling plants use the corn to produce a mix of three products – corn sweeteners, corn starches and ethanol – through a CET (constant elasticity of transformation) function.

In recent years, there has been an evident willingness in the wet milling industry to switch production between products based on relative output prices. The USDA's 'Feed Outlook' publications often refer to the fortunes of the corn producers with reference to conditions in the ethanol and corn sweetener markets. This is the rationale for using the multi-product structure for the wet-milling industry, which allows the industry to determine its output mix based on the market prices of the goods it produces.

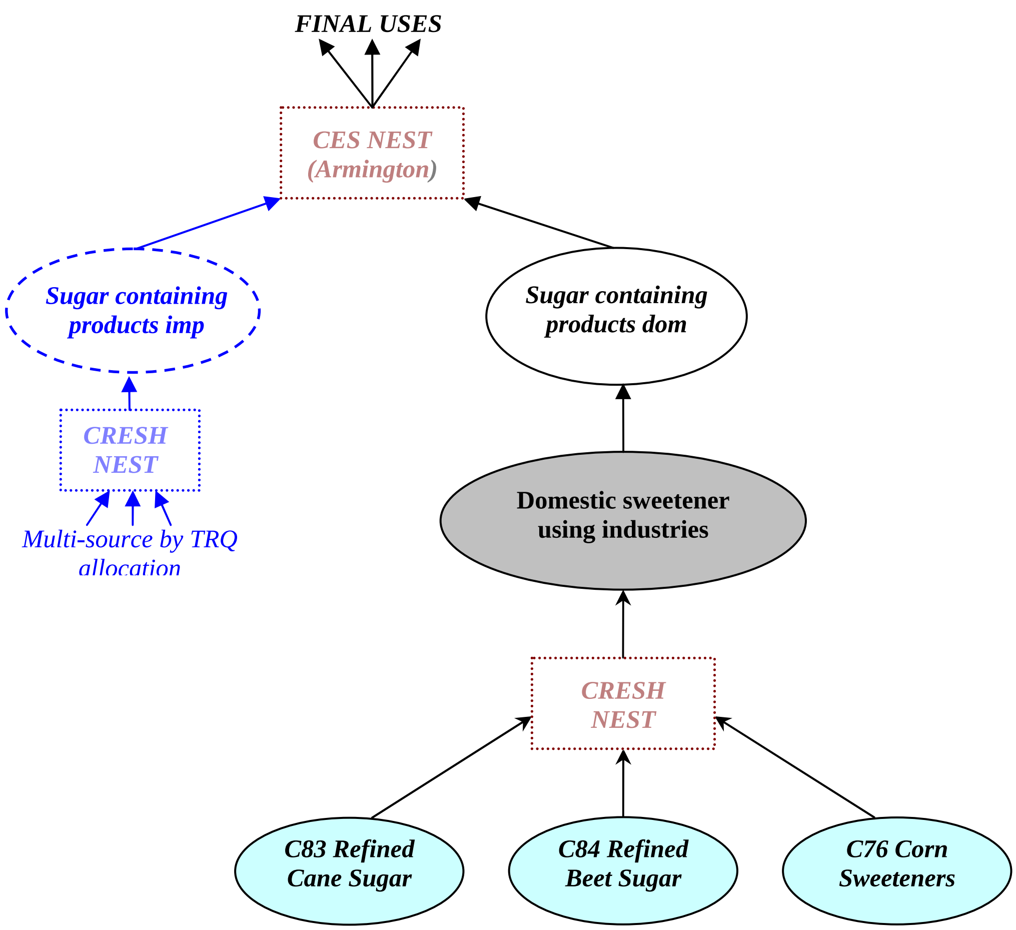
The wet-milling of corn is process distinguished from dry-milling by the soaking of the corn husks in water prior to milling. Corn is steeped and then is sent through a series of processes (grinding, screening, starch-gluten separation, starch conversion and fermentation) that lead (at different stages of this process) to feed products, starches, sweeteners and alcohols.

Currently the model takes account of corn sweetener imports, which are nested Armington-style with the domestic variety before being sold to various end-users. Ironically, the fortunes of firms involved in corn sweetener production are partly dependent on the existence of the sugar program even though they compete with sugar producers in the market for sweeteners. Unit costs for corn sweetener production are falling, but are still significantly higher than the world price of sugar. Thus, although the competition is fierce between the two sweetener products, it is likely that the corn-sweetener industry would suffer substantially if the sugar program was abandoned, as it would be likely to lose much of its market to imported sugar. The corn industry is at pains to point out that the two goods are not close substitutes, in part because they say that industry has changed plant and processes to use HFCS (mainly) and is not able to directly substitute sugar. This is only credible in the very short run, however, as the recent rapid move into HFCS and away from sugar illustrates – there is no reason to assume that a significant fall in the sugar price could not stimulate a reversal of this change in technique for food production. It is clear that producers will be (and have been in the past) willing to bear the large fixed costs of technique adjustment if the return on the alternative plant over time warrants it. This, in fact, is the crux of inter-temporal optimisation behaviour that underpins neo-classical investment theory.

Another argument used by the corn lobby, and heard by the author from several sources, rests on the claim that variable costs in the wet-milling industry are very low (around 8 cents per pound). The argument continues to suggest it is unlikely that the domestic CIF price for sugar would ever fall to that level, and thus it is unlikely that end-users of sweeteners will ever switch back into sugar and away from corn sweeteners in response to price differentials. This argument shows a partial understanding of microeconomic theory and industrial structure, but not enough of an understanding to make the argument credible. Elementary microeconomic theory shows that output decisions in the short run are made according to the variable cost and revenue functions. This is the essence of the industry's own argument - as long as the variable cost of HFCS production is lower than the price of imported sugar, there will be no substitution away from HFCS. However, while this is potentially true in the short run, the large fixed costs evident in the industry’s cost structure renders it likely that firms are making losses on HFCS production on prices far higher than 8 cents per pound. In the very short run in the presence of effectively fixed primary factor usage (capital and land), it might well be true that firms continue to produce when sugar prices fall below (say) 10 cents per pound, as they might be covering some of the fixed costs of production. In the long run, however, these firms will move their capital into uses that provide positive returns.

Figure 8 below provides a basic outline of the way that these sugar and corn sweetener products enter their markets, and then brings them together via their use in the production of other commodities with the TRQ program on sugar-containing products.

