Trade Liberalization, Product Variety and Growth in a Small Open Economy: A Quantitative Assessment

by

Thomas F. Rutherford
Associate Professor, Department of Economics, University of Colorado

and

David G. Tarr

Abstract: We develop a numerical growth model that quantifies the welfare effects of trade liberalization. Additional intermediate input varieties provide the engine of growth and dramatically magnify the welfare gains from trade liberalization. In our central model, a ten percent tariff cut leads to a 10.6 percent estimated gain in Hicksian EV. Systematic sensitivity analysis shows that there is virtually no chance of a welfare increase less than three percent, but a 6.6 percent chance of a welfare gain greater than 18 percent. We show that complementary reforms are crucial to fully realize the potential gains from the trade reform. JEL Classification: F12, F17, F13

Keywords: trade liberalization, product variety, growth, computable general equilibrium.

Address correspondence to:

David Tarr
Mailstop No. MC3-303
The World Bank
1818 H St., N.W.
Washington D.C. 20433
E-mail: dtarr@worldbank.org
Fax: (202) 522-1159
Tel.: (202) 473-7677
1. Introduction

International trade economists have typically argued that an open trade regime is very important for economic development. This view has been based partly on neoclassical trade theory, which generally finds that a country improves its welfare from trade liberalization, partly on casual empirical observation that countries which remain highly protected for long periods of time appear to suffer significantly and partly on several empirical papers (e.g., Dollar (1992), Edwards (1993), Sachs and Warner (1995)) that find that trade or trade liberalization is beneficial to growth. A troubling problem is that the numerical modeling estimates of the impact of trade liberalization have generally found that trade liberalization increases the welfare of a country by only about one-half to one percent of GDP, gains which are very small in relation to the paradigm. The consistently small estimated welfare gains in constant returns to scale (CRTS) models of trade liberalization came to be known as the “Harberger constant.” Although increasing returns to scale (IRTS) models (such as Harris, 1984) have produced gains up to ten percent of GDP, the estimates remain less than convincing for a strong version of the paradigm. For many years authors have claimed that the welfare gains from trade liberalization would be much larger if the dynamic impact of trade liberalization were taken into account, but we are only beginning to develop such models.

There are endogenous growth models, such as Young (1991), that show that if trade leads to specialization in products without productivity enhancing characteristics and there are no spillovers from trade, openness can be immizerizing. And Grossman and Helpman (1990) have shown that trade can induce shifts between the manufacturing and research and
development sectors that can either speed up or slow down worldwide growth. On the other hand, there are many endogenous growth models (for example, Romer (1990), Romer and Rivera-Batiz (1991), Grossman and Helpman (1991) and Segerstrom, Anant and Dinopoulos (1990)) that show that trade liberalization unambiguously increases economic growth. Even these latter models, however, have not shown that trade liberalization has a large positive impact on welfare. That is, due to the complexity of the models the theoretical literature has necessarily focused on a comparison of the steady-state growth paths. The theoretical literature does not derive the dynamic adjustment path, the time it takes to converge to the new steady-state path, and does not evaluate the adjustment costs or foregone consumption necessary to achieve the new higher steady state growth path. That is, even if the theoretical endogenous growth literature has shown that trade liberalization results in a new higher steady-state growth path, there could be very small welfare gains if it takes a long time to reach the new growth path and there are large adjustment costs in the transition. For example, Connolly (1999) has developed a quality ladder numerical model of North-South trade in which the South learns how to imitate and innovate by trade. She shows that after the South opens to trade with the North, the North loses due to transition costs despite having a larger long run growth rate. Although our paper incorporates some additional dimensionality relative to the theoretical literature the principal contribution of our paper is not theoretical. Rather we derive the dynamic adjustment path which allows us to numerically evaluate the welfare effect and adjustment costs during the transition.

International trade can have an impact on the total factor productivity of a country through a number of mechanisms (see Grossman and Helpman (1991) for a general

-2-
theoretical discussion). Our approach follows from Romer (1994) who emphasized that proper modeling of the impact of trade protection on the reduction in the number of available varieties is crucial to properly quantifying the welfare impact of trade liberalization. The crucial idea of our model is that imports of a larger variety of intermediate inputs allow producers to increase productivity through selection of intermediate inputs that more closely match their production requirements. Support comes from several sources: Cabellero and Lyons (1992) who show that productivity increases in industries when output of its input supplying industries increases. Coe, Helpman and Hoffmaister (1997) find that foreign research and development increases domestic total factor productivity and that the positive spillover effect of foreign research and development is stronger the more open the economy is to intermediate inputs. Finally, Feenstra et al. (1999) show that increased variety of exports in a sector increase total factor productivity in most manufacturing sectors in Taiwan (China) and Korea, and they have some evidence that increased input variety also increases total factor productivity.

We develop a dynamic small open economy model defined over a 54 year horizon, from 1997 to 2050 with terminal constraints which approximate an infinite horizon. There are two sectors $X$ and $Y$. The $Y$ sector produces goods for domestic and export markets under constant returns to scale (CRTS). Inputs into $Y$ are labor and a pure intermediate good $X$. The good $X$ is produced by both foreign and domestic firms under the large group monopolistic competition assumption and IRTS. We employ the by now standard assumption that inputs of $X$ affect the production of $Y$ according to a Dixit-Stiglitz function. This means that additional varieties of $X$ reduce the cost of producing $Y$. The only tax distortion in the
economy in the benchmark data set is a twenty percent tariff on imports. We first construct a steady state growth path with which we can compare results of counterfactual experiments. We then reduce the tariff to ten percent and compare all variables to their values in the benchmark steady-state. We construct a series of counterfactual scenarios to determine the sensitivity of the results to tax, macro and financial policies, as well as to different tariff cuts and parameter specification. We evaluate the welfare consequences of a change in policies, i.e., we report the Hicksian equivalent variation for the infinitely-lived representative agent.

Some of our most important results are as follows: with lump sum revenue replacement, reducing a tariff from 20 percent to 10 percent produces a welfare increase (in terms of Hicksian equivalent variation over the infinite horizon) of 10.6 percent of the present value of consumption in our central model. Systematic sensitivity analysis with over 34,000 simulations in this model showed that there is virtually no chance of a welfare gain of less than 3 percent but a 6.6 percent chance of a welfare gain larger than 18 percent. We investigated several modeling variants and performed a sensitivity analysis on all the key parameters and found that the welfare estimates for the same tariff cuts ranged up to 37.4 percent with capital flows, and down to 4.7 percent with our most inefficient replacement tax—a tax of capital. The latter result shows, importantly, that even the very inefficient tax on capital is superior to the tariff. Doubling the size of the tariff cuts, to better reflect the substantial liberalizations of many developing countries in the past 30 years, resulted in roughly doubling the estimated welfare gains.

Large welfare gains in the model arise because the economy benefits from increased varieties of foreign \( X \) which dominate the decrease in varieties of domestic \( X \). In order to
assess the importance of variety gains, we perform the tariff reform in the same fully dynamic model, except that we assume that the X sector is subject to constant returns to scale and perfect competition; then additional varieties do not increase total factor productivity. In this model the “Harberger constant” reemerges, as welfare gains are about 0.5 percent of the present value of consumption.

Our results illustrate the crucial importance of complementary reforms to fully realize the potential gains from the trade reform. Notably, with the ability to access international capital markets, the gains are roughly tripled. Moreover, use of inefficient replacement taxes will significantly reduce the gains. These combined results show that complementary macroeconomic, regulatory, and financial market reforms to allow capital flows and efficient alternate tax collection are crucial to realize the potentially large gains from trade liberalization.

The remainder of this paper is organized as follows. Section 2 outlines essential features of our model. Section 3 presents results and sensitivity analysis with respect to model structure and parameter specification. Section 4 concludes by briefly examining the results in the light of econometric evidence on the impact of trade liberalization on growth and discusses the role for optimal subsidies in this model.

2. Model Formulation

We consider a two sector economy. The X sector, which is composed of both domestic and foreign firms, produces intermediate goods under increasing returns to scale (IRTS) and imperfect competition. The Y sector produces exports and final goods for the
domestic market under perfect competition and constant returns to scale (CRTS) in its two inputs—labor and $X$, where $X$ is a Dixit-Stiglitz aggregate of the available varieties. Markups on goods in the IRTS sector are based on the Chamberlinian large group assumption—that is, the elasticity of demand facing the representative firm is equal to the compensated elasticity of substitution between varieties. Final demand arises from an infinitely-lived representative agent who is at the margin indifferent between an additional unit of consumption and an additional unit of investment. In this section we outline the key features of the model in terms of the objectives and constraints facing various agents.

