

Sub-national Differentiation and the Role of the Firm in Optimal International Pricing*

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Abstract

We illuminate the relationship between optimal firm pricing and optimal trade policy by exploring a generalized model that accommodates product differentiation at both the national and sub-national levels. We assume monopolistic competition in the differentiated products at the sub-national level. When the national and sub-national substitution elasticities are similar we find little opportunity for small countries to improve their terms of trade through trade distortions, because firms play an important preemptive role in optimally pricing unique varieties. We contrast this with standard applications of perfect-competition Armington models, which exhibit high optimal tariffs—even for relatively small countries.

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1 Introduction

A common feature in many trade-policy applications is the Armington (1969) assumption of national product differentiation. Brown (1987) critiques these applications, questioning the validity of simulated liberalizations that result in very large adverse terms-of-trade effects for relatively small countries. We expand this critique by noting that at the calibration stage of formulating most Armington models sub-national product differentiation is not considered. The resulting marginal-cost pricing at the sub-national level implicitly allocates market power over unique varieties away from optimizing firms and toward the whim of the policy authority. Although pervasive in applications, this allocation of market power to countries rather than firms is a troubling departure from traditional tenets.

This study contributes to the policy simulation literature in two important ways. First, we use a generalized model of nested differentiation to illustrate the mutual consistency between traditional models of national differentiation and the large-group monopolistic competition models popular in new trade theory. Second, we identify a tension in calibration assumptions between firm-level market power and national-level international-policy leverage. Market power is conceptually observable, and is shown to be an important consideration in applied welfare analysis. Assuming optimal firm-level pricing over a country's varieties can significantly reduce the implied optimal tariff.

In the past researchers have responded (at least in part) to the Brown (1987) critique of the Armington formulation by either modifying parametric assumptions, or by modifying structural assumptions. For example, McDaniel and Balistreri (2003) highlight the general view that estimated Armington elasticities are too low, and that practitioners favor higher elasticities, which imply lower optimal tariffs. Others [e.g., Brown et al. (1992)] adopt a monopolistically-competitive structure that includes firm-level differentiation and industry-wide scale effects. The approach adopted here is to develop a model that maintains the

possibility of both types of differentiation (national and sub-national). We show that the Armington and monopolistic competition structures impose specific parametric restrictions on our generalized model.¹ We thus shift the focus away from alternative structures and toward potentially measurable parameters.

Our application of the generalized model contributes to the policy debate on both the theoretic and applied fronts. We show in a stylized theoretic model that increasing the degree of firm differentiation, relative to national differentiation, acts to reduce the optimal tariff. The optimal tariff remains positive when the degree of firm differentiation is less than the degree of national differentiation.² Positive optimal tariffs under monopolistic competition are broadly consistent with the theoretic work of Flam and Helpman (1987) and Helpman and Krugman (1989). Tariffs improve a country's terms of trade regardless of whether differentiation is at the firm or at the national level, and the terms-of-trade effects of tariffs intensify when the degree of national differentiation is higher relative to the degree of firm differentiation.

We also show, however, that negative optimal tariffs are possible when the degree of firm-level differentiation is higher than the level of national differentiation.³ This result is dependent on our assumption that firm markups are based on direct competition with their domestic rivals. Although natural when firm-level differentiation is lower than national differentiation, this assumption is more tenuous when domestic varieties are more closely related to foreign varieties (relative to other domestic varieties). For example, it is natural to think of a California winery competing more closely with other California wineries. California

¹In fact, the model is also general enough to accommodate the Heckscher-Ohlin-Vanek formulation. In this case we would set the firm-level and national-level elasticities of substitution to infinity.

²The relevant measure of the level of differentiation between products is the inverse of the elasticity of substitution.

³Markusen (1990) also finds that optimal tariffs might be negative when the degree of domestic differentiation in a monopolistic-competitive industry is low. That model is somewhat different from the one employed here, however, because it characterizes the role of specialized inputs in a given industry and treats all other goods as a homogeneous traded good.

wineries will largely base their markup on proximity, in product space, to other California wines.

On the other hand, consider the production of aircraft. It is probably more reasonable to suppose that Boeing products and Airbus products are less differentiated than Boeing products and Lockheed Martin products (given that Lockheed Martin does not currently produce commercial aircraft). The assumption that Boeing would markup its product based on its degree of differentiation from Lockheed-Martin is logically problematic. For this reason we place a caveat on our negative optimal tariff results. From an empirical perspective, once we move to a model with multiple dimensions, commodities should probably be defined in a way that eliminates the oddity of more domestic differentiation relative to international differentiation within a given industry. For example, (Boeing) airliners should be considered a different good than military airplanes and aerospace components (produced by Lockheed-Martin). As with almost any empirical exercise, aggregation is not innocuous in the context of assuming markups based on the degree of domestic competition.

Another interesting result that falls out of our stylized theoretic model is that, in the presence of firm-differentiation, the optimal tariff increases as the overall degree of preference bias toward home varieties increases. This is important from the perspective of analyzing how different sets of calibration assumptions alter the policy implications. There is a great deal of *missing trade* in our actual observation of the trade equilibrium.⁴ In contrast to most theoretic models and econometric applications, simulation models accommodate *missing trade* via a preference bias toward home varieties.⁵ This bias has an effect on the optimal tariff under firm-level differentiation because it alters the relative impacts of variety changes (number of foreign versus domestic varieties) on welfare. This is an important consideration

⁴Trefler (1995) identifies missing trade relative to what one would expect from the theory.

⁵Hillberry et al. (2005) critique the over reliance calibrated models place on preference distribution parameters, and Balistreri and Hillberry (2004) illustrate the importance of home bias in a welfare analysis of the US-Canada border effect in a calibrated gravity-model application.

in any policy simulation model that includes a love-of-variety formulation and calibrated preferences over regional aggregates.

On the applied front we examine the implications, and sensitivity, of our generalized demand system in the context of the recent U.S.-Australia Free trade Agreement. We calibrate a CGE model to the Global Trade Analysis Project (GTAP) social accounts [Dimaranan and McDougall (2005)], and examine the optimal tariff relative to global free trade for small and large countries. We generally find that optimal pricing by firms producing differentiated sub-national products acts to reduce the implied optimal tariff. We also use the model to simulate the recent U.S.-Australia Free Trade Agreement under alternative assumptions about firm differentiation. We contrast our results with other studies that examine the U.S.-Australia Free Trade Agreement.

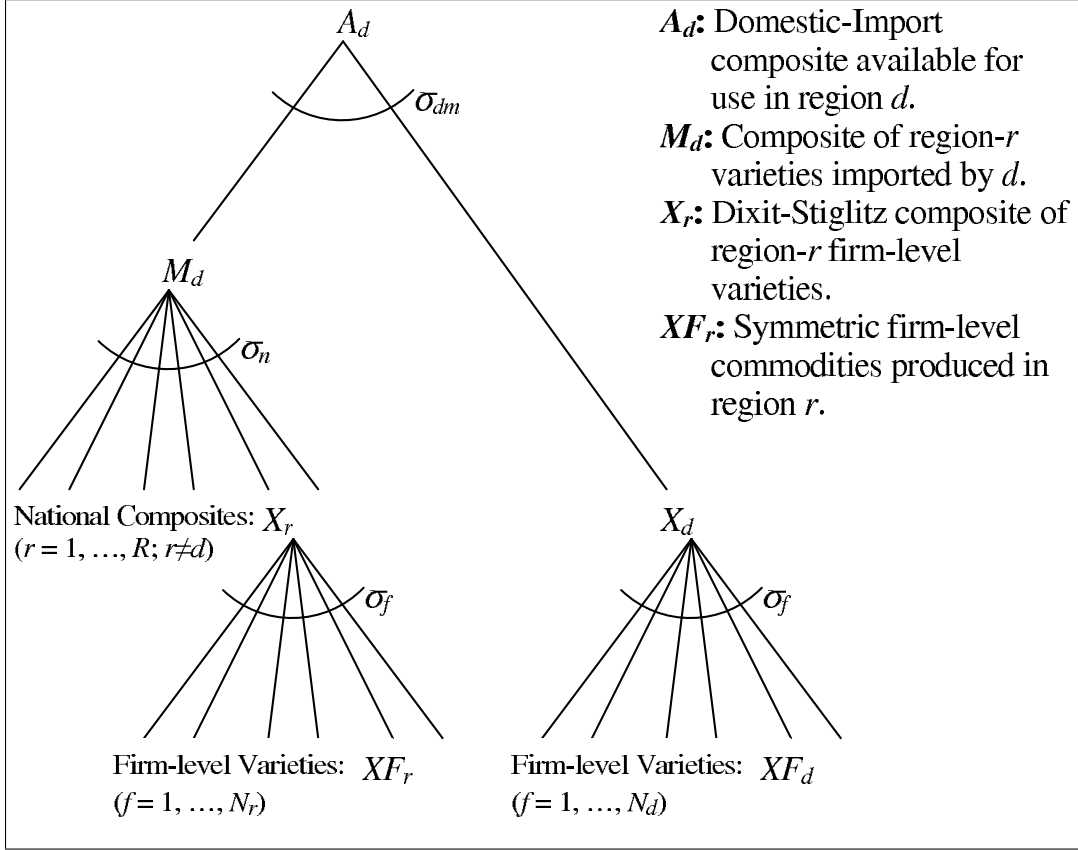
2 Generalized Demand System

Figure 1 illustrates a generalized demand system for aggregating products differentiated at both the firm and national levels. Within each country or region (indexed by $r \in R$) traded goods are produced by monopolistic competitive firms. The composite traded good, X_r , is a Dixit-Stiglitz aggregate of the N_r individual firm-specific varieties, XF_r . Although the varieties produced are different, we assume symmetry across the firms. Algebraically we can represent the sub-national aggregation of firm-level varieties by

$$X_r = [N_r(XF_r)^{\alpha_f}]^{\frac{1}{1-\alpha_f}}, \text{ where } \sigma_f = \frac{1}{1-\alpha_f}. \quad (1)$$