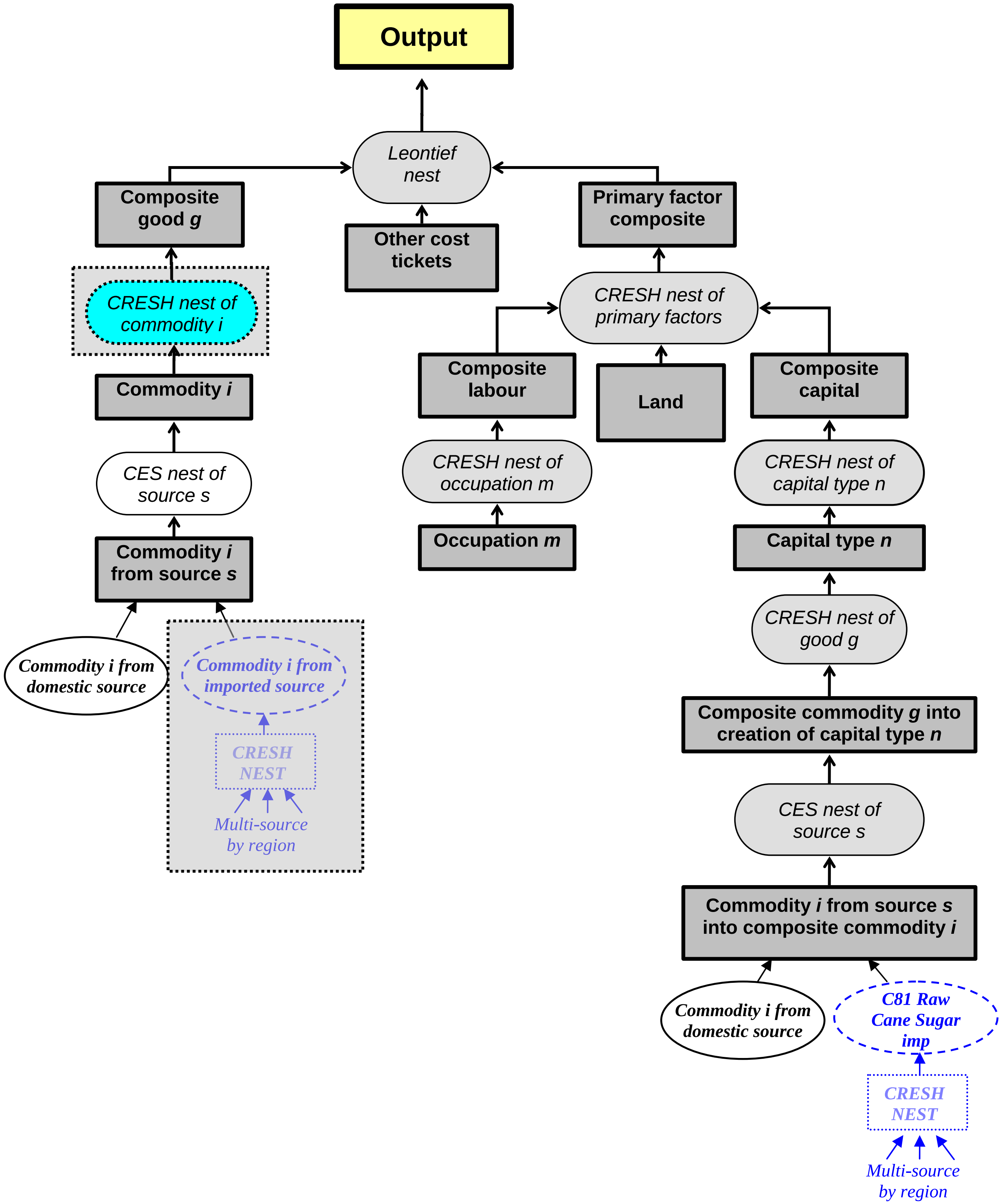
Figure 8



The U.S. sugar support program reaches down through the production chain into the final demand for sugar and other sweeteners. Imported products that contain sugar are analysed for sugar content, and then duties are applied on the basis of the sugar they contain. A TRQ program is used to administer these duties, with the intention of limiting the ability of final users of sugar containing products to implicitly substitute into 'foreign sugar' by sourcing products that contain it. This also provides some protection for the corn sweetener industry indirectly, as it also limits the downstream competition for their products. At the time of writing, this particular arm of the TRQ program is still being refined in MONASH-USA, mainly due to the limitations on data availability and the complexity involved in generating accurate duties for the various sugar-containing products under the MONASH-USA commodity classifications. The nesting of the imported products by region is identical in structure to that for sugar and corn sweeteners, and a final composite enters the model for downstream use.

The CRESH nest that combines the sweetener products was facilitated by adding an extra level of nesting to the MONASH-USA production structure. This is not an insignificant change, and is worth briefly discussing. Figure 9 below outlines the production structure of MONASH-USA and highlights the additional level of the intermediate goods nest:

Figure 9


Output
Leontief nest
Composite good g
Other cost tickets
Primary factor composite
CRESH nest of commodity i
CRESH nest of primary factors
Commodity i
Composite labour
Land
Composite capital
CES nest of source s
CRESH nest of occupation m
CRESH nest of capital type n
Commodity i from source s
Occupation m
Capital type n
CRESH nest of good g
Commodity i from domestic source
Commodity i from imported source
CRESH NEST
Multi-source by region
Composite commodity g into creation of capital type n
CES nest of source s
Commodity i from source s into composite commodity i
Commodity i from domestic source
C81 Raw Cane Sugar imp
CRESH NEST
Multi-source by region

The MONASH-USA production nest is a multi-level nested function of labour, capital, land, intermediate goods and “other cost tickets” (i.e. costs not explicitly modelled in MONASH-USA with behavioural functions - for example, the costs associated with holding inventories). In previous versions of MONASH-USA, the intermediate usage of goods was modelled as a three-stage nest: imported commodities were CRESH nested by region; then an Armington (CES) nest of the domestic and foreign sources was applied, and thirdly, the resulting vector of composite intermediate goods was utilised in fixed proportions that are pre-determined by technology (effectively, a Leontief nest). To allow for the alternative sweeteners to be substitutable in production, MONASH-USA now applies a CRESH nest to the vector of intermediate good composites prior to entering the final level of the production function. As of the time of writing, the array of substitution elasticities in the database contains all zeros except for refined cane sugar, refined beet sugar and corn sweeteners. The non-zero elasticities are applied only in cases where all three are used by an industry. With the CRESH nest in place, it would be possible to fill this array of 262,636 cells with individual estimated elasticity values, but in most cases we would expect that these substitution elasticities would be quite small as technological and technique-related considerations will largely determine the input choice for most industries as regards intermediate commodity usage.

4.3 A Generalised Complementarity Relationship

This section is a brief summary of elements of chapter 16 in GEMPACK documentation, and readers are referred to this text or Harrison *et al* (2002) for more detail. It is presented to provide some background and to aid in the understanding of the complementarity relationships developed for MONASH-USA below.

Complementarity relationships describe the values that a variable can take when some other condition – perhaps an expression – is observed to take one of a set of possible states. Denote the ‘complementarity variable’ by *X*, the ‘complementarity expression’ by *EXP*, and lower and upper bounds on *X* by *L* and *U* respectively. Mathematically, a generalised complementarity relationship takes the form

$$L <= X <= U \quad \perp \quad EXP \, , \tag{2}$$

which is notation for the set of relationships

Either	$X = L$	*and*	$EXP > 0$	[state 1]
or	$L < X < U$	*and*	$EXP = 0$	[state 2]
or	$X = U$	*and*	$EXP < 0$.	[state 3]

This three-state complementarity can also take the form of one of a pair of two-state relationships [which are really special cases of (2)] with either (a) a single lower bound, where

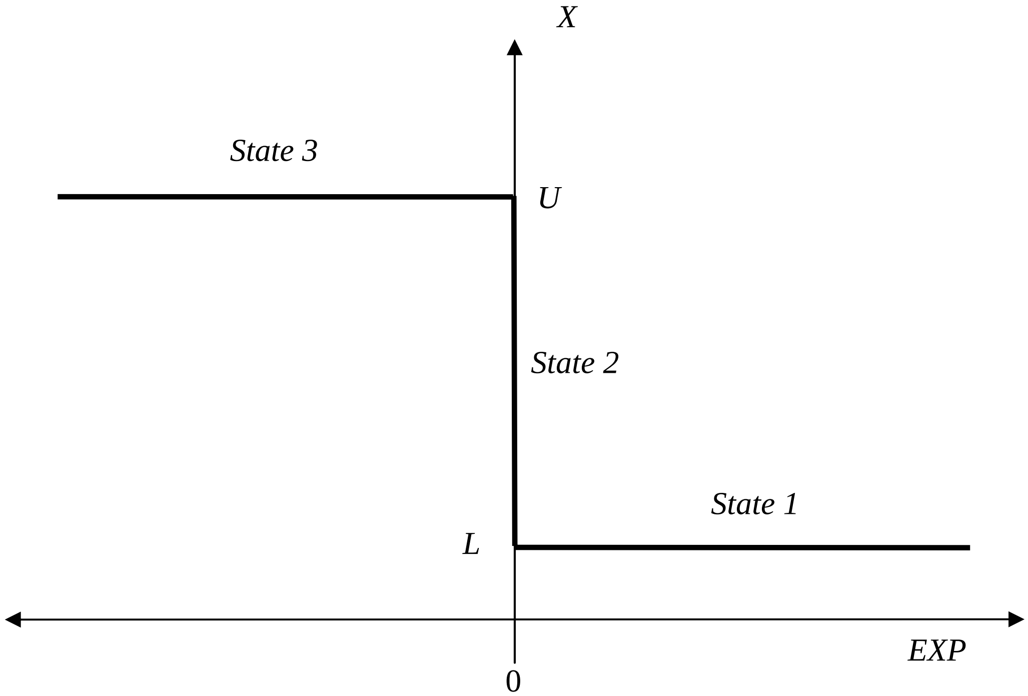
Either	$X = L$	*and*	$EXP > 0$	[state 1]
or	$X > L$	*and*	$EXP = 0$	[state 2]