2.1 Consumer Behavior

The intertemporal utility function of the infinitely lived representative consumer is the discounted sum of the utility of consumption over the horizon:

$$U = \left( \sum_{t} \Delta^{t} C_{t}^{p} \right)^{\frac{1}{p}}$$  \hspace{1cm} (1)

In this equation the parameter $\Delta$ controls the intertemporal elasticity of substitution and $\Delta$ is the single period discount factor. Aggregate consumption in a given period ($C_{t}$) is a Cobb-Douglas aggregate of consumption of domestic and imported final goods:

$$C_{t} = CD_{t}^{a_{d}} CM_{t}^{1-a_{d}}$$  \hspace{1cm} (2)

We assume that imported final goods cannot be produced in the home market, due to technical limitations of the domestic final goods sector. The agent’s intertemporal and within-period consumption decisions are weakly separable. Thus, the typical static first order condition applies on consumption decisions within a time period, given a decision on how
much to spend on consumption in any period. In the standard manner, the intertemporal
decision is based on the maximization of the utility function subject to the constraint that the
present value of consumption equals the present value of income:

$$\max U = \left( \sum \Delta^t CD_t^{\infty} \rho \right)^{\frac{1}{\rho}}$$

$$\left(1 + \tau_c\right) \left( \sum p_t^D CD_t + \sum p_t^U CM_t \right) = \sum w_t \bar{L} +$$

In this expression, $p_t^D$ is the price of domestic inputs, $p_t^U$ is the cost of imported final
goods, gross of tariff, $w_t$ is the wage rate, and all prices are defined in present value terms,
discounted to period 0 (=1997). The right side of the constraint, which is the present value
of income, includes the present value of wage income together with profits from existing
capital stocks and patents. $J_c$ is the consumption tax, discussed below. In a steady-state
equilibrium, there are no pure profits, but along an adjustment path moving to a new steady-
state there may be returns associated with existing capital and markups over marginal cost.
In other words, pure profits and losses are only associated with current (extant) firms. All
firms formed during the model horizon earn zero economic profit.

### 2.2 Government Revenue and Expenditure

The government purchases domestic final output ($GD_t$) and imported final output
($GM_t$) to assure that the benchmark steady state level of public provision is maintained, i.e.

$$GD_t^{\infty} GM_t^{1-\infty} = \bar{O}_t$$
The public sector budget constraint (which determines the replacement tax rate) is then written in present value terms as:

$$GD_t + p_t^M GM_t = \sum_i \left( T_i^M(t_i^M) + T_i^C(t_i^C) + T_i^K(t_i^K) \right)$$  \(5\)

In this equation the sum on the left represents the cost of public expenditures, and the sum on the right represents the imposition of an equal-yield constraint asserting that any change in tariff rates must be compensated by a permanent change in one of three alternative domestic tax instruments: consumption taxes, capital income taxes and final output taxes, respectively. The tariff rates \(t_i^M\) are exogenously specified policy variables, whereas the tax rates on consumption, capital income and output are determined endogenously to assure that the government budget constraint is satisfied.\(^9\)

2.3 Sales and Production of the Final Good.

Good \(Y\) is produced as differentiated products for sale in the domestic and international markets. A constant elasticity of transformation (CET) function shows the transformation possibilities in a given period between domestic (\(D_t\)) and export (\(E_t\)) sales for a given composite output level \(Y_t\). The shares of sales at home and abroad are determined by relative prices given that firms produce the final good to maximize profit subject to the CET constraint:

$$T_t = \left[ \eta_d \left( \frac{D_t}{D} \right)^{\frac{\eta}{\eta_0}} + (1 - \eta_d) \left( \frac{E_t}{E} \right)^{\frac{\eta}{\eta_0}} \right]^{\frac{\eta_0}{\eta}}$$  \(6\)
In this equation parameters $\bar{D}$ and $\bar{E}$ are the base year (1997) levels of output to the domestic and export markets, and $\theta_0$ is the baseline value share of domestic sales in total sales (the base year production level is scaled to unity) and $\theta$ is the elasticity of transformation.

Production of the $Y$ composite in any period (we drop the time subscript for the remainder of this subsection) is associated with a nested production function based on inputs of labor ($L$) and differentiated intermediate inputs ($x_i$). Given prices of intermediate goods and labor, the aggregate production sector operates so to minimize the costs of producing a given output subject to the constraint:

$$Y = \frac{L^{1-\alpha}}{\left[ \sum_{i=1}^{N} x_{i j}^{\rho} \right]^{\alpha \rho}} = \frac{L^{1-\alpha}}{\left[ \sum_{i=1}^{n_D} x_{i D}^{\rho} + \sum_{j=1}^{n_F} x_{i F}^{\rho} \right]^{\alpha \rho}} \quad (7)$$

In this function, the intermediate inputs and labor enter in a Cobb-Douglas aggregate with value shares determined by base year demands. It is evident from the production function that we have firm level rather than national product differentiation. Since costs of varieties can differ by foreign or domestic origin, at the second level, within the intermediate input ($X$) nest, we account for substitution between domestic and foreign varieties according to a constant-elasticity-of-substitution aggregation. The inputs of intermediates from domestic and foreign firms represent the effective supply of $X$ from these firm types. The effective supply of all type $j$ firms is described by:

$$\bar{x}_j = \left( \frac{\sum x_{j}^{\rho}}{n_j} \right)^{1/p} = \left( \sum_{j=1}^{n_F} x_{j F}^{\rho} \right)^{1/p} = \frac{1-p}{p} \bar{x}_j, \quad j \in \{D, F\} \quad (8)$$
in which $x_{ij} = x_j$ (by symmetry) is output of a representative type $j$ firm. $\overline{x}_j = n_j x_j$ is the total output from type $j$ firms. Holding total output from type $j$ firms constant, effective supply from type $j$ firms increases with 

$$\frac{1-\rho}{n_j} = \frac{1}{n_j^{\rho-1}},$$

which is the "variety effect multiplier." The multiplier increases with $n_j$ and increases as $F$ decreases toward 1 ($F > 1$). (The second equation in this expression reflects our assumption of symmetric firm structure.) We then may express the aggregate production function as:

$$Y = \overline{L}^{1-\sigma} \left[ n_D^{1-\rho} \overline{x}_D^{\rho} + n_F^{1-\rho} \overline{x}_F^{\rho} \right]^{\frac{1}{\rho}} \quad (9)$$

Following Romer and others, we assume that the value share of $X$ in aggregate production is related to the elasticity of substitution between varieties so that $\sigma = \rho$, which implies that the elasticity itself is defined by the value share as $\sigma = 1/(1-\sigma)$. Making this substitution, we have the following expression for aggregate output:

$$Y = \left( n_D \overline{L} \right)^{1-\sigma} \overline{x}_D^{\sigma} + \left( n_F \overline{L} \right)^{1-\sigma} \overline{x}_F^{\sigma} \quad (10)$$

2.4 Market Clearance Conditions

Output of the good $Y$ supplied to the domestic market can be consumed or invested. Investment in $X_D$ and $X_F$ sectors involve forgone consumption of domestic output. The market clearance for macro output sold in the domestic market is given by:

$$i_t = CD_t + GD_t + \sum_{j \in D,F} \left[ \beta_j B_{j} + I_{j} + n_j \left( a_j + a_{jD} x_j \right) \right] \quad (11)$$
This equation states that domestic output is purchased by households \((CD_t)\), government \((GD_t)\) and firms. In turn, the demand for domestic output from firms derives from four sources: (i) inputs to blue-print design \((\beta_j^D B_j)\), (ii) inputs to physical capital formation \((I_j)\), (iii) recurring fixed costs \((n_j a_j)\) and (iv) variable costs of production \((n_j a_j^D x_j)\). The term \(a_j^D\) is a *unit demand function* for domestic inputs to production, the value of which depends on relative prices in period \(t\).

Both firm types (domestic and foreign) are treated symmetrically, although we adopt parameters reflecting a relatively larger share of domestic inputs for the domestic firm. Domestic firms are assumed to make investments in plant and equipment, whereas foreign firms who generally import all the key components invest solely in distribution facilities such as warehouses and transportation equipment.