Throughout our analysis we adopt some simplifying assumptions about the nature of the X_r that are common in the literature. We assume each of the N_r firms is small and faces an integrated world market. This indicates a simple markup over marginal cost equal to the

Figure 1: Nested Demand System



inverse of the elasticity of substitution between firm varieties, $1/\sigma_f$. Integrated markets imply independence between the markup and the region in which the firm's output is ultimately consumed.

The parameter σ_f can take on any value greater than one. The degree of firm-level differentiation falls as σ_f increases. When σ_f takes on a value of infinity then markups are zero and we have the special case of perfect competition.⁶ Notice that (1) simply becomes the sum of the XF_r at σ_f equals infinity (α_f approaches one as σ_f approaches infinity). When σ_f is finite the free-entry assumption indicates adjustments in the number of varieties

⁶We utilize GAMS software, which accommodates assigned parameter values of $+\text{inf}$. In compilation GAMS automatically assigns the limits $1/+\text{inf} = 0$ and $(+\text{inf} - 1)/+\text{inf} = 1$. So if we have $\sigma_f = +\text{inf}$ then α_f takes on a value of 1 when the program is compiled.

such that operating profits exactly cover fixed cost payments. We also assume that all costs (marginal and fixed) associated with production use inputs in the same proportion. The constant-markup formulation indicates constant firm-level output and thus no firm-scale effects. Changes in industry output are in the form of entry or exit of symmetric varieties. The love of variety nature of the Dixit-Stiglitz aggregator, however, does indicate industry-level scale effects. For a general discussion (and critique) of these implications of the large-group monopolistic-competition assumptions see Markusen (2002), Chapter 6.

At the national level, the demand system in a given domestic country, d (where $d \in R$), is composed of a CES aggregate of the imported Dixit-Stiglitz composites and the domestic Dixit-Stiglitz composite:

$$A_d = \left[\beta_d^d (X_d)^{\alpha_{dm}} + \beta_d^M (M_d)^{\alpha_{dm}} \right]^{\frac{1}{\alpha_{dm}}}, \text{ where } \sigma_{dm} = \frac{1}{1 - \alpha_{dm}}; \text{ and} \quad (2)$$

$$M_d = \left[\sum_{r \neq d} \beta_d^r X_r^{\alpha_n} \right]^{\frac{1}{\alpha_n}}, \text{ where } \sigma_n = \frac{1}{1 - \alpha_n}. \quad (3)$$

The substitution elasticity between imported varieties is indicated by σ_n , and the substitution elasticity between the imported composite and the domestic composite is indicated by σ_{dm} . In the case that σ_n equals σ_{dm} equation (2) simply collapses to

$$A_d = \left[\sum_r \beta_d^r X_r^{\alpha_n} \right]^{\frac{1}{\alpha_n}}, \text{ where } \sigma_{dm} = \sigma_n = \frac{1}{1 - \alpha_n}. \quad (4)$$

It is relatively straightforward to accommodate the predominant policy-simulation models within the general demand system outlined in Figure 1. The special case of a simple constant-returns Armington formulation is accommodated by setting σ_f equal to infinity (marginal-cost pricing by firms) and σ_n equal to σ_{dm} . Contemporary applications tend to adopt the more complex case where σ_{dm} is some fraction—usually one half—of σ_n .⁷

⁷For example, the default elasticities used in the widely applied Global Trade Analysis Project (GTAP)

Another special case often adopted in the policy simulation literature is the Dixit-Stiglitz formulation of firm-level differentiation. Setting σ_f equal to σ_n equal to σ_{dm} collapses the system such that only firm-level varieties are relevant. Thus by adjusting the elasticities in relation to one another we can explore different assumptions about the general nature of product differentiation at the firm and national levels. The demand system has the advantage of accommodating (parametrically) a wide variety of favored structures that are relevant in the policy forum.

3 Illustrative General-Equilibrium Simulation Model

The strategy for incorporating the generalized demand system in a relatively transparent simulation environment involves formulating a stylized theoretic model. The general equilibrium is formulated as a Mixed Complementarity Problem (MCP), which is computed using GAMS software.⁸ Following Rutherford (1999) the general equilibrium includes three sets of variables which are associated with three corresponding sets of conditions:

1. **transformation activities**, which generate outputs or utility, are associated with an **optimality** condition given the technologies;
2. **prices** of inputs, outputs, and composite varieties are associated with **market clearance** conditions; and
3. nominal **income** levels for each agent are associated with **income balance**—between the value of endowments and the value of demand.

The GAMS code for the algebraic formulation of the nonlinear MCP is presented in Appendix A. A tabular GAMS/MPSGE formulation is also available from the authors.

model employ the “rule of two,” which assumes $\sigma_n = 2\sigma_{dm}$ [Huff et al. (1997)]. We do not intend to advocate, or perpetuate, the use of this arbitrary rule. We allow for it in our generalized system because of its prevalence in application. That said, Liu et al. (2002) fail to reject the “rule of two” as a maintained hypothesis.

⁸GAMS Development Corporation: <http://www.gams.com>.

Table 1: Scope of the Stylized Theoretic Model

Equilibrium Condition	(equation)	Associated Variable	Dimensions
1)Optimality			
Unit-expenditure function = True cost-of-living index	(5)	W_r (Hicksian welfare index)	R
Unit-cost of A_r = The composite price index, PA_r	(6)	A_r (Armington activity)	R
Unit-cost of X_r = the Dixit-Stiglitz price index PX_r	(7)	X_r (Dixit-Stiglitz Aggregate)	R
Marginal cost = Marginal revenue	(8)	XF_r (Firm output index)	R
Profits = 0	(9)	N_r (Number of firms index)	R
2)Market-Clearance			
Labor endowment = Demand leisure + Demand for labor	(10)	PL_r (Wage index)	R
Supply of XF_r = Demand for XF_r in X_r	(11)	PF_r (Price of firm-level output)	R
Supply of X_r = Domestic demand + Export demand	(12)	PX_r (Dixit-Stiglitz price index)	R
Supply of A_r = Demand for A_r in W_r	(13)	PA_r (Armington price index)	R
Nominal value of welfare ($W_r PW_r$) = Nominal Expenditures	(14)	PW_r (True cost-of-living index)	R
3)Income balance			
Nominal expenditure = Value of endowment + Tariff revenue	(15)	RA_r (Nominal income)	R
Total Dimensions			11R

The model incorporates many features designed to indicate how applied general equilibrium models might react, but also abstracts from many complications that might obscure the key effects. The model includes multiple regions/countries (indexed by r) that trade on integrated world markets. This allows us to examine experiments that vary the relative size of a region and discriminatory trade policies. Other than country size, all other aspects of each region's technology and preferences are assumed to be identical. Furthermore, we assume that each region is endowed with only one factor of production, labor (L_r), which might be allocated to production or used directly as an input to welfare (leisure or non-traded sector). Thus a country's size is controlled by changing its share of the total world endowment of labor. Table 1 outlines the overall scope of the numeric model indicating the equilibrium conditions and associated variables.

We proceed by specifying the conditions outlined in Table 1. For the first condition note that the unit-expenditure function indicates the marginal cost of a unit of welfare (under optimal consumption), and the welfare level will satisfy marginal cost equals marginal benefit = PW_r (the true-cost-of-living index). Let PA_r equal the price of the composite commodity A_r [from equation (4)], and PL_r represent the price of labor, then assuming Cobb-Douglas

utility, the equilibrium conditions associated with a welfare maximizing mix of goods and leisure are given by

$$PA_r^{1-\gamma} PL_r^\gamma - PW_r = 0 \quad (5)$$

The first term is the Cobb-Douglas unit-expenditure function and the second term is the price, or marginal benefit, of an additional unit of utility. The parameter γ indicates the value share of the non-tradable in welfare.