or (b) a single upper bound, where

Either	$X < U$	*and*	$EXP = 0$	[state 2]
or	$X = U$	*and*	$EXP < 0$.	[state 3].

These relationships can be summarised diagrammatically as follows:

Figure 10



The two-state complementarity relationships are represented on figure 10 by simply removing *state 3* and *U* for the lower-bound-only case, and *state 1* and *L* for the upper-bound-only case.

Two of the applications below (for calculating the total value of quota rents and tariff revenue under the TRQ regime) utilise another characteristic of complementarities that is worth briefly describing here. Generally, a complementarity with a single bound (a dual-state complementarity) can be expressed as a MAX (maximum) or MIN (minimum) expression. A complementarity with only a lower bound can be stated as

Either	$X - L = 0$	*and*	$EXP > 0$	[state 1]
or	$X - L > 0$	*and*	$EXP = 0$,	[state 2]

which is the same as

$$MIN\left(X - L, EXP\right) = 0 \,, \tag{3}$$

and for the upper bound case, by the same logic, we can reformulate and restate the relationship by

$$\begin{array}{lllll} Either & X - U <= 0 & and & EXP = 0 & \text{[state 2]} \\ or & X - U = 0 & and & EXP < 0\,. & \text{[state 3]} \end{array}$$

and

$$MAX\left(X - L, EXP\right) = 0\,. \tag{4}$$

In our application to the modelling of the U.S. sugar sector in MONASH-USA, all three complementarity types are utilised.

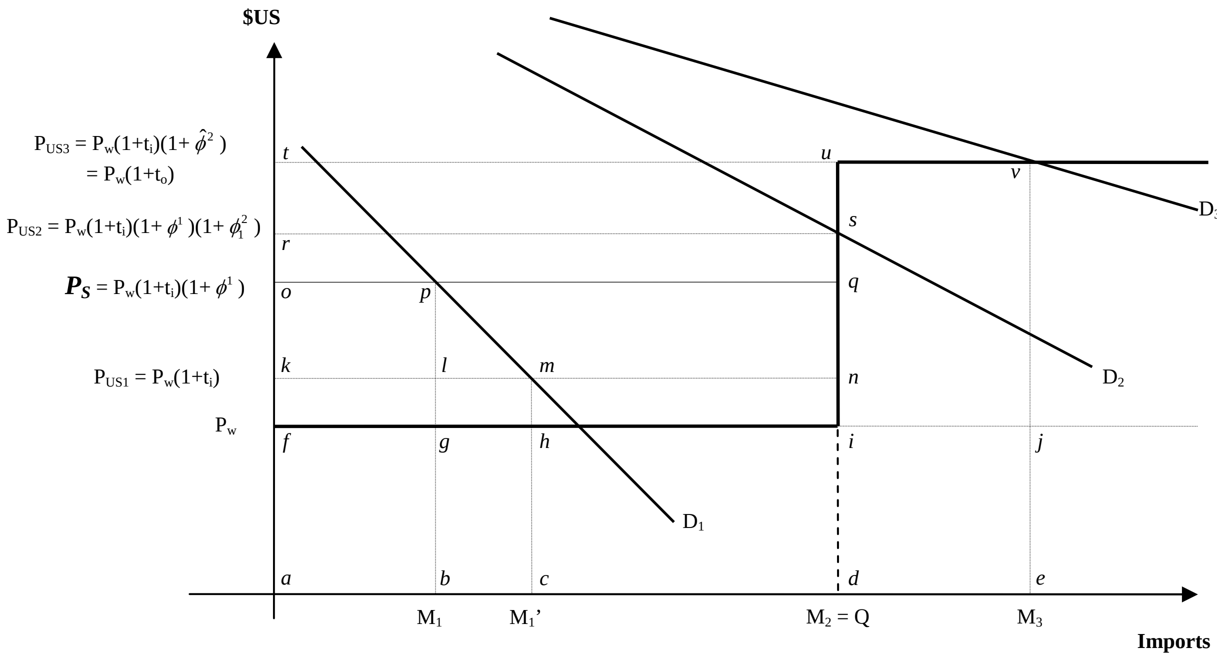
4.4 The MONASH-USA Theory of the U.S. Sweetener Sector

4.4.1 Introduction

The methodology described in this section is an extension of earlier work by Elbehri and Pearson (2000) and (particularly) Harrison *et al* (2002). The underlying method used for the modelling of complementarities also owes much to Ken Pearson, Mark Horridge and Jill Harrison, although the current paper mainly describes some extensions developed during the current project. In one sense, the differences between the former studies and the model described here are analogous to the differences between figures 1 and 5 above.

One extension is applied mainly as a result of the U.S. domestic support program, and would be true in many other examples of tradable commodities related by production to agricultural crops. In this study, the rents generated under the U.S. policies are divided into two components – a “first tier” rent per unit related to the support price, and a “second tier” rent per unit generated by the quantity constraint at the quota boundary. An import diagram like figure 1, but slightly modified, can highlight these concepts.

Figure 11



In contrast to figure 1, the rents described in figure 11 involve three types of per-unit rent variable, denoted ϕ^1, ϕ^2 and $\hat{\phi}^2$, and a support price, denoted P_s. Variable ϕ^1 represents the rent on a unit of sugar due to the support price (or "first-tier" rent), ϕ^2 denotes a variable rent per-unit caused by the quota boundary (or "second-tier" rent), and $\hat{\phi}^2$ now represents the maximum value of ϕ^2 specifically.

The underlying theory of a TRQ captured in figure 11 differs slightly from that in figure 1. This is due to a number of sugar-industry specifics, and also some differences between the theoretical bases of a model like that detailed in figure 1 and the model described in this paper. Briefly, these differences stem from:

1. The existence of the loans scheme and support price;
2. the existence of the domestic marketing allotments;
3. the obligation to import imposed on the U.S. by its WTO commitments;
4. the multi-source commitments imbedded in the TRQ quota allocations;

5. the lag between production decisions for growers and the setting of price in the final market for their product;
6. the implied lack of a domestic substitute for the imported good, and
7. the administration of U.S. TRQ quota allocation by proportional historical allocation.

These points combine to create two important outcomes for an analysis of the sugar and other sweetener industries:

1. During the marketing cycle, the distribution of market power heavily favours the foreigner supplier, and (therefore)
2. foreign suppliers accrue rents on all in-quota units of supply, even if they do not reach the quota boundary.

Let’s revisit the U.S. loans scheme again for an explanation.