The corresponding supply-demand balance for imported goods is as follows:

\[
M_t = CM_t + GM_t + \sum_{j \in (D,F)} \left( \beta_j^M B_j + n_j a_j^M x_j \right)
\]

(12)

Thus, imports enter into final demand by consumers and government and intermediate demand by firms. Imported inputs may be required to establish a new firm \((\beta_j^M B_j)\), and they may also enter into the cost of production \((n_j a_j^M x_j)\). The term \(a_j^M\) is a *unit demand function* for imported inputs to production, the value of which depends on relative prices in period \(t\).
2.5 Capital Stock Evolution

In our model, capital is firm-specific following installation, and investment rates may fall to zero as a consequence of unanticipated changes in policy parameters. Following a standard Solow growth model, investment in period $t$ produces a unit of additional capital in the following year which may be used for production in the future. Physical capital stock depreciates at a constant geometric rate:

$$K_{j+1} = \lambda K_j + I_j \quad j \in \{D,F\}$$  \hspace{1cm} (13)

whereas the number of blueprints (=number of firms) of each type are permanently in the market after they are produced:

$$n_{j+1} = n_j + B_j \quad j \in \{D,F\}$$  \hspace{1cm} (14)

The demand for capital equals the demand per firm times the number of firms:

$$K_p = a_p^F n_p \quad j \in \{D,F\}$$  \hspace{1cm} (15)

In this equation the term $a_p^F$ is a *unit demand function* for capital inputs to production, the value of which depends on relative prices in period $t$.

2.6 Firms and Production Varieties

Our model is one of a small open economy. In particular, we assume that the small open economy has only a negligible impact on the number of varieties available on world markets, and the cost of blueprints for foreign firms. In general, we observe that there are many more varieties of products available on world markets than are available in the small
open economies. Accordingly, we assume that the decision facing foreign firms is how many of the products for which blueprints already exist can be profitably introduced in the local economy. Thus, the fixed costs of initial product development are a much smaller component of the cost of production for foreign firms than for domestic firms – and a larger fraction of total fixed costs are associated with recurring fixed costs of selling in the domestic market.

An equivalent and perhaps easier way to think of this model is to assume there are two types of domestic firms selling intermediate products: producers and distributors. The distributors import the product from abroad under license at world market prices. The distributors incur once and for all costs to adapt the product to the domestic market and ongoing distribution costs, where the latter have both fixed cost and variable cost components.

In sector $X$ there is a one to one correspondence between firms and product varieties. The production of good $X$ involves both fixed and variable costs. Variable costs include inputs of domestic and imported goods and capital. These inputs are aggregated in a Cobb-Douglas production function. For a single firm, we have:

$$x_j = \phi_j \left( \theta_m^{Mj} \theta^{Mj} \left( A_m^{D_j} \theta^{Dj} \left( A_m^{K_j} \theta^{Kj} \right) \right) \right) \quad j \in \{D,F\}$$

(16)

in which $A_m^k = x_m^{a_m^k} \quad k \in \{M,D,K\}$, and the budget shares for imported, domestic and capital inputs sum to unity ($\theta^{Mj} + \theta^{Dj} + \theta^{Kj} = 1$) -- marginal costs of production exhibit constant returns to scale. Most of the costs for foreign firms selling in the domestic market are associated with capital services and imported goods (i.e., $\theta^{Dj}$ is small). In this setting the foreign firm's (distributor’s) production costs may be interpreted as the cost of maintaining imported inputs and the maintenance of a distribution system within the country.
Firm owners choose inputs which minimize costs of production, taking prices of domestic, imported and capital inputs as given. Producer inputs are chosen to minimize the cost of production:

$$\min_p \quad p_t^D a^D_{jt} + p_t^M a^M_{jt} + r_{jt} a^R_{jt}$$

s.t. \( \phi_j \begin{pmatrix} a^M_{jt} \\ a^D_{jt} \end{pmatrix} + \begin{pmatrix} a^D_{jt} \\ a^R_{jt} \end{pmatrix} = 1 \)

in which \( p_t^D \) is the price of domestic inputs, \( p_t^M \) is the cost of imported inputs, gross of tariff, and \( r_{jt} \) is the rental price of capital services for type \( j \) firms in period \( t \).

Fixed costs in the production of \( X \) have two components: (i) the present value of "overhead," i.e., the present value of the recurring fixed costs involving only domestic inputs which is incurred in every period that the firm operates \( (a_j) \), and (ii) "setup cost," a one time research and development (or blueprint) cost that must be incurred in order to design and market a new product. We assume that foreign firms (or distributors) sell products which have been designed abroad, so their setup costs represent only the cost of adapting an existing design to the domestic market. Consequently, we assume that blueprint costs are only ten percent of the total fixed costs for foreign firms, but ninety percent for domestic firms. The parameters \( \beta_j^D \) and \( \beta_j^M \) (defined above) are calibrated to be consistent with these proportions, but are varied in the sensitivity analysis.\(^{10}\) We assume in the present model that there is no international trade in blueprints. Hence domestic firms may not license designs but must purchase resources to develop new products from scratch.\(^{11}\)
The model is deterministic and firms have perfect (point) expectations of future prices. Hence, a new firm will enter at time $t$ if and only if the present value of markup revenue over marginal costs into the future is equal to or greater than the fixed costs of initial product development plus the present value of the fixed costs of operation (for foreign and domestic firms). It is possible to interpret this decision using Tobin's $q$ theory (see Baldwin and Forslid, 1996). The rate of investment in blueprints occurs to the point that the stock market value of the net income (i.e., the present value of net surplus) equals the replacement costs, namely the marginal cost of a blueprint, since R&D is perfectly competitive. We introduce a state variable for each firm type which tracks the present value of future markup earnings; this effectively treats the human capital embodied in blueprint designs in the same analytic framework as is conventionally applied to physical capital formation. The free-entry assumption assures zero profit over the infinite horizon, and the time path of future prices affect not only investment activity but the decisions by firms to enter markets and undertake product development. Optimization over the infinite horizon applies not only to consumers and competitive firms, but also to the managers of monopolistically competitive firms.\footnote{12}

The production function for the final good $Y$ listed above is perfectly symmetric with respect to its use of intermediate inputs from domestic and foreign firms, i.e, we have firm level product differentiation, with no brand or national preferences. Varieties of different vintages are equally preferred but differentiated. In this framework, all domestic firms that operate sell the same quantity of output and their varieties sell for the same markup-inclusive price. Likewise all foreign firms which operate sell the same quantity at the same price. Domestic and foreign firms enter symmetrically in the final goods production function so the
derived demand for domestic and foreign intermediates is symmetric; but their products remain differentiated so their prices may therefore differ. Since foreign and domestic firms are treated differently regarding their cost structures, their prices usually differ.

3. Model Results

We consider a 54-year model horizon, defined over the years 1997-2050. Initially there is only one distortion in the economy: a twenty percent tariff on imports of both goods $X$ and $Y$. In order to establish a point of reference we calibrate a model to a "benchmark" steady-state growth path with assumed baseline data corresponding to table 1. As is standard in these models, we have assumed that the number of firms is a continuous variable and we have taken the number of firms of each type to be an index equal to unity in the initial year of the benchmark steady state growth path. For details on the translation of input data to model parameters, see Appendix B of Rutherford and Tarr (1998).

In our central counterfactual scenarios, we reduce the tariff from 20 percent to 10 percent on an ad valorem (net) basis and compare the results in all scenarios to the benchmark steady-state equilibrium with the initial tariff in place. Unless otherwise indicated, all key variables are reported as a percentage of their values in the benchmark steady-state equilibrium.

In our central model we assume: (1) there are no spillovers from the entry of foreign firms on the costs of domestic intermediate producers; (2) that entry of an additional foreign or domestic firm conveys a positive externality (or spillover) by reducing the cost of a unit of aggregate intermediate products for the final goods industry (as explained in section 2.3); (3)
the lost tariff revenue is replaced by a tax on consumption. (Given the absence of a labor-leisure choice, this is equivalent to a Lump Sum tax.); and (4) the country has difficulty accessing international capital markets so it faces a balance of trade constraint in each period, i.e., the value of its exports must equal the value of its imports (both a world prices) in each period. Assumption (4) can arise because the country has imposed restrictions on financial flows, or because macroeconomic conditions in the country are such that it can not attract international investors. Assumptions (1)-(4) are relaxed in sections 3.2 - 3.5, respectively.

In all scenarios we present the Hicksian equivalent variation (EV). The EV is based on the intertemporal utility function optimized over the 54 year model horizon, with an approximation for the infinite horizon. (See Rutherford and Tarr (1998, Appendix A) for details.) We present EV in percentage terms, where the denominator is the present value of benchmark consumption over the infinite horizon. In the figures, we present the 54 year time path for the key variables (relative to the steady-state). The variables we report are as follows: figure 1: Final Consumption, composite of domestic and imported final goods; figures 2 and 3: Number of Domestic and Foreign Firms, respectively. (See Rutherford and Tarr (1998) for figures for several other variables.)