Associated with optimal activity levels of A_r , the activity which generates the composite of the traded commodities, are similar conditions that equate marginal cost to marginal benefit. Marginal benefit, again, is simply represented by the price of the composite, PA_r . The unit cost of A_r is a function of the domestic Dixit-Stiglitz composite price, given by PX_r , and the gross of tariff foreign prices, given by $(1 + t_{sr})PX_s$ (where $s \in R$ but $s \neq r$). Let β_{sr} , indicate the value share of X_s consumption in the total value of benchmark consumption of A_r . The condition is thus given by

$$\alpha_f \left[\beta_{rr} PX_r^{1-\sigma_{dm}} + (1 - \beta_{rr})^{\frac{\sigma_{dm}-\sigma_n}{1-\sigma_n}} \left(\sum_{s \neq r} \beta_{sr} [(1 + t_{sr})PX_s]^{1-\sigma_n} \right)^{\frac{1-\sigma_{dm}}{1-\sigma_n}} \right]^{\frac{1}{1-\sigma_{dm}}} - PA_r = 0 \quad (6)$$

The first term represents the unit cost of the Armington activity and corresponds to the nested CES structure illustrated in the top two tiers of Figure 1. The exogenous scale parameter $\alpha_f = 1 - 1/\sigma_f$ conveniently normalizes the benchmark price indexes, $PA_r = 1$ (when the benchmark PX_s are set to reflect the markup, $PX_s^0 = \sigma_f/(\sigma_f - 1)$, and there are no trade distortions).

Formulating monopolistically-competitive production of the Dixit-Stiglitz composite X_r includes three separate conditions. First there is an industry wide condition for the X_r activity (where PF_r is the price charged by a representative firm, and again N_r is the number

of firms index and σ_f is the substitution elasticity between sub-national varieties);

$$\left[N_r P F_r^{1-\sigma_f} \right]^{\frac{1}{1-\sigma_f}} - P X_r = 0 \quad (7)$$

At the firm level output, $X F_r$, is determined by profit maximization (where the demand elasticity for a small firm is σ_f). Marginal cost is simply the price of labor, $P L_r$, and marginal revenue is the price of output, $P F_r$, deflated by the usual margin given by the elasticity;

$$P L_r - P F_r \left(\frac{\sigma_f - 1}{\sigma_f} \right) = 0 \quad (8)$$

The index on the number of firms is determined by the condition that entry will adjust such that profits are zero;

$$(P F_r - P L_r) X F_r - \frac{P L_r}{(\sigma_f - 1)} = 0 \quad (9)$$

The first term in (9) is firm level profits and the second term is the value of the fixed cost payment (under the normalization that $X F_r = 1$ at the benchmark). Combining conditions (8) and (9) we can derive the familiar large-group-monopolistic-competition result that firm-level output is invariant to industry scale. When σ_f is finite the number of firms adjusts to ensure zero profits.⁹

With all of the technologies specified in conditions (5) through (9) we generate the market equilibrium conditions for each price. We derive each of the conditional demand and supply functions paying close attention to scaling (and including the fixed supply of labor endowments). Each market-clearance condition sets excess demand for each commodity to zero.

The market equilibrium condition for labor is given by the exhaustion of the labor endowment, L_r , on direct demand for labor in the welfare activity and on demand for labor in

⁹As a matter of programming practicality, when $\sigma_f = \infty$ the index on the number of firms is fixed at one ($N_r = 1$) and $X F_r$ is allowed to vary.

production;

$$L_r - \gamma W_r \frac{PW_r}{PL_r} - e_r N_r XF_r = 0 \quad (10)$$

The scale parameter e_r is added (where $e_r = (1 - \gamma)L_r$) to facilitate a convenient normalization of the number of firms and the output level by each firm ($N_r = XF_r = 1$ at the benchmark).

The price of firm output, PF_r , is determined in the aggregate market for firm output. Total firm-level output is given by the product of the number firms, N_r , and the activity level of the representative firm, XF_r , scaled by the parameter ϕ which converts the quantity into real units. Demand is indicated by the activity level X_r . The equilibrium condition is

$$\phi N_r XF_r - X_r^{af} = 0 \quad (11)$$

The composite activity, X_r , includes the exponent, α_f , to net out the industry-wide scale effect in demand for firm output. That is, the variable X_r measures the quantity of the composite Dixit-Stiglitz commodity that arrives for consumption (this includes the usual industry-wide scale effect).

Supply of the Dixit-Stiglitz composite is, therefore, given by X_r , and total demand is the sum of domestic demand and export demand. The market clearance conditions that determine the PX_r are thus given by

$$\begin{aligned} X_r &= \alpha_f^{1-\sigma_{dm}} \beta_{rr} A_r \left(\frac{PA_r}{PX_r} \right)^{\sigma_{dm}} \\ &- \sum_{s \neq r} \left[\alpha_f^{1-\sigma_{dm}} \beta_{rs} A_s PA_s^{\sigma_{dm}} \left(\frac{1}{(1+t_{sr})PX_s} \right)^{\sigma_n} \left(\sum_{q \neq s} \left(\frac{\beta_{qs}}{1-\beta_{ss}} \right) [(1+t_{qs})PX_q]^{1-\sigma_n} \right)^{\frac{\sigma_n - \sigma_{dm}}{1-\sigma_n}} \right] \\ &= 0 \end{aligned} \quad (12)$$

Notice that the rather complex export-demand term (the last term) simplifies greatly when the elasticity of substitution between national varieties equals the domestic-import elasticity (i.e., $\sigma_n = \sigma_{dm}$). Again, the parameter β_{rs} indicates the benchmark value share of consumption by region s of the Dixit-Stiglitz composite produced in region r .

Associated with the price indexes on the Armington composites, PA_r , are the market equilibrium conditions

$$A_r - (1 - \gamma)W_r \frac{PW_r}{PA_r} = 0 \quad (13)$$

The first term is total supply and the second is Cobb-Douglas demand from the welfare activity. The final market clearance condition ensures that the nominal value of welfare equals the nominal value of representative-agent expenditures, RA_r ;

$$PW_r W_r - RA_r = 0 \quad (14)$$

The variable associated with (14) is the true-cost-of-living index, PW_r . Dividing (14) by PW_r yields the standard market balance condition in quantities. We complete the general equilibrium by requiring balance between expenditures and incomes:

$$RA_r = PL_r L_r + \sum_{s \neq r} t_{sr} PX_{sr} \left[\alpha_f^{1-\sigma_{dm}} \beta_{rs} A_s PA_s^{\sigma_{dm}} \left(\frac{1}{(1+t_{sr})PX_s} \right)^{\sigma_n} \left(\sum_{q \neq s} \left(\frac{\beta_{qs}}{1-\beta_{ss}} \right) [(1+t_{qs})PX_q]^{1-\sigma_n} \right)^{\frac{\sigma_n - \sigma_{dm}}{1-\sigma_n}} \right] \quad (15)$$

Income equals the value of the labor endowment, where L_r is the endowment quantity, plus the value of tariff revenues.

Conditions (5) through (15) specify a complete multi-region general equilibrium that incorporates the generalized demand system illustrated in Figure 1. Only relative prices are determined, however, so we remove the market clearance condition for labor in the focus region, H (Home), and declare the associated price as the numeraire ($PL_H = 1$).

Table 2: Experimental Parameters for the Illustrative Model

Parameter	Description	Range
$\sigma_f = \frac{1}{1-\alpha_f}$	Elasticity of substitution between firm-level varieties	$1 < \sigma_f \leq \infty$
σ_n	Elasticity of substitution between import varieties	$0 < \sigma_n < \infty$
σ_{dm}	Elasticity of substitution between domestic and import varieties	$0 < \sigma_{dm} < \infty$
θ	Benchmark share of the focus region, H, in world endowments	$0 < \theta < 1$
λ	Home-bias parameter (proportional reduction in benchmark trade)	$0 < \lambda < 1$
γ	Benchmark share of non-traded (leisure) in welfare	$0 < \gamma < 1$

Our primary goal is to examine the effects of changing the relative elasticities, but we are also concerned with examining the interaction of these effects with changes in the first-order calibration. The first-order calibration is indicated by the specific values of the value share parameters (γ and β_{rs}) the scale parameters (ϕ_r and e_r) and the endowment levels (L_r). We control the γ directly, but changing the assumed country size or the degree of home bias affects multiple benchmark parameters. To cleanup the experimental instruments we introduce two new summary parameters, θ and λ , and then solve for the implied β_{rs} , ϕ_r , e_r and L_r that actually enter the model. The parameter θ indicates the benchmark share of the home region's endowment in total world endowment, and λ controls the degree of home bias in preferences. Table 2 summarizes the parameters that are utilized in our experiments.

The parameters θ , λ , and γ control the first-order calibration, while the elasticities control the second-order curvature. The first-order calibration involves using the parameters in Table 2 to specify the remaining parameters (the β_{rs} , ϕ_r , e_r and L_r) that appear in conditions (5) through (15). Normalizing the total world labor endowment to 100, we have that L_H equals 100θ , and the remainder of the 100 labor units are distributed equally to each of the other regions establishing each of the L_r . The benchmark scale parameters can then be computed as $e_r = (1 - \gamma)L_r$ and $\phi_r = (\alpha_f(1 - \gamma)L_r)^{\alpha_f}$.