The trade restrictions imposed by the TRQ program do not constitute a stand-alone policy, and should not be viewed as such. Rather, they form a component of the overall domestic sugar-sector support program. The U.S. sets a support price that, in effect, guarantees cane growers and millers a minimum return on their activity (given input costs and technology) and which, because of the forfeiture clause, acts much like a classic buffer-stock scheme. Sugar stocks can be ignored when looking at systematic producer behaviour, as they tend not to accumulate in a systematic way and (generally) must be released onto the market in the following year as part of the domestic supply quota. The demand function for sugar (and its arguments) are autonomous from the perspective of the U.S. price setting authority and so, given (a) a demand function and (b) a target price floor, the authority must control supply to achieve it’s aims. The world price of sugar is much lower than the support price set in the U.S, a thus trade policy aimed at imposing quantitative restrictions on imports must be a component of the overall support program. However, because the U.S. commitments under the WTO require that a certain quantity of imports be allowed to enter the U.S. market, the free variable in the hands of the authorities’ is the domestic level of supply.

Assume that the various quantities have been determined, and cane is ready for harvesting. At this point, supply to the U.S. market is very inelastic (as discussed in regard to figures 3 and 4). Foreign suppliers can potentially move the domestic price by restricting supply and sending their sugar elsewhere: domestic producers do not export sugar, foreign producers have alternative markets for their product and know that the U.S. has obligations that require it to import sugar, and also know that these obligations are country specific (as they entrenched in the *ex ante* U.S. TRQ quota allocations). Foreign sugar producers would certainly receive a lower price in other markets, but they also face a quite inelastic demand schedule in the U.S, so their potential net revenue position after a redirection of their exports is unclear. Politics is also an important issue in relation to foreign supplier behaviour, as thumbing their noses at the U.S. supply controls may jeopardise their future TRQ allocations, and so a game of strategy (in the economic sense) is being played out.

An important implication of the structure of the U.S. sugar program is that foreign suppliers accrue rents on all units of U.S. sugar imports up to the quota boundary even if they do not reach the constraint. Thus, if one foreign supplier delivers less than their total quota allocation, they still receive the U.S. market price of at least P_S (and probably more).

In figure 11, the current U.S. situation is depicted by demand curve 2, but the three demand curves of figure 1 are again applied for comparative purposes.

With demand curve D_1, imports are at an in-quota level M_1, generating tariff revenue *fklg* and creating total rents at the support price of *kopl*. The *ad-valorem* equivalent tariff rate is a function of the CIF price of imports, which in this example is equal to the LDP price (P_S for D_1) minus the tariff, or *pb* minus *lg*. In figure 1, D_1 generated an outcome measured against import quantity M_1' and LDP price P_{US1}, involving more tariff revenue (by area *lghm*) and zero rents. The support price is responsible for a deadweight loss equal to area *plm*.

Given demand schedule D_2, the level of demand is sufficient to fill the quota and generate a second-tier rent above the support price at a market price of P_{US2}. Tariff revenue reaches an in-quota maximum of *fkni* while the total rent *krsn* is now comprised of two parts; the maximum possible first-tier rent *koqn* plus a second-tier rent of *orsq*. In MONASH-USA, the two rents are modelled separately, with the second-tier taking the form of a complementarity, and as the value of *total* rents is determined by (in the language of Pearson) a "piece-wise linear function" (explained below), these are modelled using a technique that relies on the MAX and MIN equivalency of complementarity relationships. The outcome under demand curve D_2 in figure 11 is identical to that in shown in figure 1 except for the slightly different interpretation of some of the 'rectangles'.

Demand schedule D_3 is not affected by the different focus taken here.

Point 7 above (quota administration by proportional historical allocation) raises an issue that can potentially lead to errors in the modelling of policies like the U.S. sugar support program if it not addressed. In a more general approach like that in Pearson and Elbehri (2000), import source countries are implicitly treated as distinct suppliers for trade quantities up to and including the quota level. As such, a particular foreign supplier could potentially supply an in-quota level of the product and not accrue rents while a different supplier is on the quota boundary and does accrue rents. This means that the two sources of supply are treated as heterogenous, comprising distinct commodities that cannot be easily substituted for one another.

This implied heterogeneity raises a problem in logic, which can be understood by considering the following thought experiment. Take a multi-country TRQ allocation like that in the U.S, and assume that there are only two suppliers. Suppose that supplier 1 – let's say Brazil – is supplying an on-quota level of the product and deriving rents, while supplier 2 - let's call this one Australia - is supplying an in-quota quantity and is receiving the world price. Let's also assume that supplier 2 is supplying 10 metric tons less than its quota allocation. From the U.S. perspective, this is clearly a sub-optimal outcome that can be improved by reducing imports from Brazil by (let's say) 5 metric tons and increasing imports from Australia by 5 metric tons. By doing so, the total level of import supply does not change, but all sugar is imported at in-quota levels within the TRQ allocations, at therefore at the world price - saving the U.S. the value of the rents it formerly paid to Brazil. This adds to the argument, made above, that all sugar imports must enter the U.S. at the same price, regardless of whether or not a particular foreign supplier is filling its quota allocation, as the alternative raises errors in logic and suggests outcomes that fly in the face of the empirical evidence.

4.4.2 Simulating the Sugar Program in MONASH-USA

This section describes the core of the application of the TRQ theory discussion above to MONASH-USA. The commodity and industry set dimensions are suppressed in the exposition to avoid unnecessary clutter and confusion. It is worthwhile remembering that the relevant equations are applied to variables that are defined across the new set TRQCOM in MONASH-USA, which includes (at the time of writing) raw sugar, refined beet sugar and refined cane sugar. Using this approach (i.e. defining a subset of COM to which these expressions can be supplied) allows other TRQ commodities to be added to the model simply by changing the domain of the set TRQCOM and adding the appropriate data. Plans are already in place to add dairy, beef and other U.S. commodities governed by TRQs to this commodity subset.

We'll start by looking at some definitions.

The first-tier rent is the rent attributable to the support price. The rate of the rent generated by imports from region *r* is given by the gap between the support price P_s and the U.S. dollar marginal cost of sugar production in region *r*, denoted $MC^{dc,r}$ (with the superscript 'dc' referring to 'domestic currency'), measured as a proportion *of* $MC^{dc,r}$,

$$\phi^{1,r} = \frac{P_s - MC^{dc,r}}{MC^{dc,r}}. \qquad (5)$$

This formulation can be numerically inconvenient in a linearised system, and so we apply it as a 'power' (i.e. the rate plus 1),

$$\left(1+\phi^{1,r}\right) = \frac{P_s}{MC^{dc,r}}. \qquad (6)$$

The support price is read from data and treated as a naturally exogenous policy variable. $MC^{dc,r}$ is a function of the foreign currency value of the marginal cost of production in region *r* inflated by a (foreign currency) freight and insurance margin for region *r*, denoted $M_{FI}^{fc,r}$, and deflated by the U.S. exchange rate with region *r*, e^r.

$$MC^{dc,r} = \frac{MC^{fc,r}\left(1+M_{FI}^{fc,r}\right)}{e^r}. \qquad (7)$$

The values of $MC^{fc,r}$ and $M_{FI}^{fc,r}$ are read from data. Depending on the region in question, $MC^{fc,r}$ can vary with the level of import supply in MONASH-USA. The application of a transport margin, amongst other modelling benefits, captures the notion of "economic distance" as opposed to geographical distance. For example, while Australia is comparatively far from the United States, the transport margins on Australian sugar are surprisingly low as shipping route is relatively direct (across the Pacific ocean) and involves the use of large intercontinental bulk carriers that move sugar at a relatively low per unit cost compared to (for example) rail transport from Canada or Central America.