3.1 Tariff Reduction with Central Assumptions

We first consider the scenario in which we cut all tariffs from 20 percent to 10 percent. In this scenario, Hicksian equivalent variation (EV) increases by 10.6 percent of the present value of consumption over the infinite horizon. Results for all model variants are reported in table 2.
What is driving these results is the following. The removal of the tariff on imported intermediates results in an increase in the tariff ridden demand curve for imports and an increase in the price foreign firms receive for their products. This increases the present value of quasi-rents for foreign firms. Entry by foreign firms occurs in any period until the present value of the quasi-rents are driven down to the one time start up costs of establishing a domestic presence for the foreign firm plus present value of the fixed costs of operating the domestic subsidiary. After about 10 years, the number of foreign varieties stabilizes for the duration of the model horizon at about 30 percent more than in the steady state (see figure 3). The increase in imports, however, results in a substitution effect that reduces the demand for and price of domestic varieties; this shuts down investment and firm creation for the domestic variety for a period of about 6 years.

Although the increase in foreign varieties has the impact of decreasing the demand for domestic varieties of the intermediate good $X$, the domestic industry eventually stabilizes after 8 years at about 90 percent of its steady state value, rather than progressively going into demise. The principal reason for this is that the marginal productivity of domestic $X$ in $Y$ production increases as use of domestic $X$ in $Y$ declines. The entire labor force is employed in the production of $Y$, and it is not possible to reduce labor usage applied to domestic $X$ without also reducing labor usage in imported $X$. Thus, as domestic $X$ declines due to substitution toward cheaper imported $X$, its marginal product increases to eventually arrest the further decline of the domestic $X$ industry.

The transitional dynamics of the model in the early years are dominated by the increase in the number of foreign firms. The increase in the number of firms has an immediate
impact on the labor productivity in the final good sector inducing output of the final good sector to increase in the first year. This immediate increase in productivity and output of the final goods sector allows the economy to satisfy two constraints painlessly: (1) the economy is able to invest more in intermediate goods (it takes capital to produce the foreign variety) without reducing consumption in the short run relative to the steady state. Although the economy faces the problem of determining the optimal tradeoff between consumption and investment, the tradeoff is within the framework of an expanded choice set relative to the steady state. In fact, the economy consumes about 7 percent more in the initial years compared with the benchmark steady state (see figure 1); and (2) despite the period by period balance of trade constraint, the economy is able to import more foreign intermediate varieties, without reducing its imports of final goods. The economy meets its balance of trade constraint by exporting more of the final good. Thus, reducing the tariff does not result in any adjustment costs in this model except for the losses that accrue to the specific capital owners in the domestic intermediate goods sector.13 One possible way to dampen the productivity surge would be to assume that capital is acquired at increasing marginal costs, see Rutherford and Tarr (1999).

Due to an increase in the rental rate on capital during the transition, during the 54 year model horizon the economy grows at a rate (2.1 percent), which is above its steady-state growth rate (2 percent). In the long run, however, the domestic interest rate and the international interest rate converge asymptotically, so that the growth rate of the economy converges back to the original 2 percent steady-state growth rate.14 Thus, the gains we
estimate in this model are a combination of level effects and transitional dynamics; they are not the result of a higher steady-state growth path.

Since our model employs the Chamberlinian large group assumption, the markup over fixed costs remains unchanged, so there are no rationalization gains. Thus, these calculations show that the Ethier-Dixit-Stiglitz characterization of production, where additional varieties lowers costs, is sufficient to generate the large welfare gains and increase in per-capita income.

3.2 Tariff Reduction with Spillovers to the costs of Domestic Competitors

There are two kinds of spillovers in this model. Most importantly, an additional intermediate variety creates an externality for the final good sector by reducing the cost to the final good sector of a composite unit of intermediate inputs. In this scenario only, we allow for a second type of spillover: an increase in the number of foreign firms decreases the blueprint costs for domestic firms, with a spillover elasticity, \( \zeta \), is equal to four percent. (The cost of domestic blueprints is proportional to \( e^{T \eta_k} \), where \( \eta_k \) equals the proportional change in the number of imported varieties.) In the results reported in table 2, we take \( \zeta = 0.04 \) so that a 100 percent increase in the number of foreign varieties relative to the steady state, reduces the blueprint costs of domestic firms by roughly 4 percent relative to the steady state blueprint costs. When we cut the tariff on both final and intermediate imports from 20 percent to 10 percent, starting in the initial period, the equivalent variation of this scenario is 10.9 percent of the present value of consumption. In the sensitivity analysis reported in table 3 we simulate several values of \( \zeta \) up to 0.3. EV increases to 12.4 with \( \zeta = 0.3 \). The greater the spillover elasticity on the blueprint costs of domestic firms, the faster the domestic industry
recovers. Relative to the benchmark, the number of domestic firms in the year 2050 as a function of \( \ell \) is: -4\% (\( \ell = 0 \)); +1\% (\( \ell = 0.04 \)); +5\% (\( \ell = 0.2 \)); and +9\% (\( \ell = 0.3 \)).

Thus, spillovers on the blueprint costs of domestic firms does have a positive impact on the Hicksian equivalent variation, but the impact is smaller than the impact of several other elasticity and share parameters reported in table 3. The reason for the somewhat muted impact of this parameter is that what is most important to the welfare increase is the externality (or other spillover) from the number of varieties rather than the geographic source of them. With blueprint spillovers, once the profitability of investment is restored for the domestic industry producing good \( X \), the growth of new foreign varieties falls relative to no spillovers on domestic blueprint costs–so there are more domestic firms and varieties, but fewer foreign varieties. The loss of productivity due to the loss of foreign varieties mutes the gain in welfare due to the increased number of domestic varieties and the lower costs of creating them. As explained in the introduction, in quality ladder models it is possible to exclude all spillover externalities, so that in quality ladder models a greater range of results is derived from modifying spillover assumptions.

### 3.3 Constant Returns to Scale (No Variety Multiplier)

In this model, we replace increasing returns to scale and imperfect competition in the intermediate sector with constant returns to scale and perfect competition in a homogenous intermediate good. Although decisions by consumers and investors optimize the consumption-capital stock choice, only total output of the intermediate is important, so there is no productivity boost from additional varieties.
The Harberger constant reemerges, as equivalent variation for this scenario drops to 0.5 percent of the present value of consumption over the infinite horizon. Transitional dynamics are then more painful, since in order to finance the additional investment in the earlier period, consumption falls in the early years relative to the steady state.

3.4 Impact of Alternate Replacement Taxes

In the scenarios in this subsection, we use two alternate taxes as the replacement tax for the lost tariff revenue: a tax on output; and a tax on capital. The consumption tax is a Lump Sum distortionless tax in our model, but a tax on domestic output discriminates against domestic output in favor of imports, and against final output in favor of intermediate production. As a result of the relative inefficiency of the domestic output tax, the equivalent variation is reduced to a gain of 5.2 percent of the present value of consumption.

Finally, the tax on capital produces a consumption path that is inferior to the one with an output tax, but preferable to the benchmark path with the tariff in place, i.e., the tax on capital is the most inefficient of our three replacement taxes, but is better than a tariff in our model. In our model, the intermediate good $X$ uses capital intensively since only intermediate production uses capital as a primary input and only final goods use labor as a primary input. A tax on capital then discourages the introduction of new varieties since it discourages the investment required for the introduction of new varieties of products and discourages the production of intermediates relative to the production of final goods. The economy loses the productivity boost from the varieties and the gain in equivalent variation is 4.6 percent of the value of consumption. These results illustrate the importance of efficient tax replacement.
With inappropriate replacement tax mechanisms, the gains from trade liberalization can be drastically cut.

3.5 Capital Flows

In this scenario, the tariff is reduced from 20 percent to 10 percent, but the country is assumed to be able to borrow on international capital markets provided the borrowing is repaid within the model horizon. Thus, the period by period balance of trade constraint is replaced by the constraint that the present value of its exports less imports is zero over the model horizon, but all other assumptions in the central model remained unchanged. In this scenario Hicksian equivalent variation is 37.4 percent of the present value of benchmark consumption over the infinite horizon. There is an initial jump in consumption of about 23 percent relative to the steady state.

Why is the increase in EV with capital flows more than three times the EV value without capital flows? The ability of the country to borrow and run trade deficits allows the country to pay for additional imports which are are used to finance the start up capital of new foreign firms and to pay for the additional imports of foreign varieties. Foreign firms increase by almost 100 percent of their steady state value with capital flows by the year 2003, as opposed to an increase of about 35 percent of their steady state value without capital flows. The larger increase in foreign firms leads to a considerably larger increase in labor productivity, consumption and the wage rate in the early years.

What is interesting is that there is a much larger increase in the number of domestic firms with capital flows—in fact, the number of domestic firms increases dramatically relative to the steady state value by the end of the model horizon. This is explained by a real exchange
rate effect. The capital inflows in the early years result in less real exchange rate depreciation in the early years of the model compared with no capital flows (in fact, they result in real exchange rate appreciation in the first two years); but the capital outflows in the later years of the model result in a strong real exchange rate depreciation in those years (see Rutherford and Tarr, 1998, figure 2). The steeper real exchange rate depreciation with capital flows in the years following 2020 (compared with central assumptions) raises the costs of importing foreign varieties in those years, and shifts demand toward domestic varieties. Domestic agents, who fully anticipate future real exchange rate movements, recognize profit opportunities and begin to invest by the year 2003. Among the models we consider, it is perhaps ironic that the model with capital flows, where we see the largest initial increase of foreign firms, ultimately leads to by far the strongest resurgence of domestic firms, even compared to the model with spillovers on the costs of domestic competitors.