The value-share parameters, β_{sr} , depend on country size and the trade reduction index, λ . This is easiest to illustrate by first defining the assumed value of benchmark trade flows from country s to r , m_{sr} , in terms of endowments and λ . We assume that, in the absence of

taste bias ($\lambda = 0$), each country r consumes its benchmark income share ($L_r/100$) of each of the traded composites, but as λ grows there is a proportional reduction in trade. The assumed benchmark trade flows are given by

$$m_{sr} = (1 - \lambda)e_s \frac{L_r}{100}, \text{ where } (s \neq r). \quad (16)$$

We can then specify benchmark domestic consumption of domestic varieties as the domestic income share of domestic production plus the volume of reduced trade across the s partners;

$$m_{rr} = e_r \left(\frac{L_r}{100} + \lambda \sum_{s \neq r} \frac{L_s}{100} \right) \quad (17)$$

The value-share parameters are then computed as

$$\beta_{sr} = \frac{m_{sr}}{e_r} \quad (18)$$

Thus, the β_{rr} rise with λ , and the β_{sr} , where $s \neq r$, fall with λ . We utilize the trade reduction index, λ , to accommodate the stylized fact that there is a great deal of “missing trade” in the world trading system, and most calibrated models utilize preference parameters to explain this. When trade volumes are reduced preferences are skewed toward home varieties, and this impacts the optimal tariff. As Balistreri and Hillberry (2004) point out, most applied general equilibrium models adopt a first-order calibration that implicitly skews preferences toward home varieties. This preference skew is important because, in an environment with symmetric domestic and foreign firms, the love-of-variety effect is more intense for home varieties.¹⁰ Setting $\lambda > 0$ allows us to explore the implication of home biased preferences

¹⁰Our assumption that firms are *small* ensures firm-level symmetry between foreign and domestic firms when there are no distortions. Most theoretic and econometric exercises rely on transport or trade costs to reduce trade, and assume that the love of domestic varieties equals the love of foreign varieties. This contrasts sharply with calibrated models, which rely on the preference weights, the β_{sr} , to explain the trade pattern.

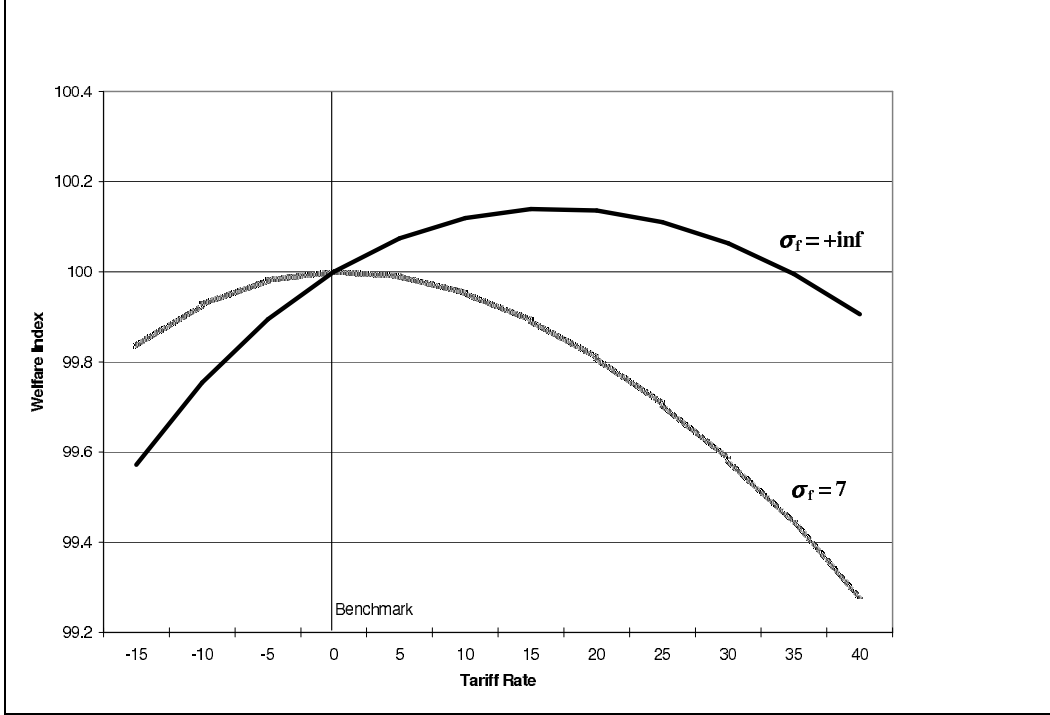
for the optimal tariff when sub-national varieties are distinct. In general, increasing λ above zero indicates higher optimal tariffs. Tariffs increase the number of domestic relative to foreign varieties, and home-biased preference indicate that this is welfare improving (even if the number of gained domestic varieties is exactly the same as the number of lost foreign varieties).

With the specification of the β_{sr} , ϕ_r , e_r and L_r , the calibration of the benchmark general equilibrium is complete for any valid numeric values of the experimental parameters in Table 2 (and setting the tariff rates to zero). At the benchmark equilibrium the activity levels take on the following values: ($W_r = L_r$, $A_r = e_r$, $X_r = \alpha_r e_r$, and $XF_r = N_r = 1$). The benchmark price indexes reflect the markup over marginal cost on the sub-national varieties where appropriate ($PX_r = PF_r = \sigma_f/(\sigma_f - 1)$, where as $PW_r = PA_r = PL_r = 1$). Benchmark incomes are simply given by the value of labor endowments at a wage rate of one ($RA_r = L_r$). The computational system includes $11R$ variables and $11R$ associated equilibrium conditions, where R is the total number of regions specified. The actual computer code used to solve the system is included as an appendix to this paper.

4 Results from the Illustrative Model

The first experiments that we examine explore the impact of firm-level differentiation on the optimal tariff. Figure 2 shows the welfare curves as we vary the tariff imposed by region H from -15% to 40% under two scenarios. First we adopt a set of relative elasticities not unlike those typically adopted in standard Armington applied general equilibrium models. That is, $\sigma_f = +\infty$ and $\sigma_n = \sigma_{dm} = 7$. In the second case we include firm-level differentiation, which is equal to the level of national differentiation (i.e., $\sigma_f = \sigma_n = \sigma_{dm} = 7$). In both scenarios we set the first-order calibration at the central case, characterized by a relatively small focus region size ($\theta = 0.001$); no home bias in preferences ($\lambda = 0$); and a labor value

Figure 2: Welfare and tariffs with and without firm differentiation ($\sigma_n = \sigma_{dm} = 7$, $\theta = 0.1\%$, $\lambda = 0$, and $\gamma = 0.2$)



share in welfare of 20% ($\gamma = 0.2$).

The curve under an assumption that $\sigma_f = +\infty$ confirms the finding of Brown (1987) that small-country tariffs are large under the typical Armington formulation. The optimal tariff for this relatively small country is 17%. Because the country is a monopoly supplier of its export variety the optimal tariff reflects the optimal markup over marginal cost, approximately $1/(\sigma_n - 1)$. In contrast when we make an assumption consistent with sub-national differentiation, allocating the market power over exports to firms, the optimal tariff drops dramatically to less than 1/2% (a finer search reveals the optimal tariff to be about 0.4%).

One significant contribution of our generalized demand system is that all of the intermediate cases are also available. Table 3 presents the computed optimal tariffs under different assumptions about the level of firm differentiation and country size. As one might expect the optimal tariff increases with both the level of substitution between firm varieties and

Table 3: Computed optimal tariffs in percent ($\sigma_n = \sigma_{dm} = 7$, $\lambda = 0$, and $\gamma = 0.2$)

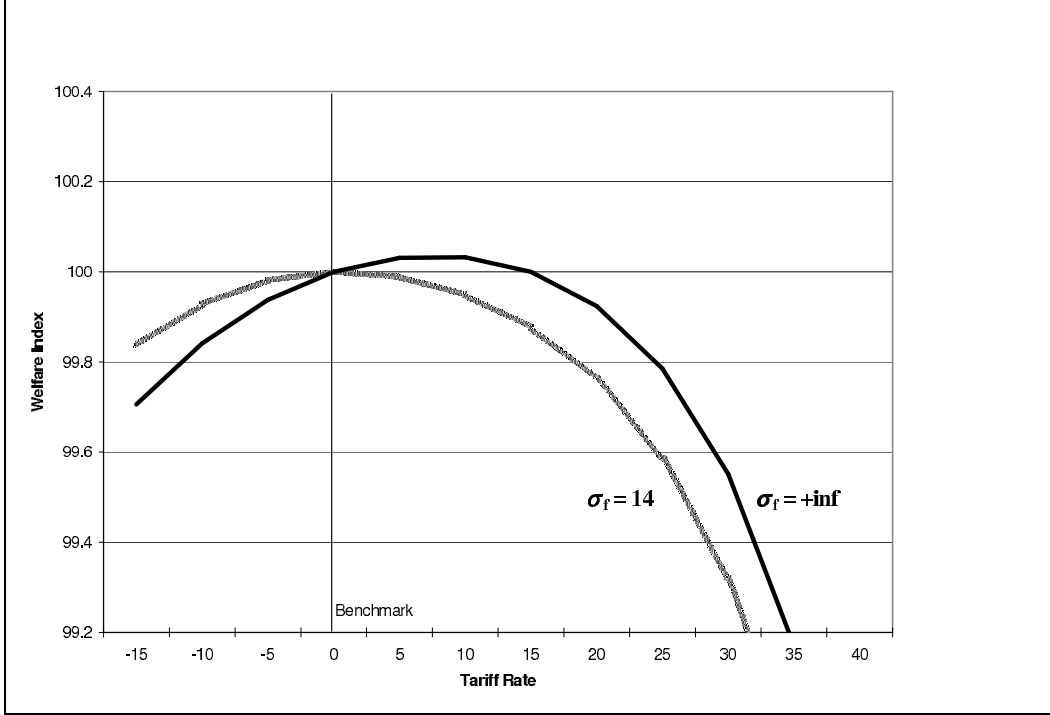
σ_f	θ (relative country size)						
	0.1%	1.6%	3.1%	6.3%	12.5%	25%	50%
3.5	-16	-11	-4	6	13	17	23
7	0	7	10	14	16	19	24
14	9	13	14	16	18	20	25
30	13	15	16	17	18	20	25
100	16	16	17	17	18	20	25
$+\infty$	17	17	17	18	19	21	25