The calculation of the second-tier rent makes use of a complementarity relationship between the quantity of imports and the value of the rent. The method used here owes much to Elbehri and Pearson (2000), but is applied here with some extensions/modifications. The complementarity relationship required for the second-tier rent sets the value of the power of the rent at 1 when imports are in-quota, and at some number between 1 and $\left(1+\hat{\phi}^{2,r}\right)$ when imports are on-quota. Furthermore, when import volumes exceed the quota the value of the rate of the rent is fixed at $\hat{\phi}^{2,r}$. You may notice that this defines a three-state complementarity like that described by expression (2) with an upper bound of $\left(1+\hat{\phi}^{2,r}\right)$ and a lower bound of 1. As the "expression" component of the complementarity relies on its value being "less than", "equal to" or "greater than" zero, and as GEMPACK prefers the absolute value of the components of the complementarity to be between 0 and 5 for numerical reasons, the expression is defined to be

$$EXP = 1 - \left\{ \frac{M^r}{Q^r} \right\}. \tag{8}$$

The value of Q^r and the initial value of M^r are read from data, and the ratio is calculated by formula.

Expression (8) needs to be to be applied with some caution. When import volumes are in-quota, the expression takes a value greater than zero; when on-quota, the expression is equal to zero; and when imports are over-quota, is less than zero. These states all occur at orders of magnitude very likely to be in the right range[6]. However, the danger is that a formulation like (8) can potentially allow (via the complementarity expression) the values of rents and CIF prices for individual regions to move independently of each other if the regional/import-sourcing nesting utilises substitution elasticities between regions (in the relevant CRESH nest) that are too low. This then leads to the situation, discussed above, in which one region could supply imports at an in-quota level and generate no rents, while another is supplying on-quota and does accrue rents. Such an outcome implies that imports from different regions would be entering the U.S. at different CIF prices. This makes no sense for a relatively homogeneous commodity like raw sugar.

The complementarity expression can be reformulated here as

$$1 <= \left(1+\phi^{2,r}\right) <= \left(1+\hat{\phi}^{2,r}\right) \quad \perp \quad \left\{1 - \frac{M^r}{Q^r}\right\} \tag{9}$$

[6] In fact, only when imports are 6 or more times larger than the quota is this violated, which is unlikely to happen while a quota boundary and TRQ policy is in place.

such that

$$\begin{array}{lllll} \textit{Either} & \left(1+\phi^{2,r}\right)=1 & \textit{and} & 1>\dfrac{M^r}{Q^r} & \text{[state 1]} \\ \\ \textit{or} & 1<\left(1+\phi^{2,r}\right)<\left(1+\hat{\phi}^{2,r}\right) & \textit{and} & 1=\dfrac{M^r}{Q^r} & \text{[state 2]} \\ \\ \textit{or} & \left(1+\phi^{2,r}\right)=\left(1+\hat{\phi}^{2,r}\right) & \textit{and} & 1<\dfrac{M^r}{Q^r}. & \text{[state 3]} \end{array}$$

The value of $\left(1+\hat{\phi}^{2,r}\right)$ is a function of the in-quota and over-quota powers of the tariffs. The complementarity could equivalently have been specified using a lower bound of zero and an upper bound of $\hat{\phi}^{2,r}$ for variable $\phi^{2,r}$, but the implementation in MONASH-USA of these relationships uses the powers of the rents. This approach has the advantage of ruling-out a numerical domain that includes zero (which can create numerical solution problems) and allows the variables in the model to be related via multiplicative relationships as, for example, is the case in the definition of $\left(1+\hat{\phi}^{2,r}\right)$ (outlined below).

The actual power of the second-tier rent, $\left(1+\phi^{2,r}\right)$, is calculated by the complementarity expression. As the level of demand for the importable expands while the total import volume is on the quota boundary, the value of $\left(1+\phi^{2,r}\right)$ increases until it reaches $\left(1+\hat{\phi}^{2,r}\right)$. An initial value for $\left(1+\phi^{2,r}\right)$ is read from data. Closure swaps carried out by the complementarity sub-routines in GEMPACK are informed by an initial "complementarity simulation" - basically, the model runs a “preliminary” (but accurate) simulation prior to the "true" simulation, from which it determines the state of the complementarity relationships pre- and post-simulation. For example, if the software "knows" that sugar imports from a particular region start in-quota and end on-quota, the percentage change in imports can be easily deduced prior to running a "true" simulation and can be used as a shock to the (now) exogenously set import volume variable, leaving the model with the task of determining the value of the rent given this information on volume. In the case of a three-state complementarity, states 1 and 3 imply that the premium is known (zero in state 1, equal to $\hat{\phi}^{2,r}$ in state 3) and can be set exogenously while imports must be endogenous; in state 2, the import volume is known (equal to the quota level) and the rent can be calculated endogenously.

The linkages between $\left(1+\phi^{2,r}\right)$ and the rest of the MONASH-USA equation system begin with defining the power of the total rent premium for region *r*, denoted

$$\left(1+\phi^{TOT,r}\right)=\left(1+\phi^{1,r}\right)\left(1+\phi^{2,r}\right) \tag{10}$$

and the CIF price of imports for region *r*,

$$P_{cif}^{r}=P_{s}\left(1+\phi^{2,r}\right). \tag{11}$$

Next, the powers of *ad-valorem*-equivalent rates of the excise tariffs are calculated. Firstly, for the in-quota tariff rate we have

$$\left(1+t_{i}^{e,r}\right)=\left\{1+\frac{t_{i}^{r}}{P_{cif}^{r}}\right\}, \tag{12}$$

and then for the over-quota tariff rate,

$$\left(1+t_{o}^{e,r}\right)=\left\{1+\frac{t_{o}^{r}}{P_{cif}^{r}}\right\}. \tag{13}$$

The value of the upper bound on the complementarity expression for $\left(1+\phi^{2,r}\right)$ can now be defined as

$$\left(1+\hat{\phi}^{2,r}\right)=\frac{\left(1+t_{0}^{e,r}\right)}{\left(1+t_{i}^{e,r}\right)}. \tag{14}$$

Next, the power of the total price-wedge, denoted $\left(1+w^{r}\right)$, is defined by

$$\left(1+w^{r}\right)=\left(1+t_{i}^{e,r}\right)\left(1+\phi^{TOT,r}\right). \tag{15}$$

$\left(1+w^r\right)$ is used to explain the gap between $MC^{dc,r}$ and the basic price of imports to the domestic user. When the level of imports is in-quota, expression (15) becomes

$$\left(1+w^r\right)=\left(1+t_i^{e,r}\right)\left(1+\phi^{1,r}\right), \tag{16}$$

and once imports have started entering the U.S. in over-quota volumes, (16) becomes

$$\left(1+w^r\right)=\left(1+t_i^{e,r}\right)\left(1+\phi^{1,r}\right)\left(1+\hat{\phi}^{2,r}\right). \tag{17}$$

Making use of expression (14), (17) can be re-stated as

$$\left(1+w^r\right)=\left(1+t_0^{e,r}\right)\left(1+\phi^{1,r}\right). \tag{18}$$

Thus, when the model determines that the volume of imports has exceeded the quota, the price wedge between $MC^{dc,r}$ and the landed duty paid price reaches a maximum value.