3.6 Sensitivity Analysis

In order to assess the robustness of the estimates, we executed 34,385 simulations of the central model. In each simulation values for the eight key parameters of the model were drawn randomly from uniform probability distributions. In this model, we assume the tariff rate is cut from 20 percent to 10 percent with lump sum tax replacement, there are no spillovers of foreign firm entry on the costs of domestic producers, and there is a period by period balance of trade constraint.

In figure 4, we display the sample distribution for Hicksian EV. The mean of the resulting sample distribution is an increase in EV equal to 10.5 percent of the present value of consumption, which is approximately the point estimate in the central case. The sample
variance is 23.8. Based on the sample distribution, there is a 95 percent probability that the welfare gain exceeds 4.5 percent. We observe that the distribution is skewed to the right. Notably, there is virtually no chance of a gain in Hicksian EV of less than 3 percent, but there is a 6.6 percent chance of a gain in Hicksian EV greater than 18 percent.

In order to better understand the impact of the parameters in our model we have also performed “piecemeal” sensitivity analysis. Central parameter values are employed in all scenarios, except for the parameter subjected to piecemeal sensitivity analysis. In table 3 we present these results. We also show the impact of different tariff changes. Except for the row where the benchmark tariff is changed, in all scenarios the tariff rate is reduced from 20 to 10 percent. Lump sum tax replacement and period by period balance of trade constraint is also assumed. We report results for a high, low and some intermediate value of the parameter that typically is different from the parameter value employed in our central simulation. We present the Hicksian equivalent variation (with the approximation for the infinite horizon) as a function of the parameter value.

The result from row 1 reports the impact of spillovers of domestic blueprint costs discussed in section 3.2. The results in row 2 and 3 indicate that, as is typical in comparative static models, the more elastic are the substitution possibilities, the greater the gains. In particular, with a larger elasticity of transformation, the economy is able to export more in response to a real exchange rate depreciation following tariff reduction, which allows it to pay for more imports; and the additional intermediate imports provide a productivity boost through the additional varieties. The impact of this parameter is quite strong.18
For the share of intermediates in final production ("), there are offsetting effects: a higher share of intermediates in final production should increase the number of varieties because again the proportional change induced by a ten percent tariff cut should induce a larger absolute increase in the number of varieties; but the larger is ", the smaller is the variety multiplier for any number of varieties. This explains why EV as a function of ", is not monotonic in the range of our central elasticity value.

In Rutherford and Tarr (1998, Appendix A) we show that as the rental rate on capital and the benchmark growth rate approach each other, a given permanent increase in consumption over the infinite horizon yields a larger EV. In rows 5 and 6, we see that EV increases as (R - G) decreases.

The larger the share of imports in intermediate use (2), the larger the EV gains. The reason is that for the given ten percent cut in the tariff, the same proportional effect on the share of imports, generates more imported varieties, with the consequent productivity boost, when this share is high. Although this share has a strong impact on welfare, information on this parameter is relatively good.

We have simulated the impact of changing the tariff to 10 percent from an initial tariff rate of 60 percent, 40 percent and 5 percent. The results are roughly proportional to the size of the tariff change, e.g., the cut from 40 percent to 10 percent is about three times the EV as the cut from 20 percent to 10 percent. Comparative static models produce the result that the welfare gains increase more than proportionately with the size of the tariff cut primarily because the area of the Harberger triangles increases more than proportionately with the tariff cut; but the results in this paper are based primarily on the externality from the number of
varieties which in these simulations do not increase more than proportionally with the tariff cut.

Finally, we simulate a change in the share of fixed costs that foreign firms must pay for blueprint costs (as opposed to the present value of recurring fixed costs). EV declines significantly as the share of blueprint costs increases. Since blueprint costs must be paid in the initial period that the firm is formed, they entail initial capital costs to a much greater extent than recurring fixed costs. This drives up the rental rate on capital in the early years and slows the formation of firms.

4. Extensions and Conclusions

4.1 Are the Welfare Estimates too Big?

Although estimates of equivalent variation have been widely seen as too small, some may question whether our estimates are too large. To put these numbers in perspective, in Rutherford and Tarr (1998, appendix A) we have analytically derived the relationship between a permanent increase in the steady state growth rate and equivalent variation. A welfare gain of between 10 and 35 percent of consumption corresponds to a permanent increase in the growth rate of between 0.4 and 1 percent. A policy induced change in the growth rate of this magnitude is quite plausible in the context of the actual long term per capita growth rates over the 25-30 year period beginning in 1962. For example, Sachs and Warner (1995) estimate that open economies have grown about 2.45 percent faster than closed economies, with even greater differences for open versus closed economies among developing countries. They note that trade liberalization is often accompanied by macro stabilization and other market reforms,
and their open economy variable can be picking up these other effects as well. But they argue that trade liberalization is the \textit{sine qua non} of the overall reform process, because other interventions such as state subsidies often are unsustainable in an open economy. Moreover, Frankel and Romer (1999) have shown that adjusting for the simultaneity bias in cross country regression studies such as Sachs and Warner, does not reduce the estimated impact of openness on growth.

These econometric estimates suggest that our central estimate of equivalent variation, which corresponds in our central model to a growth rate change of 0.4 percent, may still be too small. But larger tariff changes than our ten percent cut produce larger welfare gains.

4.2 \textbf{Rationalization Gains and their Impact}

Suppose the markup over fixed costs for intermediate firms is endogenous. Then, typically, additional competition from new firms results in a reduction in the markup of price relative to marginal costs. A reduced markup means that in equilibrium there are rationalization gains as firms operate at a lower point on their downsloping average cost curve. Since the first order effect of the tariff change is to increase the quasi-rents for foreign firms, and the rationalization is a second order effect of entry on the markup, there should still be a net increase in the number of firms even with the small group assumption; hence welfare gains from additional varieties should persist with endogenous markups. But, firms operating at a larger scale means there will be fewer firms operating in equilibrium. Since the externality for the final goods sector is dependent on the number of firms, the reduced number of firms would reduce the welfare gains relative to our model. On the other hand, the rationalization
gains would be an additional welfare benefit relative to what we have estimated in our model. Thus, there are competing welfare effects of the small group assumption relative to our model.

4.3 Optimal Subsidies and Negative Tariffs

Since additional varieties provide an externality, the optimal tariff in this model is negative. Since it is additional varieties, not their geographic source that is important, a superior intervention instrument to a negative tariff would be a subsidy to the creation of a new firm, either domestic or foreign. We do not advocate such a policy, however, since opportunistic behavior by firms or political economy considerations will make successful application of subsidies unlikely. For example, lobbyists will claim their industries quality as intermediate when they are final.

4.4 Conclusions

These results of this paper show that when we introduce an Eithier-Dixit-Stiglitz production structure into a numerical general equilibrium model, we may vastly exceed the Harberger constant for the welfare impact. The results clearly support the paradigm that trade liberalization can lead to significant income increases, and the results are consistent with estimated gains of trade liberalization from cross-country growth regressions. But the results also illustrate the crucial importance of complementary reforms to fully realize the potential gains from the trade reform. Notably, with the ability to access international capital markets, the gains are more than tripled and inefficient replacement taxes will significantly reduce the gains. The tariff in our model, however, is more inefficient that even the most inefficient alternate replacement tax.
References


——— 1997a, Quantifying the Uruguay Round, Economic Journal 107, September, 1405-1430.

——— 1997b, Economic Implications for Turkey of a Customs Union With the European Union, European Economic Review 41, 861-870.


Keuschnigg, C. and W. Kohler, 1996, Austria in the European Union: Dynamic Gains from Integration and Distributional Implications, Economic-Policy 0(22), April, 155-90.


——— 1997, Discussion of Baldwin, Francois and Portes, Economic Policy, April, 170-173.