the relative country size. For small countries the optimal tariff is critically dependent on the degree of firm differentiation assumed. For a country that has a relative size of 0.1% of the world economy the optimal tariff ranges from a -16% to a +17% depending on σ_f . The negative optimal tariffs found for small countries with more firm differentiation than national differentiation ($\sigma_f < \sigma_n$) are consistent with Markusen (1990).

When relative country size is large the optimal tariff is insensitive to the level of firm differentiation assumed. This is the result of the complex interaction of country size, the degree of market power held by firms, and the approximation error implicit in our assumption that the demand elasticity equals the substitution elasticity. As country size increases the average markup on firm-level products is too high (from an industry perspective) because income effects become important. Traditional large-country terms-of-trade effects offset these effects, however, and optimal tariff rates are very high regardless of the level of firm differentiation assumed.

Figure 3 and Table 4 show the same pattern of results when we double the elasticity of substitution between national varieties. As mentioned in our introduction one might mitigate large optimal tariffs in the Armington framework by increasing the Armington elasticity, σ_n . We show this implication, as the optimal tariff for the small country drops from 17% to 8% when the national-level elasticity is set to 14 rather than 7. The key contribution that our generalized demand system offers, however, is a decoupling of the optimal tariff from

Figure 3: Welfare and tariffs with and without firm differentiation ($\sigma_n = \sigma_{dm} = 7$, $\theta = 0.1\%$, $\lambda = 0$, and $\gamma = 0.2$)



the specific Armington elasticity. For small countries, allocating market power over distinct varieties to firms rather than countries centers the welfare curves in Figures 2 and 3 over an approximately zero tariff, regardless of the Armington elasticity. Armington elasticities are thus free to be set in a way that best reflects trade responses, and not as a control on the optimal tariff.

Another interesting result that emerges from our stylized theoretic model is that the optimal tariff increases as the degree of home bias increases. In Table 5 we hold the size of the country to be relatively small, at 0.1% of world income, but increase the value of λ from zero to 0.5. The results in Table 5 show a dramatic increase in the optimal tariff as home bias increases, even for a relatively small country and regardless of the degree of sub-national differentiation assumed.

The dramatic increase in the optimal protection illustrated in Table 5 is due to an unequal

Table 4: Computed optimal tariffs in percent ($\sigma_n = \sigma_{dm} = 14$, $\lambda = 0$, and $\gamma = 0.2$)

σ_f	θ (relative country size)						
	0.1%	1.6%	3.1%	6.3%	12.5%	25%	50%
3.5	-23	-20	-17	-8	10	7	12
7	-7	-3	0	3	6	9	13
14	0	3	5	6	8	10	14
30	4	6	7	8	9	10	14
100	7	7	8	8	9	11	14
$+\infty$	8	8	8	8	9	11	14

Table 5: Computed optimal tariffs in percent ($\sigma_n = \sigma_{dm} = 7$, $\theta = 0.1\%$, and $\gamma = 0.2$)

σ_f	λ (trade reduction index) Higher values indicate more home bias					
	0.0	0.1	0.2	0.3	0.4	0.5
3.5	-16	9	12	13	14	14
7	0	14	15	15	16	16
14	9	15	16	16	16	16
30	13	16	16	16	16	16
100	16	17	17	17	17	17
$+\infty$	17	17	17	17	17	17

weighting of the number of home, versus foreign, varieties. Home-biased preferences directly increase the value of β_{HH} relative to the β_{FH} (where the subscripts index the Home, H , and Foreign, F , regions). Home agents benefit directly when the tariff increases N_H relative to N_F , as a result of the asymmetric preference weights. The love-of-variety effect is more intense for home varieties at $\lambda > 0$. The unequal weighting of varieties is a critical departure from the theoretic literature, but it is our understanding of how applied simulation models accommodate the trade pattern.

The pattern of results presented in Table 5 is important to the contemporary debate over unobserved trade costs. Hillberry et al. (2005) indicate that we might not need to worry about whether a calibrated model accommodates missing trade through taste bias or through unobserved trade frictions—as long as policy is independent of the unobserved trade frictions.¹¹ Our analysis suggests that this may hold in the case of perfect competition (the optimal tariff varies little in the final row of Table 5), but when sub-national differentiation is considered the degree that the model attributes missing trade to a taste bias affects the optimal tariff.

In turn, this is an important consideration in applied welfare analysis. For example, the second row of Table 5 shows an optimal tariff of zero if we assume no taste bias but an optimal tariff of 14% for a modest amount of taste bias. When alternative methods of calibration (taste bias versus unobserved trade frictions) influence the implied optimal tariff, welfare analysis of policy will be affected.

¹¹In fact, Hillberry et al. (2005) argue that the strong correlation between observed trade and trade frictions and the taste-bias parameters is evidence that policy is *not* independent of unobserved trade frictions and, therefore, we *should* be worried about calibrated taste bias.

5 Application of the generalized model

To give the generalized model an applied context it is useful to compare it to models that appear in the literature. To explore the performance of the generalized model we calibrate a version of it to the Global Trade Analysis Project (GTAP) social accounts [Dimaranan and McDougall (2005)] and conduct a number simulation experiments. The model is coded in GAMS/MPSGE and is available upon request. Although somewhat muddled by the complications of real trade patterns, the experiments tend to support our general findings (from the relatively transparent model presented above). The incentive for small countries that trade intensively (those with relatively less home bias in preferences) to unilaterally impose high rates of protection are reduced when firm-level differentiation is considered.

The overall scope of the applied model includes the world general equilibrium in multiple commodities and regions. Geographically we include four focus countries and the remainder of the world is aggregated into four regions:

- Australia
- Canada
- United States
- Chile
- Rest of America
- East Asia
- Europe
- Rest of World

The commodities in the model include the following nine aggregates:

- Agriculture
- Coal oil gas and other minerals
- Other processed food and tobacco products
- Textiles apparel and leather products
- Wood products
- Metals and metal products
- Other manufactures
- Services
- Savings good

The model uses this level of aggregation to give an indication of how an applied model might react, but also maintains a high degree of tractability. Given the methodological nature of

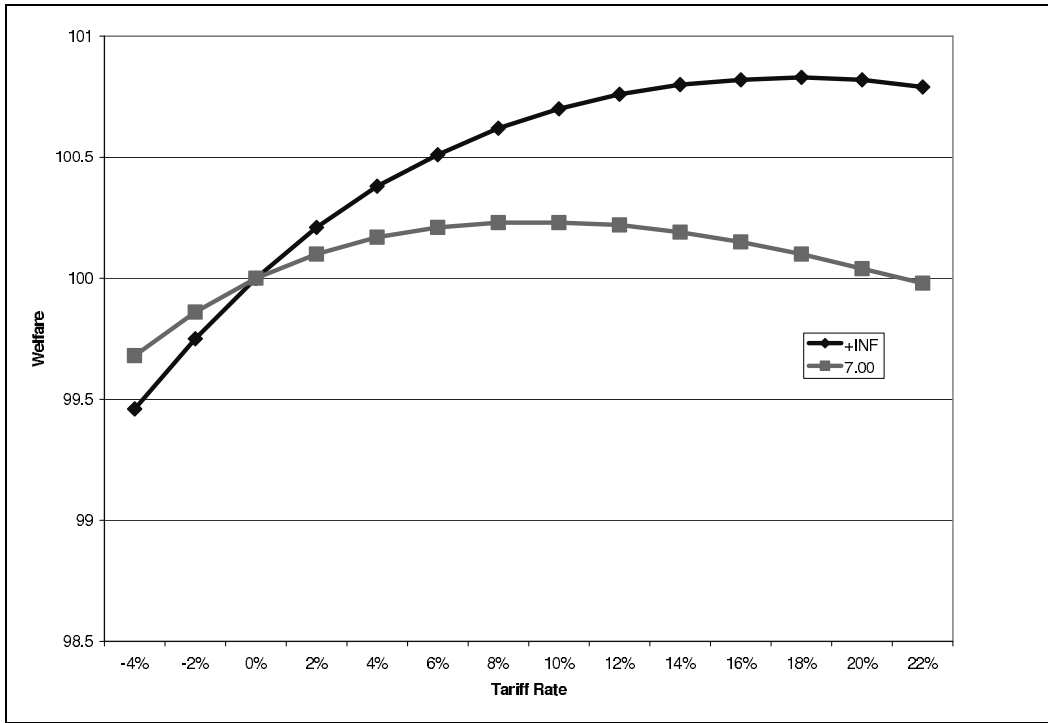
our exercise we simply accept the GTAP data as an accurate representation of the world social accounts. Furthermore, we make no attempt at estimating actual trade elasticities. We simply make the following assumptions across each commodity. We set the elasticity of substitution between import varieties at seven ($\sigma_n = 7$). Consistent with many applications we set the domestic-import elasticity at one half the import-variety elasticity ($\sigma_{dm} = 3.5$). The key experimental control is to vary the firm-level elasticity between seven and infinity ($\sigma_f = 7$ or $\sigma_f = \infty$).