The basic price of the imported good to the domestic user (the landed duty-paid price) denoted P_{ldp}^r, is

$$P_{ldp}^r=P_{cif}^r\left(1+t_i^{e,r}\right). \tag{19}$$

Combining expressions (6), (11), (14), (15) and the complementarity relationship defining $\left(1+\phi^{2,r}\right)$, the value of P_{ldp}^r can be divided into three potential states:

Firstly, when imports are at in-quota levels, we obtain

$$P_{ldp}^r=MC^{dc,r}\left(1+\phi^{1,r}\right)\left(1+t_i^{e,r}\right)=P_s\left(1+t_i^{e,r}\right); \tag{20}$$

secondly, when the level of imports is at on-quota volumes, we have

$$P_{ldp}^r=MC^{dc,r}\left(1+\phi^{1,r}\right)\left(1+\phi^{2,r}\right)\left(1+t_i^{e,r}\right)=P_s\left(1+\phi^{2,r}\right)\left(1+t_i^{e,r}\right), \tag{21}$$

with $\left(1+\phi^{2,r}\right)$ varying between 1 and $\left(1+\hat{\phi}^{2,r}\right)$;

and, thirdly, when the volume of imports exceeds the quota, the landed duty-paid price becomes

$$P_{ldp}^{r} = MC^{dc,r}\left(1+\phi^{1,r}\right)\left(1+\hat{\phi}^{2,r}\right)\left(1+t_i^{e,r}\right) = P_s\left(1+\hat{\phi}^{2,r}\right)\left(1+t_i^{e,r}\right), \tag{22}$$

which, by again making use of (14), can be re-stated as

$$P_{ldp}^{r} = P_s\left(1+t_0^{e,r}\right). \tag{23}$$

The value of P_{ldp}^{r} is the price variable that enters the CRESH nest determining the choice of regional source, and the higher-level Armington nests that determine the choice of domestic and imported varieties of this good. In our case, with the focus on sugar, both the regional-substitution and Armington elasticities are set relatively high. This ensures that the theory developed in the discussion above is appropriately captured in the model's behaviour; at the regional-source level, a high substitution elasticity ensures (as mentioned briefly above) that when the level of a given region's supply of imports to the U.S. hits the quota boundary, any tendency for an increase in its LDP price via the complementarity expression and $\left(1+\phi^{2,r}\right)$ will cause a large degree of substitution away to other sources that are still at in-quota volumes and, thus, stop the second-tier rent from increasing. In the Armington nest, a high Armington elasticity ensures that the domestic and imported varieties are treated as very close substitutes, implying that domestic and foreign suppliers face the same demand schedules and prices in the U.S. market for sugar.

Next, consider the calculation of the total value of rents. When import volumes are in the range between zero and the quota boundary, the first-tier rent $\phi^{1,r}$ is captured by the supplier at a constant rate per unit. The function that describes this component of total rents is a relatively simple linear function,

$$TVR_{IQ}^{r} = \bar{\phi}^{1,r} MC^{dc,r} M^{r}, \ \forall M^{r} < \bar{Q}^{r}, \tag{24}$$

where TVR_{IQ}^{r} denotes the total value of rents for region *r* while import volumes are in-quota. In this case, the value of the rent per-unit is fixed and the total value of imports is variable. When the import volume is reaches an on-quota level, there is a second component to the total value of rents, and the function becomes

$$TVR_{OQ}^{r} = \left(\bar{\phi}^{1,r} + \phi^{2,r}\right) MC^{dc,r} \bar{Q}^{r} \,. \tag{25}$$

There are now two fixed values; the level of imports (set at the quota level Q^r), and the first-tier rent. The second tier rent varies along the quota boundary, taking a value between 0 and $\hat{\phi}^{2,r}$. When import volumes exceed the quota volume, TVR_{IQ}^{r} reaches a maximum as the value of the second-tier rent reaches a maximum. This defines a piece-wise linear function with arguments that switch between being fixed and variable.

To capture this set of relationships accurately in MONASH-USA, a complementarity based on a MIN function is used. Firstly, an expression is defined for calculating the value of total rents up to a point just before import volumes exceed the quota. Denoting the variable as TVR_1^r, we have

$$TVR_1^r = \phi^{TOT,r} MC^{dc,r} M^{r},\ \forall M^{r} \,. \tag{26}$$

Next, an upper-bound is defined for the rate of the rents captured in the brackets of (25). As these are modelled as powers in MONASH-USA, the expression for this upper bound, denoted Φ_{UB}^{r}, is

$$\Phi_{UB}^{r} = \left(1+\phi^{1,r}\right)\left(1+\phi^{2,r}\right) - 1 \,. \tag{27}$$

Thirdly, an expression is formulated to capture the upper bound on the total value of rents, found by combining (25) with (27) to generate

$$TVR_2^r = \Phi_{UB}^{r} MC^{dc,r} Q^{r} \,. \tag{28}$$

There is now a requirement to choose the expression – from equations (26) and (28) – that generates the minimum value for any given value of M^r in (26). Thus, we need an expression like

$$TVR^{r} = \mathrm{MIN}\left\{TVR_1^r, TVR_2^r\right\} \tag{29}$$

where TVR^r denotes the correct value of total rents. Recall that this relationship can be represented by an expression like

$$TVR^r - TVR_1^r = \text{MIN}\left\{0, TVR_2^r - TVR_1^r\right\}. \tag{30}$$

Therefore, we can define an expression to calculate a value for the left hand side of (30) – which we'll denote by Z^r -

$$Z^r = TVR^r - TVR_1^r \tag{31}$$

and then define a complementarity relationship

$$Z^r <= 0 \quad \perp \quad Z^r - \left(TVR_2^r - TVR_1^r\right). \tag{32}$$

The relationship captured in (32) is a two-state complementarity with an upper bound of zero on Z^r. According to this relationship,

Either	$Z^r < 0$	*and*	$Z^r - \left(TVR_2^r - TVR_1^r\right) = 0$	[state 2]
or	$Z^r = 0$	*and*	$Z^r - \left(TVR_2^r - TVR_1^r\right) < 0$.	[state 3]

The model chooses the correct expression for total rents from (26) and (28) via equation (31). This process that informs this 'choice' begins by subtracting TVR_1^r from TVR_2^r to obtain

$$TVR_2^r - TVR_1^r = MC^{dc,r}\left[\Phi_{UB}^r Q^r - \phi^{TOT,r} M^r\right]. \tag{33}$$

When import volumes are at in- or on-quota levels, we know that $\phi^{TOT,r} < \Phi_{UB}^r$ and $M^r <= Q^r$. Therefore, we also know from (33) that $TVR_2^r > TVR_1^r$. When the import volume is at over-quota levels, $\phi^{TOT,r} = \Phi_{UB}^r$ and $M^r > Q^r$, implying via (33) that $TVR_2^r < TVR_1^r$. It is also true that TVR^r can only be equal to TVR_1^r or TVR_2^r. By a process of elimination, we can now see how this choice of expression to calculate rents will work:

Assume that $TVR_2^r > TVR_1^r$, implying that import volumes are at on-quota or in-quota levels. Under these circumstances, if TVR_2^r was incorrectly chosen to inform TVR^r, then both of $Z^r > 0$ and $Z^r - \left(TVR_2^r - TVR_1^r\right) = 0$ would be true, which is a possibility ruled out by the complementarity conditions. This has the effect of forcing Z^r to its upper bound (zero) meaning that, in light of expression (31), it must be true that $TVR^r = TVR_1^r$. This correctly enforces the choice of TVR_1^r as the relevant expression, which means that both of $Z^r = 0$ and $0 - \left(TVR_2^r - TVR_1^r\right) < 0$ are true, and the complementarity conditions for state 2 are satisfied.

Alternatively, assume that $TVR_2^r < TVR_1^r$, which implies that the volume of imports has exceeded the quota. If TVR_1^r was incorrectly used to inform TVR^r, the complementarity expression would take a positive value – i.e. we would have $Z^r = 0$ and $0 - \left(TVR_2^r - TVR_1^r\right) > 0$, a situation ruled out by the complementarity relationships. Therefore, when the condition $TVR_2^r < TVR_1^r$ is true, the condition $TVR^r = TVR_1^r$ can not also be true. If, on the other hand, it is true that TVR^r is informed by TVR_2^r, equation (31) determines that $Z^r < 0$ and the complementarity expression becomes $TVR_2^r - TVR_1^r - \left(TVR_2^r - TVR_1^r\right) = 0$, which satisfies state 3 of the complementarity.