Table 1: Equilibrium Variables

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U$</td>
<td>Utility level of the representative agent</td>
</tr>
<tr>
<td>$C_t$</td>
<td>Aggregate final consumption in period $t$</td>
</tr>
<tr>
<td>$CD_t, CM_t$</td>
<td>Final consumption of domestic and imported goods</td>
</tr>
<tr>
<td>$p_t^D, p_t^M, w_t$</td>
<td>Present value price of domestic and imported goods and wages</td>
</tr>
<tr>
<td>$r_j^t$</td>
<td>Present value of the rental rate on capital for firm type $j$</td>
</tr>
<tr>
<td>$GD_t, GM_t$</td>
<td>Government purchases of domestic and imported final goods</td>
</tr>
<tr>
<td>$T_{t}^{M}(t)$</td>
<td>Tariff revenue in period $t$, a function of the exogenous tariff rate</td>
</tr>
<tr>
<td>$T_{t}^{C}(\tau^C), T_{t}^{K}(\tau^K), T_{t}^{Y}(\tau^Y)$</td>
<td>Tax revenue associated with replacement taxes on consumption, capital income and output, respectively</td>
</tr>
<tr>
<td>$Y_t, D_t, E_t$</td>
<td>Period $t$ aggregate output; domestic supply; and exports</td>
</tr>
<tr>
<td>$x_t^D, x_t^F$</td>
<td>Output per firm by domestic and foreign firms in period $t$</td>
</tr>
<tr>
<td>$n_j^t$</td>
<td>Number of type $j$ firms producing in period $t$</td>
</tr>
<tr>
<td>$I_{j}, K_{j}, B_{j}$</td>
<td>Investment, capital stock and number of new blueprints, respectively, associated with type $j$ firms in period $t$.</td>
</tr>
<tr>
<td>$a_j^D, a_j^K, a_j^M$</td>
<td>Demand per unit of output of type $j$ firms in period $t$ for domestic inputs, capital and imported inputs, respectively (for variable costs)</td>
</tr>
</tbody>
</table>

Note: The subscript $t$ denotes the period $t$ in all cases; $j$ refers to either foreign or domestic firms.

-35-
Table 2: Estimated Welfare and Growth Effects of Tariff Reduction*

<table>
<thead>
<tr>
<th>Model</th>
<th>EV4</th>
<th>G2010</th>
<th>G2050</th>
<th>Gterm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Central Assumptions</td>
<td>10.6</td>
<td>2.6</td>
<td>2.2</td>
<td>2.1</td>
</tr>
<tr>
<td>2. Spillovers for Domestic Intermediate Producers</td>
<td>10.9</td>
<td>2.6</td>
<td>2.2</td>
<td>2.1</td>
</tr>
<tr>
<td>3. Constant Returns to Scale</td>
<td>0.5</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>4. Output Tax Replacement</td>
<td>5.2</td>
<td>2.4</td>
<td>2.1</td>
<td>2.0</td>
</tr>
<tr>
<td>5. Capital Income Tax Replacement</td>
<td>4.6</td>
<td>2.4</td>
<td>2.1</td>
<td>2.0</td>
</tr>
<tr>
<td>6. Capital Flows</td>
<td>37.4</td>
<td>4.2</td>
<td>2.7</td>
<td>2.2</td>
</tr>
</tbody>
</table>

* Parameter choices for all models are shown in table 3 and footnote 10.

Unless otherwise indicated, all models include: lump sum replacement taxes, no spillover effect of new foreign varieties on the domestic cost of new blueprints, and period by period balance of trade constraint.

EV4  
Hicksian equivalent variation over the infinite horizon as a percent of the present value of benchmark steady state

G2010  
Average consumption growth 1997-2010

G2050  
Average consumption growth 1997-2050

Gterm  
Terminal growth rate (from 2049 to 2050)
Table 3: Piecemeal Sensitivity Analysis

<table>
<thead>
<tr>
<th>Parameter a</th>
<th>Upper</th>
<th>Intermediate</th>
<th>Lower</th>
<th>Upper</th>
<th>Intermediate</th>
<th>Lower</th>
</tr>
</thead>
<tbody>
<tr>
<td>(</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$0_{DX}$</td>
<td>2.0</td>
<td>1.5</td>
<td>0.5</td>
<td>17.1</td>
<td>14.1</td>
<td>7.0</td>
</tr>
<tr>
<td>$1/(1-D)$</td>
<td>0.7</td>
<td>0.6</td>
<td>0.3</td>
<td>11.6</td>
<td>11.1</td>
<td>9.7</td>
</tr>
<tr>
<td>&quot;</td>
<td>0.4</td>
<td>0.6</td>
<td>0.8</td>
<td>11.0</td>
<td>10.8</td>
<td>12.5</td>
</tr>
<tr>
<td>G</td>
<td>0.03</td>
<td>0.025</td>
<td>0.01</td>
<td>14.6</td>
<td>12.4</td>
<td>7.9</td>
</tr>
<tr>
<td>R</td>
<td>0.06</td>
<td>0.055</td>
<td>0.04</td>
<td>9.3</td>
<td>9.9</td>
<td>13.0</td>
</tr>
<tr>
<td>$2_i$</td>
<td>0.6</td>
<td>0.4</td>
<td>0.25</td>
<td>13.6</td>
<td>7.9</td>
<td>4.6</td>
</tr>
<tr>
<td>$t^M$</td>
<td>60%</td>
<td>40%</td>
<td>5%</td>
<td>59.5</td>
<td>32.6</td>
<td>-4.0</td>
</tr>
<tr>
<td>$2_F$</td>
<td>0.7</td>
<td>0.4</td>
<td>0.1</td>
<td>4.3</td>
<td>5.9</td>
<td>10.6</td>
</tr>
</tbody>
</table>

The piecemeal sensitivity analysis employs central values for all parameters (see below) other than the tested parameter, lump sum tax replacement and period by a period balance of trade constraint.

Hicksian equivalent variation over the infinite horizon as a percent of the present value of consumption in the benchmark steady state.

Key: Parameter definitions and their values in the central simulation:

- (0.04 Elasticity of blueprint costs wrt the number of foreign firms
- $0_{DX}$ 1.0 Elasticity of transformation in aggregate production (domestic versus exports)
- $1/(1-D)$ 0.5 Intertemporal elasticity of substitution
- " 0.66 Intermediate share of aggregate cost
- G 0.02 Baseline growth rate
- R 0.05 Baseline interest rate
- $2_i$ 0.5 Import share of intermediate inputs
- $t^M$ 20% Tariff rate on imports (in the benchmark steady state) which is exogenously changed to 10%
- $2_F$ 0.1 The share of the fixed costs of foreign firms represented by blueprint costs.
Figure 1: Consumption Path following Tariff Reform
Figure 2: Domestic Firms following Tariff Reform

% change from steady state

2000 2010 2020 2030 2040 2050

CENTRAL
CAPITAL FLOWS
CRTS
SPILLOVERS
Figure 3: Foreign Firms following Tariff Reform
Figure 4: Sample Distribution (34,385 simulations)
Appendix A: Growth and Welfare over the Infinite Horizon

This appendix derives algebraic relations relating changes in the growth rate of consumption to the equivalent variation in infinite-horizon consumption. It then shows how these formula may be employed to provide consistent estimates of infinite horizon welfare based on equilibrium choices over a finite horizon. These functions relating growth to welfare are interesting for two reasons. First, they provide some intuition as to the importance of changes in growth rates vis-a-vis the more conventional static efficiency estimates of the welfare costs of protection. Second, these equations are required for estimating the infinite-horizon welfare change, given welfare changes over the time horizon of the model, the terminal consumption level and the terminal (steady-state) consumption growth rate.

We begin with a constant-elasticity of substitution utility function:

$$U(C) = \left[ \sum_{t=0}^{\infty} \Delta^t C_t^\sigma \right]^{1/\sigma}$$

The elasticity of intertemporal substitution is given by $\sigma = 1/(1-\rho)$. The model is based on ordinal utility, so the optimal consumer choices are unaffected by monotonic transformations of the utility function. For example, this utility function is equivalent to:

$$U(C) = \sum_{t=0}^{\infty} \Delta^t \frac{C_t^{1-1/\sigma}}{1-1/\sigma}$$

The advantage of the former function is that because it is linearly homogeneous in consumption levels ($U(\lambda C) = \lambda U(C)$), a one percent change in $U$ corresponds to a one percent equivalent variation in income. If we let $\bar{C}$ denote a reference consumption path, and let $C$ denote an alternative time path of consumption levels, the equivalent variation in infinite-horizon welfare then corresponds to:
We now evaluate the equivalent variation of a permanent change in the consumption growth rate, assuming that the initial level of consumption in period $t=0$ is held constant. Take $\overline{C}_t = (1 + \overline{g})^t$ and $C_t = (1 + g)^t$. It then follows that the equivalent variation in income is:

$$EV_w = \left[ \frac{\sum_{r=0}^{\infty} \Delta^t C_t^0}{\sum_{r=0}^{\infty} \Delta^t \overline{C}_t^0} \right]^{1/p} - 1$$

In order to relate this expression to the calibrated equilibrium calculations such as those conducted in our paper, it is helpful to replace the utility discount parameter, $\gamma$, by an expression based on the baseline growth rate and interest rate. In other words, in order to compute a baseline equilibrium, we do not begin with a given value of the utility discount factor. We instead assume a balanced baseline growth path with a given growth rate ($\overline{g}$), and a given interest rate ($\overline{r}$). It is then a simple matter to show that the utility discount factor is given by:

$$\Delta = \frac{(1 + \overline{g})^{1/\overline{\alpha}}}{1 + \overline{r}}$$

Substituting into the equivalent variation equation, we then have:

$$EV = \left[ \frac{\overline{r} - \overline{g}}{1 + \overline{r} - (1 + \overline{g}) \left( \frac{1 + \overline{g}}{1 + \overline{r}} \right)^{p}} \right]^{1/p} - 1$$

This expression provides us with a useful check on the magnitude of welfare gains arising from our calculations. Figure A1 simply computes the Hicksian welfare metric for growth rate increases ranging from 0 to 1 percent. Two lines correspond to baseline growth rates of 1 percent and 2
percent. Both functions are based on a baseline interest rate of 5 percent and an intertemporal elasticity of substitution equal to one half. We see that growth rate changes of a 0.5 percent produce welfare changes on the order of 10 to 15 percent, depending on the initial growth rate. Holding constant the baseline interest rate, the welfare change is an increasing function of the baseline growth rate.