We start the analysis by examining the unilateral incentives for countries to impose tariffs under the alternative assumptions about firm-level differentiation. To setup the experiment we utilize an updated baseline of global free trade. Once the model is calibrated we remove all trade distortions to generate the benchmark equilibrium. This is important for looking at unilateral incentives to protect, because the observed rates of protection include product mix as well as country mix distortions.

With the free-trade benchmark established, we then identify the optimal rate of protection for a given domestic country under a uniform tariff on all imports of all commodities from all foreign countries. This will be a relatively efficient tax mechanism because it tends not to distort across commodities or source countries. Given this setup one should not be surprised to see relatively large optimal rates of protection. We warn the reader that these hypothetical experiments are designed to illustrate our argument, and should not be interpreted as policy prescriptions.

Actual tariffs on specific products (and possibly on specific products from specific countries) are inefficient relative to our experiment because they have an impact on relative prices in addition to increasing the average price. The relative price changes cause demand substitutions that are highly distortionary. In contrast, the uniform tariff that we analyze has relatively minor impacts on relative prices across commodities or on relative prices across different source regions. The uniform tariff is, therefore, relatively efficient (compared to the

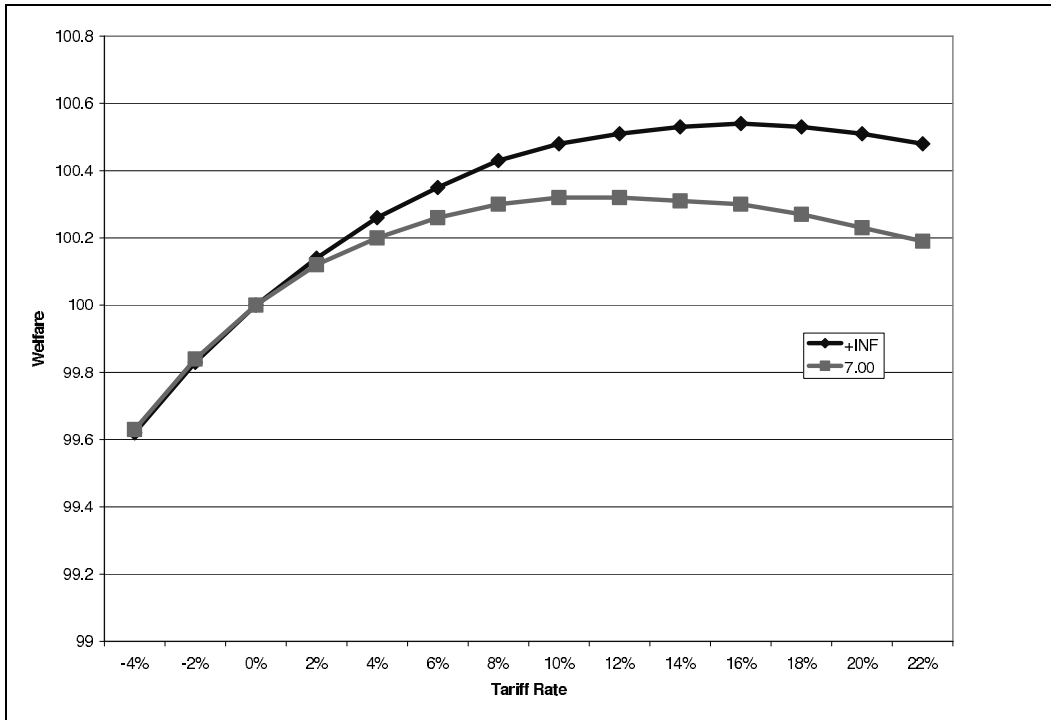
Figure 4: Canadian welfare under a uniform tariff relative to global free trade



more common targeted protection observed in the data).

Figure 4 illustrates how Canada's welfare changes with the tariff rate under the alternative assumptions about firm-level differentiation. Relative to the global-free-trade benchmark a typical Armington model indicates that Canada's optimal uniform tariff would be 18% on all imports. In contrast, if we assume that firm varieties are also differentiated the optimal tariff is cut in half. Unlike the theoretic model presented above, however, we do not see a (nearly) complete elimination of the optimal tariff. We suggest that this is due to the presence of a home bias in the calibrated model. Considering Table 5 we can see that inserting even a modest amount of home bias in preferences escalates the optimal tariff (even when we assume a high degree of firm differentiation). So, although muted, we find general support for our hypothesis that firm differentiation is important when we examine Canada's unilateral incentives.

Figure 5: Chilean welfare under a uniform tariff relative to global free trade



We find less evidence of a zero optimal tariff for Chile. Figure 5 plots the welfare curves for Chile. Under no firm differentiation the optimal tariff for Chile is 16%, and this falls to 11% under firm differentiation that is equal to the level of national differentiation. Again, this points to the larger issue of home bias. If there are large networking costs, or other unobserved costs which restrict trade, and simulation models accommodate the observed trade flows by asserting a preference for the home variety, then the simulation models are likely to exhibit sizable optimal tariffs even for small countries, and even when we consider firm differentiation.

Given the results presented in Section 4 and knowledge of how simulation models accommodate the trade pattern, it is not surprising that the reduction of the optimal tariff is larger for Canada than it is for Chile. Canada is relatively trade intensive and less remote than Chile. Lessons from the gravity literature (in international trade) suggest that more

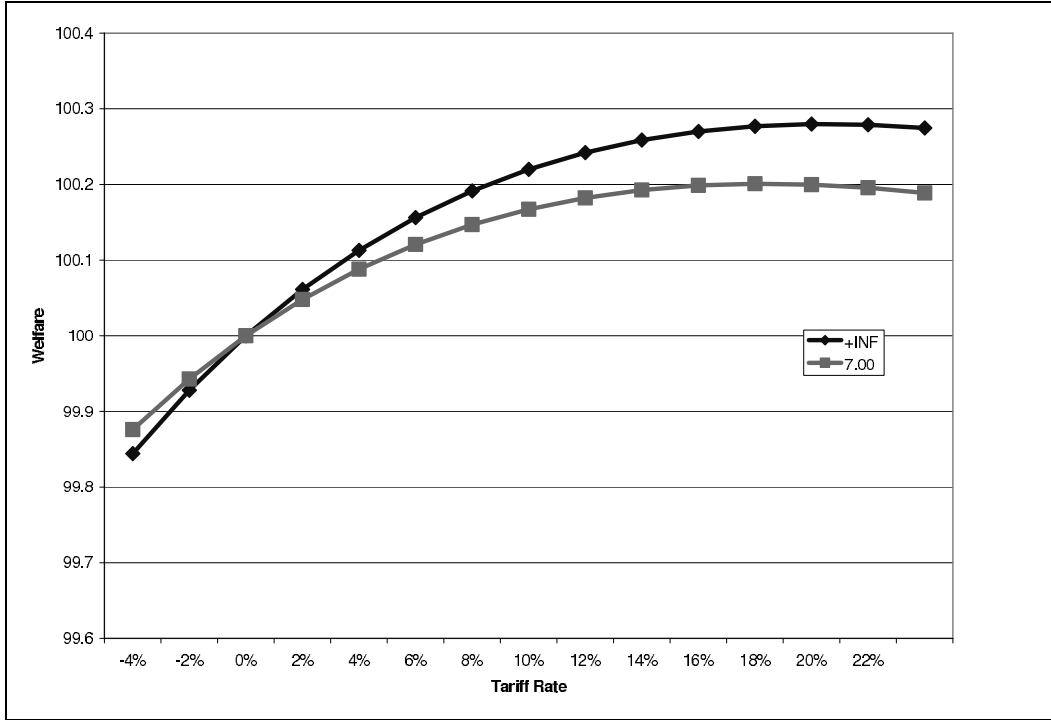
unobserved trade costs will be associated with more remote regions. The calibrated model will systematically impose more home bias on average to those countries that are more remote. The results for Australia are similar to those for Chile, which generally support the argument that home bias is important.