The total value of rents from a macro perspective can then be calculated as a sum across the regional dimension *r* of TVR^r [7]. As the U.S. dollar CIF price of imports includes the entire rent on a unit of sugar, there is no need to make any further allowance for the welfare effects of these price premiums as they are already accounted for in the current account balance via the CIF value of imports. This approach allows an accurate calculation of rents at both the regional-source level and at the aggregate level, and thus enables a more rigorous welfare analysis to be conducted with MONASH-USA.

Finally, an equation is added to calculate tariff revenue. Two approaches were developed for this task:

The first uses a similar method to that applied in calculating rents at the regional-source level, where a two-state complementarity relationship is defined for a piece-wise linear function. In this case, a MAX function approach is used instead of a MIN function. The generalities of this method have already been described above, so in this case an understanding of that material will be

[7] In application, total rents are calculated by also summing across the set TRQCOM which, as mentioned, has been suppressed in this discussion.

assumed. The complementarity relationship implied in this case has two "variable" states and one "fixed" state. Tariff revenue is a function of the rate of the tariff and the quantity of imports:

1. In state 1, import volumes are in-quota, the tariff is levied at the in-quota rate, and total revenue varies with the quantity of imports. Total tariff revenue is a function of the in-quota tariff rate and the level of imports.
2. In state 2, when the import volume reaches the quota, the in-quota tariff still applies but the volume of imports is fixed. Total tariff revenue is a function of the (fixed) value of the quota and the in-quota tariff rate.
3. In state 3, when the volume of imports exceeds the quota, the import volume reverts to being variable and the tariff is charged at the over-quota rate. Total tariff revenue in this case is a function of (a) the in-quota rate multiplied by the in-quota tariff rate plus (b) the amount by which imports exceed the quota multiplied by the over-quota tariff rate.

To implement these relationships, two tariff revenue functions are defined:

Firstly, a function for tariff revenue when imports are in-quota is defined,

$$TAR_{INQ}^{r} = t_i^{e,r} P_{cif}^{r} M^{r} \tag{34}$$

which, in light of the definition of the ad-valorem-equivalent tariff rate, can also be stated as

$$TAR_{INQ}^{r} = \frac{t_i^{r}}{P_{cif}^{r}} P_{cif}^{r} M^{r} = t_i^{r} M^{r} .$$

Secondly, there is a function for tariff revenue when imports are over-quota,

$$TAR_{OVQ}^{r} = t_i^{e,r} P_{cif}^{r} Q^{r} + t_o^{e,r} P_{cif}^{r} \left(M^{r} - Q^{r} \right). \tag{35}$$

Note that no limitations are imposed on the domain over which the values of these functions can range. Rather, we make use of the fact that these functions will cross at the quota boundary - setting $M^{r} = Q^{r}$ in both expressions, we obtain

$$TAR_{INQ}^{r} = t_i^{e,r} P_{cif}^{r} Q^{r} \tag{36}$$

and

$$TAR_{OVQ}^{r} = t_i^{e,r} P_{cif}^{r} Q^r + t_o^{e,r} P_{cif}^{r} \left(Q^r - Q^r \right) = t_i^{e,r} P_{cif}^{r} Q^r \,. \tag{37}$$

When import volumes are in-quota we know that $M^r < Q^r$, and as $t_o^{e,r} > t_i^{e,r}$ is always true, it follows that

$$TAR_{OVQ}^{r} = t_i^{e,r} P_{cif}^{r} Q^r + t_o^{e,r} P_{cif}^{r} \left(M^r < Q^r \right) < 0 \,.$$

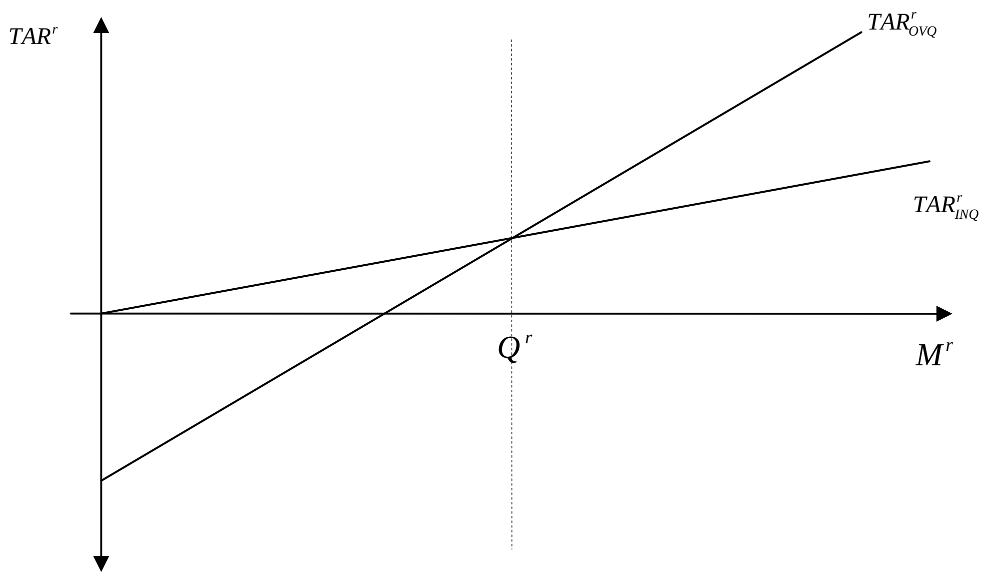
The value of TAR_{INQ}^{r} is always non-negative, and so we know that $TAR_{INQ}^{r} > TAR_{OVQ}^{r}$ when $M^r < Q^r$.

When import volumes are over-quota so that $M^r > Q^r$, subtracting TAR_{INQ}^{r} [equation (34)] from TAR_{OVQ}^{r} [equation (35)] yields

$$TAR_{OVQ}^{r} - TAR_{INQ}^{r} = P_{cif}^{r} \left(M^r - Q^r \right) \left[t_o^{e,r} - t_i^{e,r} \right]. \tag{38}$$

Because it is always true that $t_o^{e,r} > t_i^{e,r}$, it is also always true that TAR_{OVQ}^{r} is larger than TAR_{INQ}^{r} when $M^r > Q^r$.