Figure A2 investigates the sensitivity of this function to the baseline interest rate. As expected, the higher the interest rate, the lower the welfare gain associated with a permanent change in the growth rate. A higher interest rate implies a larger discount on future consumption increases, so that future gains in consumption are less important.

Figure A3 illustrates the relationship between the intertemporal elasticity of substitution and the welfare gain associated with a half a percentage increase in the consumption growth rate. Again, the results are intuitive. The higher the elasticity of intertemporal substitution, the larger the achievable gain from an increase in future consumption. When the intertemporal elasticity is close to zero, an increase in the growth rate has not effect on welfare because period 0 consumption does not change. However, as the intertemporal elasticity increases from zero, the consumer benefits more as she is able to more easily substitute current consumption for future consumption.

In our model calculations, we adopt a finite-horizon model which approximates the infinite-horizon equilibrium. We apply terminal conditions which assure that terminal period investment is positive and increasing with aggregate GDP (See Lau, Palke and Rutherford 1997 for details on the terminal approximation.) Having computed equilibrium values for period 0 to T, we have an explicit utility index over consumption in these periods, but this index fails to account for consumption increase in the post-terminal period. We can approximate the infinite horizon welfare index, however, based on the following functions of the finite-horizon model: (i) the welfare index for periods 0 to T, $U_T$, (ii) terminal period consumption, $C_T$, and (iii) post-terminal growth, $g_w$. We
produce an infinite-horizon welfare index based on the assumption that the economy exhibits steady-state growth at rate $g_\infty$ from period $T+1$ to the infinite horizon.

In order to lay out the formulae for this approximation, we begin by splitting the infinite-horizon welfare into two periods, $t = 0$ to $T$ and $t > T$. We assume a growth rate of $g_\infty = \frac{C_T - C_{T-1}}{C_T}$ for the post-terminal period, then:

$$U(C) = \left[ \sum_{i=0}^{T} \Delta^t C_i^p \right]^{1/p}$$

$$= \left[ \sum_{i=0}^{T} \Delta^t C_i^p + \sum_{i=T}^{\infty} \Delta^t \left\{ C_T (1 + g_\infty)^{(t-T)} \right\}^p \right]^{1/p}$$

$$= \left[ \sum_{i=0}^{T} \Delta^t C_i^p + C_T^p \frac{\Delta^T}{1 - (1 + g_\infty)^p} \right]^{1/p}$$

When working with a calibrated model, it may be easier to begin from a reference balanced growth path. Substituting for $\Delta$ as in the previous appendix, and denoting the average consumption growth rate through period $t$ as $g_t$, the equivalent variation in income can be written:

$$EV = \left( \frac{r - g}{1 + r} \right)^{1/p} \left\{ \sum_{i=0}^{T} \left[ \frac{1 + g_i}{1 + r} \left( \frac{1 + g_i}{1 + g} \right)^p \right]^t \right. $$

$$+ \left. \frac{1 + g_T}{1 + r} \left( \frac{1 + g_T}{1 + g} \right)^p \left[ \left\{ \frac{1 + g_\infty}{1 + r} \left( \frac{1 + g_\infty}{1 + g} \right)^p \right\}^{-1} \right] \right\}^{1/p} - 1$$

Alternatively, this expression can be written in terms of the welfare level through period $T$ and the level and growth rate of consumption in the post-terminal period, i.e.

\[ EV = \left( \frac{r - g}{1 + r} \right)^{1/p} \left\{ \sum_{i=0}^{T} \left[ \frac{1 + g_i}{1 + r} \left( \frac{1 + g_i}{1 + g} \right)^p \right]^t \right. \]

\[ + \left. \frac{1 + g_T}{1 + r} \left( \frac{1 + g_T}{1 + g} \right)^p \left[ \left\{ \frac{1 + g_\infty}{1 + r} \left( \frac{1 + g_\infty}{1 + g} \right)^p \right\}^{-1} \right] \right\}^{1/p} - 1 \]

\[ EV = \left( \frac{r - g}{1 + r} \right)^{1/p} \left\{ \sum_{i=0}^{T} \left[ \frac{1 + g_i}{1 + r} \left( \frac{1 + g_i}{1 + g} \right)^p \right]^t \right. \]

\[ + \left. \frac{1 + g_T}{1 + r} \left( \frac{1 + g_T}{1 + g} \right)^p \left[ \left\{ \frac{1 + g_\infty}{1 + r} \left( \frac{1 + g_\infty}{1 + g} \right)^p \right\}^{-1} \right] \right\}^{1/p} - 1 \]

1) In the finite horizon model we use a utility function,

$$U_T = \left( \sum_{i=1}^{T} \Delta^t C_i^p \right)^{1/p}$$

in which there is no additional “weight” on period $T$ consumption. In the finite horizon model, a constraint on the terminal capital stock such that investment follows a steady-state growth path. Having computed the finite horizon equilibrium, we then compute the infinite horizon welfare index.
In which we define: $\theta_T = \frac{1-\theta^r}{1-\theta}$, where $\theta = \frac{1+\bar{g}}{1+r}$ and:

$$\gamma (\bar{g}_s, \bar{g}) = \left[ \frac{1 - \theta}{(1 + \bar{g})^\rho} \right]^{\frac{1}{\rho}}$$

In a constant growth rate model, the term $\gamma (\bar{g}_s, \bar{g})$ is always unity, so the welfare then depends solely on the utility index through model horizon and the terminal consumption level relative to the original steady-state growth rate.
Appendix B: Benchmark Assumptions and Calibration

Consider the input data as outlined in Table 1. Scaling base year final goods output to unity, we then define imported and domestic intermediate inputs as:

\[ x_M = \theta_i \alpha, \quad \text{and} \quad x_D = (1 - \theta_i) \alpha. \]

Labor inputs for final goods production may then be inferred through exhaustion of product:

\[ L_M = \theta_i (1 - \alpha), \quad \text{and} \quad L_D = (1 - \theta_i) (1 - \alpha). \]

Base year wage income is the sum of these values, \( L = L_D + L_M \).

The intermediate value share determines markups over marginal cost, and this in turn defines markup revenues given assumed sales by firm type:

\[ m_{kf} = x_f (1 - \alpha), \quad f \in \{D,M\} \]

Capital returns in intermediate goods production are defined as a fraction of variable cost:

\[ vk_f = k_{vs} (x_f - m_{kf}) \]

Imported inputs to intermediate goods production are also defined as a fraction of variable cost:

\[ mx_f = m_{vs} (x_f - m_{kf}) \]

Domestic inputs to intermediate production are determined by exhaustion of product:

\[ dx_f = (1 - k_{vs} - m_{vs}) (x_f - m_{kf}) \]

The user cost of capital equals interest plus depreciation, so the initial capital stock in can then be inferred from capital returns:

\[ k_{xf} = \frac{vk_f}{r + \delta} \]
fixed costs of intermediate goods production equal the sum of recurring fixed costs and blueprints.