It is also useful to examine the results for the U.S. The relative size of the U.S. economy and the U.S. presence in world markets indicate that the optimal uniform tariff must be relatively high. Figure 6 plots the welfare curves for the U.S. For the U.S. the optimal rate of protection is relatively insensitive to our assumption about firm differentiation. This is consistent with the analysis in Section 4 (Table 3), where we showed that traditional large country effects dominate the firm differentiation effect at relatively modest shares of world income. The optimal tariff for the U.S. falls from 20% under the standard Armington formulation to 18% when we consider firm differentiation. This is roughly in the range of the results presented in Table 3 for an economy the size of the U.S.

To summarize our unilateral policy experiments, we find consistently smaller optimal tariffs when firm differentiation is included. This supports our overall hypothesis that firm differentiation is important. We also find, however, that in the applied model the reduction in optimal tariffs is not as dramatic as in our purely theoretic experiments. We suggest that this is due to the tendency for simulation models to accommodate a lack of trade to home bias. We find evidence that remoteness, which is correlated with home bias in calibrated models [Hillberry et al. (2005)], tends to reduce the impact of adding firm-level differentiation.

One additional point deserves mentioning in the context of our unilateral experiments. Notice that for each focus country that imposes a positive tariff over the relevant range, the welfare curve under no differentiation lies everywhere above the welfare curve assuming firm-level differentiation. This indicates that there is more to lose by reducing tariffs (below the optimal) when we ignore firm-level differentiation. Again this strongly supports our argument that traditional methods might understate the value of liberalization, if in fact

Figure 6: U.S. welfare under a uniform tariff relative to global free trade



firm varieties are important.

In addition to looking at hypothetical unilateral experiments we utilize the calibrated applied model to examine the removal of tariffs between the US and Australia. This allows us to examine the model's performance relative to applied applications that appear in the literature. We compare our results to a number of studies that have examined the likely impacts of the US-Australia Free Trade Agreement. Table 6 presents the results from four different parameterizations of our calibrated model, and selected results from three studies that appear in the literature.

The first scenario, ARM_7, is intended to give a close comparison of the pilot model to the United States International Trade Commission (2004) analysis of the US-Australia Free Trade Agreement. Aggregate results from the USITC study are reported under the column heading USITC 9090 in Table 6. In the scenario ARM_7 the pilot model adopts

Table 6: Simulating the US-Australia Free Trade Agreement

	Calibrated Pilot Model				Literature Estimates		
	ARM_7	MC_7	ARM_30	MC_30	USITC 9090	CIE	BKS
	$\sigma_f = +\infty$ $\sigma_n = 7$ $\sigma_{dm} = 3.5$	$\sigma_f = 7$ $\sigma_n = 7$ $\sigma_{dm} = 3.5$	$\sigma_f = +\infty$ $\sigma_n = 30$ $\sigma_{dm} = 15$	$\sigma_f = 30$ $\sigma_n = 30$ $\sigma_{dm} = 15$			
Change in US Welfare (\$M)	885	629	972	1,549	491	1,231	19,400
Change in US Total Imports (\$M)	1,852	1,777	21,482	24,630	1,161	NA	NA
Change in US Exports to Australia (\$M)	2,959	3,005	29,790	31,724	2,539	NA	NA
Change in US Imports from Australia (\$M)	2,769	2,954	32,017	44,356	1,759	NA	NA

a national-level elasticity of substitution of 7 across all sectors and an infinite sub-national elasticity (equivalent to sub-national perfect competition). This is roughly consistent with the Armington formulation of the USITC's 9090 model.¹² Thus, the model gives roughly consistent results. The change in US welfare and change in US imports from Australia are lower in the 9090 study but this might be attributed to exceptions in the actual agreement that are considered in the USITC analysis, but not in our scenario. We simply remove all tariffs as measured in the GTAP data.

In the next scenario, MC_7, the model is parameterized with a national and subnational

¹²There are a number of differences between the pilot calibration and simulations that we perform here and the model implemented by the United States International Trade Commission (2004). Most notably, our model simply adopts a single national-level elasticity across sectors. A national level elasticity of 7 is roughly consistent with the average of the commodity specific elasticities used by the USITC. Furthermore, our model takes the GTAP data and benchmark distortions at face value, where as the USITC 9090 model adds significant corrections and modifications. The data aggregations and scenario shocks also differ between the pilot and USITC models. To facilitate rapid diagnostics our model is more aggregated. The scenario examined in the pilot model is a complete liberalization of tariffs between the US and Australia. The USITC scenario includes detailed exceptions that were a part of the actual agreement. The simplifications made to the pilot model were made to facilitate a timely comparison and we would advise a more careful consideration of the real world in any actual simulation. That said, we feel that the results from our model are sufficiently close to the USITC's results to make a legitimate and useful comparison.

(firm-level) elasticity of substitution of 7. Adding sub-national monopolistic competition slightly reduces the US benefits from the FTA and slightly changes the aggregate trade flows. The loss in US welfare might be attributed to a reduction in foreign varieties that is not offset by increases in US or Australian varieties (in contrast Australian welfare impacts increase in the MC_7 case relative to the ARM_7 case).

The next two scenarios, ARM_30 and MC_30, indicate how the pilot model responds when the national elasticity of substitution is 30 and the sub-national elasticities are respectively infinite and 30. These scenarios illustrate the problematic nature of mitigating high optimal tariffs through elasticity increases. These scenarios have similar relative results, but larger welfare benefits and extremely large trade responses. Depending on whether we look at imports or exports, the ARM_7 and MC_7 scenarios generate bilateral trade responses in the range of 19% to 26%. In contrast, moving these elasticities up to 30 generates trade responses in the range of 188% to 390% of base flows—an order of magnitude higher.

In Table 6, we also include the aggregate welfare results used by the United States International Trade Commission (2004) to compare their model with other estimates. The column titled CIE includes the welfare calculation made by the USITC based on the Berkelmans et al. (2001) study for the Center for International Economics, and the column titled BKS is the welfare estimate made by Brown et al. (2004). It is notable that although our model adopts a monopolistic competition structure it does not come close to replicating the welfare impacts reported by Brown et al. (2004). As noted in the USITC study, the Brown et al. (2004) welfare results are substantial at 85% of their reported base trade volumes with the US.¹³ One reason that the results of Brown et al. (2004) are larger is because they assume substantial benchmark distortions in service sectors, which vanish as a result of the FTA.

We view our demonstration of the U.S.-Australia liberalization using our generalized

¹³Trade volume is measured as the sum of US imports from Australia plus the sum of US exports to Australia.

model as encouraging and useful. Our model generates results in the range of most standard models, but accommodates monopolistic competition elements that may be important to the measurement of potential gains from liberalization. The model offers a way of accommodating the gains associated with scale and variety effects without exaggerating trade responses. The model is demonstrated to be tractable in a real policy context and allows the user the flexibility to choose any level of national and sub-national differentiation.

6 Conclusion

Reconciling observed intra-industry trade with policy simulation models often involves adopting an assumption of product differentiation. Most applications assume national-level differentiation with perfect sub-national competition, or alternatively, firm-level monopolistic competition and no distinction between national varieties. It is well known that these different structures produce different implied optimal tariffs. This, along with industry scale effects, means that the different structures generate different simulated impacts from liberalization. Accurate policy simulation seems to dictate a careful examination of the actual industrial organization. Ideally, with unlimited resources and time, one might develop the *right* structure for each industry and product.

Unfortunately, policy relevance also dictates a timely response with relatively transparent economy-wide results. Parsimony in modeling is the rule. Following the critique of Brown (1987), we caution that assuming differentiated national products, although convenient, can lead to significant implications for the welfare analysis of commercial policy. In particular, we highlight the implicit allocation of market power over distinct varieties to policy makers and away from firms. This is troubling in that, traditionally, economists assume that the agents involved in the actual transactions (exporting firms in this case) extract the rents.

To show the importance of the implicit allocation of market power we develop a general-

ized model that parametrically accommodates both national and firm-level differentiation. Firm-level differentiation is accommodated via a standard model of monopolistic competition. The model is parsimonious but controls the degree of market power allocated to countries, versus firms, on a continuum. Our theoretic exploration of this new model is limited, but we have developed some interesting results, which are important for contemporary research.

Most importantly we show that the optimal tariff falls when we make parametric assumptions that allocate market power to firms rather than countries. This is important because it indicates that many contemporary studies that adopt national differentiation, with sub-national perfect competition, might understate the true benefits of liberalization. We show that the optimal tariff is most sensitive to our assumptions about firm-level differentiation for small countries and when there is relatively little home bias in the pattern of trade. We also demonstrate the generalized demand system in a pilot applied general equilibrium simulation of the US-Australia Free Trade Agreement. Moving the research forward, the theoretic implications of our generalized demand system deserve a closer examination. Through this examination we hope to highlight the important role of the firm in optimally pricing varieties on international markets.