Figure 12



With these functions defined as above, a complementarity relationship based around a MAX function can be used to generate the value of tariff revenue for any level of imports. Basically, the logic imbedded in the tariff revenue functions allows the complementarity function to simply choose the larger of TAR^r_{OVQ} and TAR^r_{INQ} for any given level of M^r. In a similar way to the quota rent calculation, we start with

$$TAR^r = \text{MAX}\left\{TAR^r_{INQ}, TAR^r_{OVQ}\right\}, \tag{39}$$

and modify it to obtain

$$\Psi^r = \text{MAX}\left\{0, TAR^r_{OVQ} - TAR^r_{INQ}\right\}. \tag{40}$$

where

$$\Psi^r = TAR^r - TAR^r_{INQ}. \tag{41}$$

Now we define a complementarity relationship,

$$\Psi^r => 0 \quad \perp \quad \Psi^r - \left(TAR^r_{OVQ} - TAR^r_{INQ}\right) \tag{42}$$

that says

$$\textit{Either} \qquad \Psi^r = 0 \qquad \textit{and} \qquad \Psi^r - \left(TAR^r_{OVQ} - TAR^r_{INQ}\right) > 0 \qquad \text{[state 1]}$$

$$\textit{or} \qquad \Psi^r > 0 \qquad \textit{and} \qquad \Psi^r - \left(TAR^r_{OVQ} - TAR^r_{INQ}\right) = 0 . \qquad \text{[state 2]}$$

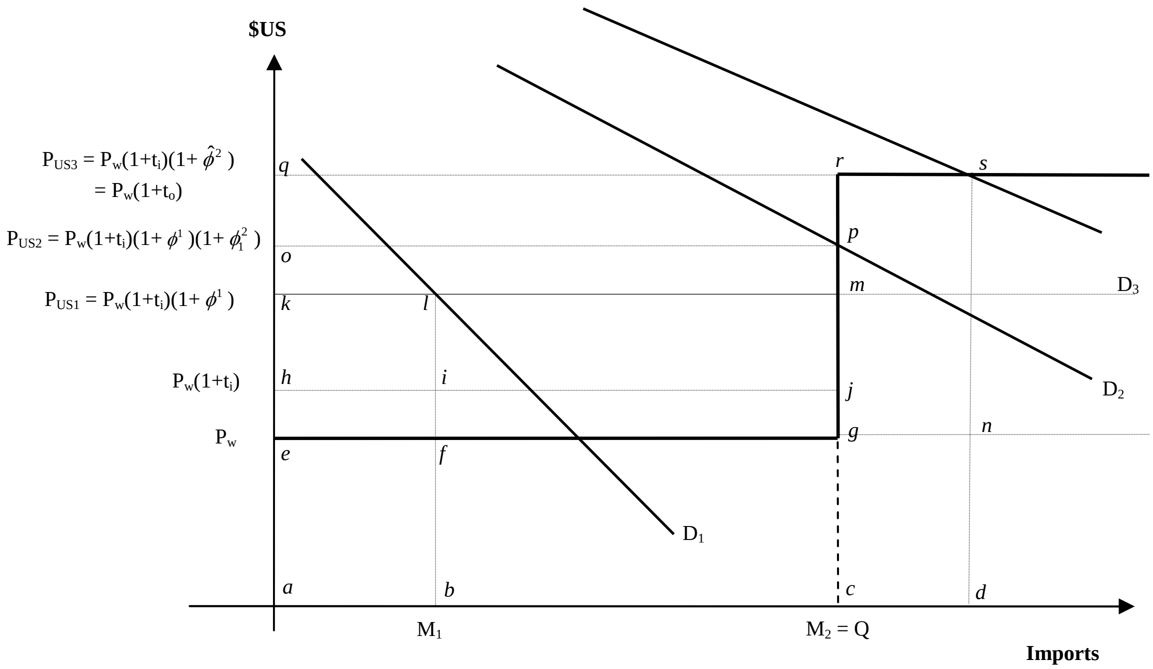
If the import volume is less than the quota level, the model should choose TAR^r_{INQ} to inform TAR^r. As such, we know from (41) that $\Psi^r = 0$. It is (therefore) also true under these circumstances that $\Psi^r - \left(TAR^r_{OVQ} - TAR^r_{INQ}\right) > 0$, simply because equation (38) implies that $\left(TAR^r_{OVQ} - TAR^r_{INQ}\right) < 0$. Thus, the conditions for state 1 of the complementarity are satisfied.

When the volume of imports exceeds the quota, the model should set TAR^r equal to TAR^r_{OVQ}. As we also know in this case [from equation (38)] that $TAR^r_{OVQ} > TAR^r_{INQ}$, it follows that $\Psi^r > 0$. Under these circumstances, it must therefore be true that $\Psi^r - \left(TAR^r_{OVQ} - TAR^r_{INQ}\right) = 0$, because $\Psi^r = \left(TAR^r_{OVQ} - TAR^r_{INQ}\right)$.

One final modification needs to be applied. As explained above, the model will choose the state of the complementarity condition according to the satisfaction of the various conditions in the complementarity statement. In the event that the import volume is equal to the quota, none of the complementarity conditions are satisfied - the model is "in between" states. The point of the equality between TAR^r_{OVQ} and TAR^r_{INQ} in this case is to cause a switch in complementarity states as the value of imports passes through Q^r. The problem is that, under a tariff rate quota policy, the import volume can persist at Q^r, which effectively "captures" the values of TAR^r_{OVQ} and TAR^r_{INQ} and holds them equal to each other, therefore also holding the complementarity between states. To get around this, a small scalar is added (via the appropriate formula) to the value of TAR^r_{OVQ}, preventing the state of the complementarity from switching until the import volume exceeds the quota by some pre-determined amount. Although this might appear to be a purely numerical fix, it actually makes economic sense - in reality, raw sugar is usually transported internationally by ship, and ships carry tens of thousands of tons at a time. Thus, supply decisions are made with more regard for the "shipload" than by the kilogram.

The second approach to calculating tariff revenue takes advantage of some data generated by MONASH-USA that may not always be available in other applications. This method has the benefit of being relatively simple, and is due to an excellent suggestion by Ken Pearson..

Figure 13



In figure 13, the total LDP value of imported sugar is calculated as *aklb* for an in-quota import volume (for D_1), *aopc* for an on-quota (for D_2) level and *aqsd* for an over-quota (for D_3) quantity. These values can be broken down into two components - a basic value calculated at the “world price” as represented by $MC^{dc,r}$, plus a “wedge” given by the sum of the rents and tariff revenues. The total “wedges” are *eklf* for D_1, *eopg* for D_2 and *eqsn* for D_3, and total rents in each case are *hkli*, *hopj* and *hqrj*, respectively. These values are calculated via the equations discussed above and by other expressions already present in MONASH-USA. In each case for the respective demand curves, subtracting total rents from the “wedge” leaves an area of tariff revenue: *ehif* for D_1, *ehjg* for D_2, and *ehjg* plus *grsn* for D_3. It is important to remember that these tariffs are excises or *ad-valorem*-equivalents of excises with a denominator that varies with the CIF price, and so their placement on the graph is only important to the extent that they reflect the correct quantities. Equations are added to the model to subtract the total value of rents from the “wedge”, generating the value of tariff revenue.

The first new equation for this purpose is one that captures the value of imports at the support price. This variable, denoted VM_s^r, is a function of the loan rate/support price (which is fixed, given the policy parameters) and volume of imports,

$$VM_s^r = P_s M^r . \tag{43}$$

Manipulating equation (6) shows that the support price subsumes the first tier rent,

$$P_s = \left(1+\phi^{1,r}\right) MC^{dc,r} . \tag{44}$$

Next, the total value of the second tier rent is calculated. Denoting this value by $VR^{2,r}$, we have

$$VR^{2,r} = \phi^{2,r} P_s Q^r . \tag{45}$$

When the volume of imports is less than the quota, the value of $\phi^{2,r}$ is zero and thus, so too is $VR^{2,r}$. The LDP value of imports, denoted by VM_{ldp}^r, is a standard variable calculated in CGE models. Armed with this information, the total value of rents can be calculated by subtracting VM_s^r and $VR^{2,r}$ from VM_{ldp}^r,

$$TAR^r = VM_{ldp}^r - VM_s^r - VR^{2,r} . \tag{46}$$

4.5 Concluding Remarks

This paper has outlined the theoretical developments applied to the MONASH-USA CGE model to enhance its capability in analysing TRQ-type policies, or indeed, any policy involving complementarity relationships. A discussion of data issues and simulation results from some experiments conducted with this version of MONASH-USA are available in a forthcoming Centre of Policy Studies working paper. These two papers combine to provide an overview of the entire project and its outcomes. This project is ongoing at the time of writing, and further information can be sourced from the author.

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