We use a parameter $f_{cshr}$ to define how these shares are separated:

$$f_{c0f} = f_{cshr} mk_f$$

Blueprints do not depreciate, so the value of a firm's equity is related to the base year dividends through the interest rate:

$$f_f = \frac{(1-f_{cshr}) mk_f}{r}$$

Base year firm creation is determined by the steady-state growth rate (there is no depreciation of blue-prints in this model):

$$i_f = g f_f$$

Domestic and intermediate inputs to investment are based on the import value share in investment:

$$im_f = m_vsi_f i_p \quad id_f = (1-m_vsi_f) i_f.$$  

Base year capital investment in firms is sufficient to cover growth plus depreciation of the capital stock:

$$ix_f = k x_f (g + \delta).$$

Net investment by households in the intermediate goods sector equals the total value of blueprint and capital formation, less the value of markup revenue net of recurring fixed costs:

$$I = \sum_f i_f + ix_f - (mk_f + mk_f - f_{c1f})$$

As we assume that tariff revenues are returned to the consumer in a lump sum, we must determine base year tariff revenue and imports to final demand simultaneously. The following system of equations then determine base year tariff revenue ($T$) and imports ($c_m$):

$$T = \frac{f}{1+f} \left( c_m + \sum_f mx_f + im_f \right)$$

and
Solving, we have

\[ T = \frac{t \left( \theta_C (L - I) + \sum_f mx_f + im_f \right)}{1 + t (1 - \theta_r)} \]

Domestic consumption is then

\[ c_d = (1 - \theta_C) (L - I + T) \]

Total demand for domestic output is equal to the sum of final demand, inputs to intermediate production, recurring fixed costs for intermediate demand, inputs to new firms and investment in capital goods for new firms:

\[ D = c_d + \sum_f dx_f + fc_f + id_f + ix_f \]

We assume that both firm types supply to the domestic and import markets in the same proportions, we therefore use market share to define production to the domestic and export market by firm type.

\[ d_D = (1 - \theta_x) D, \quad d_M = \theta_x D \]

Imports include those for final consumption, X production and X-sector investment:

\[ M = \frac{c_m + \sum_f mx_f + im_f}{1 + t} \]

The value of total exports equals the net of tariff value of imports. Imposing trade balance, the value of exports equals the value of imports deflated by the base year tariff: And then from our assumption of symmetry of export shares across domestic and foreign firms, we have:

\[ e_M = \theta_x M, \quad e_D = (1 - \theta_x) M \].
Figure A1: Welfare Effect of a Change in the Growth Rate

\( (r = 5\%, \ F = 0.5) \)
Figure A2: Welfare Effect of a Change in the Growth Rate

\( (r = 7\%, F = 0.5) \)
Figure A3: Intertemporal Elasticity and Welfare Gains

\( (r = 5\%, \; g = 0.5\%) \)
Endnotes

1 Of course, all aspects of the paradigm that trade or trade liberalization leads to faster growth have been subject to criticism. See, for example, criticisms by Rodrik (1992) and Harrison and Hanson (1999). Importantly, causality has been questioned in ordinary least squares results, see Rodriguez and Rodrik (2000). However, after developing an instrumental variable for trade, Frankel and Romer (1999) find that ordinary least squares does not overestimate the positive impact of trade on growth.

2 Examples of constant returns to scale models with estimates of welfare gains from trade liberalization of less than one percent of GDP include: de Melo and Tarr (1990; 1992; 1993); Harrison, Rutherford and Tarr (1993; 1997a; 1997b); Morkre and Tarr (1980; 1995); and Tarr and Morkre (1984).

3 Estimates from some of the IRTS based models have been controversial, since in the trade liberalization counterfactual other behavioral assumptions were simultaneously modified (see Harrison, Jones et al., 1993; and Harrison, Rutherford and Tarr, 1997a).

* We would like to thank Richard Baldwin, Glenn Harrison, Elias Dinopoulou, two anonymous referees of this journal and seminar participants at the conference in Milan Italy on Technology Diffusion and Developing Countries for helpful comments. Research support was provided by the World Bank under RPO No. 68140, “The Dynamic Impact of Trade Liberalization in Developing Countries.” The views expressed are those of the authors and are not necessarily those of the World Bank.
Keuschnigg and Kohler (1996) and Rutherford and Tarr (1997) have developed CRTS Ramsey type models. Their results show that a comparative static model may be a close approximation to the annual welfare gains from trade liberalization in a dynamic model, if the dynamic model does not have an increasing returns to scale sector. The only numerical application of an endogenous growth model we know is Connolly (1999). Using a quality ladder model, she estimates that the Southern country will gain from 20 to 29 percent of GDP from an exogenous shift from autarchy to 13 percent imports of intermediates. Some numerical general equilibrium modelers have produced comparative “steady state” estimates of the welfare gains which are two to four times the comparative static estimates of their models (e.g., Harrison, Rutherford and Tarr, 1996, 1997a; Francois, McDonald and Nordstrom, 1996; and Baldwin, Francois and Portes, 1997). These are multi-sector quantifications of the Baldwin (1989) “medium term growth bonus,” which hold the rental rate on capital constant and allow the capital stock to vary. Harrison, Rutherford and Tarr (1996; 1997a) and Rodrik (1997) have explained, however, that these estimates overestimate the gains from trade liberalization in a fully dynamic representation of their models because they fail to adjust for the foregone consumption cost of achieving the higher capital stock. Nonetheless, the estimates for Hicksian equivalent variation remain less than five percent of GDP, except for the Baldwin, Francois and Portes paper; and Rodrik (1997) has estimated that after adjusting for the foregone consumption cost of investment, the estimated equivalent variation in the Baldwin, Francois and Porter paper would also be less than five percent.

But see Keller (1998) for an opposing view.

Our analysis can be viewed as an extension of Ethier (1982) and Markusen (1989, 1991). Markusen investigated the implications of the substantial trade in imported intermediate inputs using static and two period models. In an earlier model of ours, Rutherford and Tarr (1999), we choose a functional form such that product varieties did not lead to a productivity boost in final demand. As a result the welfare gains were considerably smaller. This paper relaxes that assumption and adapts the model so that it may still produce a steady state growth path.
The intertemporal elasticity of substitution $F_T = 1/(1-D)$. See table 1 for the assumed values of elasticities in different sectors in our central elasticity scenarios.

Note that population is fixed over the time horizon. Economic growth results solely from productivity improvements due to the accumulation of varieties, and the real wage increases over time relative to the prices of domestic output and imports.

In any equilibrium only one of the replacement tax instruments is non-zero, depending on the scenario-specific replacement tax option.

The key value shares in our model are as follows: intermediate use in final output .67; imports in intermediate (final) demand .5 (0); share of imports in the marginal costs of foreign (domestic) firms 0.75 (0.0); blueprint cost share of total fixed costs for foreign (domestic) firms 0.1 (0.9).

We believe that this assumption allows for a greater range of model variants and impacts. The reason is that, as discussed above, we can think of our model equivalently as one where foreign firms are replaced with domestic firms who only distribute foreign products. Domestic distributors are then licensed distributors of the foreign product, i.e., domestic licensees are permitted. The key difference in our model between domestic firms and either foreign firms or domestic distributors, is that domestic firms produce the product and blueprint domestically and thus have a different cost structure. If we allowed domestic firms to purchase blueprint designs, we would substitute a payment to foreigners for the use of domestic resources to generate a blueprint. As a consequence, comparative advantage would play less of a role since domestic firms would be less dependent on domestic factor costs. Moreover, we would not be able to model the effect of spillovers of foreign varieties on domestic blueprint costs as we do below.

Although the underlying logic is unchanged, this achieves a considerable simplification over our previous model (Rutherford and Tarr, 1999) in which we tracked the level of investment for all vintages through the model horizon.

In her quality ladder model, Connolly (1999) has also found that the productivity boost from opening trade allows the small developing economy to increase consumption in the early years despite increasing investment expenditures. Thus, our result of the expansion of consumption and investment can also occur
in a quality ladder model, but in a quality ladder model it would presumably be dependent on the positive spillovers from trade that Connolly assumes.

14 Although they converge asymptotically, the domestic and international rental rates can differ by a substantial amount during the transition due to the differentiation of domestic and imported goods. Savings and investment are characterized by an infinitely lived representative agent with a constant discount rate. The international interest rate and the discount factor together determine the long-run growth rate in this model.

15 Each good is used as an intermediate in production of the other good, and thus both goods use both factors of production indirectly.

16 The latter occurs because consumers optimize consumption over the model horizon subject to their lifetime income constraint or permanent income. With the ability to borrow on international capital markets, consumers can smooth consumption more easily.

17 The lower and upper values of the uniform probability distributions for the parameters are:

\[
0.02 < \theta < 0.08 ; 0.5 < \theta_{dx} < 1.5 ; 0.3 < 1/(1-D) < 0.7 ; 0.6 < \eta < 0.72 ; 0.01 < g < 0.03 ; 0.04 < r < 0.06 ;
0.3 < \zeta < 0.7 ; 0.85 < \zeta_f < 0.95.
\]

See table 3 for parameter definitions.

18 Barro and Sala-i-Martin (1995, p.79) indicate that values of the intertemporal elasticity of substitution significantly different from our central value are inconsistent with cross-country data in a Ramsey model.