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A Appendix: Illustrative General-equilibrium Simulation Model

```

1 $TITLE MULTI-REGION TRADE MAQUETTE WITH MONOPOLISTIC COMPETITION
2
3 $eolcom !
4 $if not setglobal theta $setglobal theta 0.001
5 $if not setglobal sig_n $setglobal sig_n 7
6 $if not setglobal sig_dm $setglobal sig_dm 7
7 $if not setglobal sig_f $setglobal sig_f 14
8 $if not setglobal lam $setglobal lam 0
9 $if not setglobal gam $setglobal gam 0.2
10 $if not setglobal hg $setglobal hg no
11
12 set r      regions      /
13     h ! home (focus) region
14     f1 ! foreign region 1
15     f2 ! foreign region 2
16 /;      alias (r,s,t,u);
17
18 parameters
19     theta      share of world endowment allocated to h,
20     sig_n      elasticity of substitution between national varieties,
21     sig_dm      elasticity of substitution between domestic and imports,
22     sig_f      elasticity of substitution between firm-level varieties
23     lam        home bias parameter (proportional decrease in trade volume)
24     gam        share of economy that is not x sector
25     hg        switch for trade in homogeneous good
26     e(r)      value of benchmark traded goods by region
27     h(r)      value of benchmark leisure by region
28     m(r,s)    benchmark consumption of xr composite by region s
29     beta(s,r) benchmark consumption shares of traded composites;;
30
31 *      Assign values for the sensitivity parameters.
32 theta      =      %theta%;
33 sig_n      =      %sig_n%;
34 sig_dm     =      %sig_dm%;
35 sig_f      =      %sig_f%;
36 lam        =      %lam%;
37 gam        =      %gam%;
38 hg         =      %hg%;
39
40 *      Calculate e(r) based on the leisure to income
41 *      share and symmetric foreign countries. Nominal
42 *      world income is normalized to 100 at the benchmark.
43 e("h")=100*(1-gam)*theta;
44 e(r)$(ord(r) gt 1)=100*(1-gam)*(1-theta)/(card(r)-1);
45 h(r)=e(r)*(gam/(1-gam));
46 display e;
47

```

```

48 *      Imports equal income share of foreign endowments
49 *      less the proportional trade reduction (1-lam).
50 m(s,r)      =(1-lam)*e(s)*e(r)/sum(t,e(t));
51 *      Domestic consumption equals income share of home
52 *      endowment plus the volume of reduced trade
53 m(r,r)      =e(r)*((e(r)/sum(t,e(t)))+
54              lam*(sum(s$(ord(s) ne ord(r)),e(s)/sum(t,e(t))))
55              );
56 beta(s,r)=m(s,r)/e(r);
57
58 *      Declare the policy instrument
59 parameter tar      home country tariff rate /0.0/;
60
61 *      Elasticity dependent first-order parameters
62 Parameter alpha_f benchmark reference price correction;
63 alpha_f      = ((sig_f-1)/sig_f);
64
65 Positive Variables
66      x(r)      quant index on dix-stig composite (gross of scale effect)
67      xf(r)      quantity index on aggregate output from firms
68      n(r)      number of firms index
69      a(r)      armington activity
70      w(r)      welfare
71
72      px(r)      price index on dixit-stiglitz composite from r
73      pf(r)      price of a representative firm variety from r
74      pa(r)      price index on armington composite
75      pw(r)      true-cost-of-living index
76      pl(r)      price index on labor
77      py      price index on homogeneous factor
78
79      ra(r)      nominal income;
80
81 Equations
82      prf_x(r)      optimal dixit-stiglitz activity level
83      prf_xf(r)      profit maximization (mc=mr)
84      prf_n(r)      free entry condition (tr=tc)
85      prf_a(r)      optimal armington activity level
86      prf_w(r)      optimal consumption
87
88      mkt_px(r)      mkt clearance for dixit-stiglitz composite
89      mkt_pf(r)      mkt clearance for firm output
90      mkt_pa(r)      mkt clearance for armington aggregate
91      mkt_pw(r)      mkt clearance for utils
92      mkt_pl(r)      mkt clearance for labor
93      mkt_py      mkt clearance for homogeneous factor
94
95      bc_ra(r)      budget constraint
96 ;
97
98 prf_x(r)..

```

```

99      ((n(r)*pf(r)**(1-sig_f))**(1/(1-sig_f)))*(1/sig_f)
100      + pf(r)*(not 1/sig_f)
101      - px(r) =g= 0;
102
103 prf_xf(r)..
104      pl(r)*(not hg)+py$hg - pf(r)*(1-1/sig_f) =g= 0;
105
106 prf_n(r)..
107      ((pf(r)-(pl(r)*(not hg)+py$hg))*xf(r)
108      -(pl(r)*(not hg)+py$hg)*(1/(sig_f-1)))*(1/sig_f)+
109      (n(r)-1)*(not 1/sig_f) =e= 0;
110
111
112 prf_a(r)..
113      alpha_f*(beta(r,r)*px(r)**(1-sig_dm)+
114      (1-beta(r,r))*((sig_dm-sig_n)/(1-sig_n))*
115      (sum(s$(ord(s) ne ord(r)),beta(s,r)*
116      (px(s)*(1+tar$(ord(r) eq 1)))*(1-sig_n)
117      )**((1-sig_dm)/(1-sig_n)))
118      )**(1/(1-sig_dm)) - pa(r) =g= 0;
119
120 prf_w(r)..
121      pa(r)**(1-gam)*((pl(r)**gam)*(not hg)+(py**gam)$hg)
122      - pw(r) =g= 0;
123
124 mkt_px(r)..
125      alpha_f*e(r)*x(r)
126      -a(r)*(alpha_f*m(r,r))*
127      (pa(r)/(alpha_f*px(r)))*sig_dm
128      -sum(s$(ord(s) ne ord(r)),
129      a(s)*(alpha_f*m(r,s))*
130      (pa(s))*sig_dm *
131      (1/(alpha_f*px(r)*(1+tar$(ord(s) eq 1)))*sig_n *
132      (sum(t$(ord(t) ne ord(s)),
133      beta(t,s)/(1-beta(s,s))*
134      (alpha_f*px(t)*(1+tar$(ord(s) eq 1)))*(1-sig_n))
135      )**((sig_n-sig_dm)/(1-sig_n))) =g= 0;
136
137 mkt_pa(r).. a(r)*e(r) - w(r)*e(r)*pw(r)/pa(r) =g= 0;
138
139 mkt_pf(r).. alpha_f*e(r)*n(r)*xf(r)-alpha_f*e(r)*x(r)**alpha_f =g= 0;
140
141 mkt_pl(r)..
142      (e(r)*(1/(1-gam)))-
143      e(r)*(gam/(1-gam))*w(r)*pw(r)/pl(r)-
144      e(r)*n(r)*xf(r))*(not hg) + (-pl(r))$hg =g= 0;
145
146 mkt_py..
147      sum(r,e(r)*(1/(1-gam)))-
148      e(r)*(gam/(1-gam))*w(r)*pw(r)/py-
149      e(r)*n(r)*xf(r)

```

```

150         )$(hg) + (-py)$ (not hg) =g= 0;
151
152 mkt_pw(r)..
153     pw(r)*w(r)*(e(r)*(1/(1-gam))) - ra(r) =g= 0;
154
155 bc_ra(r).. ra(r) =e=
156     pl(r)*(e(r)+h(r))$(not hg)+ py*(e(r)+h(r))$hg+
157 *tariff revenues
158     tar*sum(s$(ord(s) ne 1),
159     px(s)*a(r)*(alpha_f*m(s,r))*
160     (pa(r))**sig_dm *
161     (1/(alpha_f*px(s)*(1+tar)))**sig_n *
162     (sum(t$(ord(t) ne ord(r)),
163     beta(t,r)/(1-beta(r,r))*
164     (alpha_f*px(t)*(1+tar))** (1-sig_n))
165     )**((sig_n-sig_dm)/(1-sig_n))
166     )$(ord(r) eq 1);
167
168 model mrtmc_mcp /
169     prf_x.x, prf_a.a, prf_w.w,prf_xf.xf,prf_n.n,
170     mkt_px.px, mkt_pa.pa, mkt_pf.pf,mkt_pl.pl,mkt_py.py,mkt_pw.pw,
171     bc_ra.ra/;
172
173 *Assign the benchmark index levels:
174 x.l(r)=1;xf.l(r)=1;n.l(r)=1;a.l(r)=1;w.l(r)=1;
175
176 px.l(r)=sig_f/(sig_f-1);pf.l(r)=sig_f/(sig_f-1);
177 pa.l(r)=1;pw.l(r)=1;
178
179 ra.l(r)          =(e(r)*(1/(1-gam)));
180
181 * Set the numeraire
182 pl.fx("h")$(not hg)=1;py.fx$hg=1;
183
184 *Set the level values to zero for unused variables
185 py.l$(not hg)=0;pl.l(r)=1$(not hg);
186
187 mrtmc_mcp.iterlim=0;
188 solve mrtmc_mcp using mcp;
189 abort$(mrtmc_mcp.objval > 1e-5) "MCP BENCHMARK IS NOT BALANCED";

```