5

Partial Equilibrium Modeling

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I Introduction

By definition, partial equilibrium models do not take into account many of the factors emphasized in general equilibrium trade theory. While this is the root of the practical limitations of applied partial equilibrium modeling, it is also the source of its basic advantage. By focusing on a very limited set of factors, such as a few prices and policy variables, applied partial equilibrium models allow for relatively rapid and transparent analysis of a wide range of commercial policy issues. As long as the limitations of the approach are kept in mind, useful insights can often be drawn under time and data constraints that preclude more complex forms of analysis. In many circumstances, in fact, it may be difficult to justify devoting otherwise scarce resources to more complex and less transparent models, when they may yield only marginal extensions of the basic insights drawn from simpler approaches. In other situations, such as econometric exercises, it may simply be impossible to introduce general equilibrium constraints to the relevant market equations.

Our primary objective in this chapter is to present basic techniques for a relatively simple, partial equilibrium approach to comparative static analysis of commercial policy. However, while our ultimate goal is partial equilibrium analysis, we start by grounding the modeling framework in standard general equilibrium trade theory. Our intent is to use trade theoretic concepts as a reference point, both to offer general equilibrium interpretations for "'partial" equilibrium measures related to welfare and to make explicit what limitations we adopt when we choose this type of approach. Standard partial equilibrium welfare measures are linked explicitly in this chapter to the framework for welfare measurement developed in Chapter 3. Throughout this chapter, we ignore issues related to externalities and imperfect competition. These issues are covered in later chapters, particularly those dealing with imperfect competition, dynamics, employment, and the environment. Multi-market extensions of the basic framework developed here are offered in Chapter 8.

A number of variations on the theme of applied partial equilibrium modeling are covered in this chapter. They serve to illustrate not only different approaches to modeling competition between imports and domestic goods (i.e., perfect and imperfect substitute models), but the implications of different solution strategies, including both linear and non-linear specifications. Both sets of issues are revisited in later chapters on more complex models. The chapter is organized as follows: We first explore formal linkages between general equilibrium trade theory and simple partial equilibrium models. We then develop a simple perfect substitutes model and an imperfect substitutes (Armington) model. Both model types are implemented on spreadsheets. Finally, an application in which the analysis of U.S. protection of the steel industry is contrasted under alternative approaches is offered.

II Tariffs, Imports, and Welfare

II.1 Income and Expenditures in an Open Economy

Consider a country trading with the rest of the world, facing a set of world prices P^*. Making standard assumptions, we can then specify a national income or GDP function as follows:

$$GDP = R(\boldsymbol{v}, \boldsymbol{P}) + \tau \tag{5.1}$$

where $\boldsymbol{v}$ is the national resource base, $\boldsymbol{P}$ represents internal prices and τ represents tariff revenue.[1] With tariffs $\boldsymbol{t}$ we then also have

$$\boldsymbol{P} = \boldsymbol{P}^*(1+\boldsymbol{t}) \tag{5.2}$$

We assume that we are able to specify a single measure of national welfare W in terms of prices and income. We therefore are going to abstract away from issues of income distribution (see Chapter 10). We define the expenditure function in terms of prices $\boldsymbol{P}$ and welfare W. The expenditure function relates national expenditures to welfare and prices and represents the minimum level of expenditure necessary, at internal prices $\boldsymbol{P}$, to achieve welfare level W. Formally, we have the following condition:

1 The approach followed here follows Dixit and Norman (1980). See Dixit and Norman for a discussion of the properties of national revenue and expenditure functions, and the assumptions typically made to keep them well behaved.

$$GDP = E(\boldsymbol{P}, W) \tag{5.3}$$

Combining equations (5.1) and (5.3) relates national income to expenditures. This is simply the dual expression of the more familiar condition that the value of national income (plus any transfers) will equal the total value of final expenditures and represents the national budget constraint.

$$R(\boldsymbol{v}, \boldsymbol{P}) + \tau = E(\boldsymbol{P}, W) \tag{5.4}$$

We can extend the basic system further. In particular, from Hotelling's Lemma, we know that domestic output of good X^1 will be

$$X^1(\boldsymbol{P}, \boldsymbol{v}) = \frac{\partial R}{\partial P^1} = R_{P^1} \tag{5.5}$$

At the same time, domestic demand for goods x can be derived, again in equilibrium, from equation (5.3).

$$C^1(\boldsymbol{P}, W) = E_{P^1} \tag{5.6}$$

Combining equations (5.5) and (5.6), we have import demand, defined in general equilibrium as the difference between consumption and domestic production:

$$M^{D1} = E_{P^1} - R_{P^1} \tag{5.7}$$

Equation (5.7) tells us that, properly defined, an import demand function represents the reduced form, general equilibrium excess demand for that good. In Figure 5.1, we have represented this with the curve M^{D1}, which plots import demand as a function of changes in internal prices for the good. As developed, the curve represents the reduced form response of import demand to changes in prices in the import market. To close the system, we have drawn import supply as the curve M^{S1}.

Tariffs

Next, consider the role of tariffs in this framework. We can show (Dixit and Norman 1980, Chapter 4) that, when we introduce a tariff on good 1 from a free trade equilibrium, the marginal welfare effects of the tariff can be represented by the following equation:

$$\begin{aligned} E_W dW &= t \cdot dM - M \cdot dP^* \\ &= t^1 \cdot dM^1 - M^1 \cdot dP^{1*} \end{aligned} \tag{5.8}$$

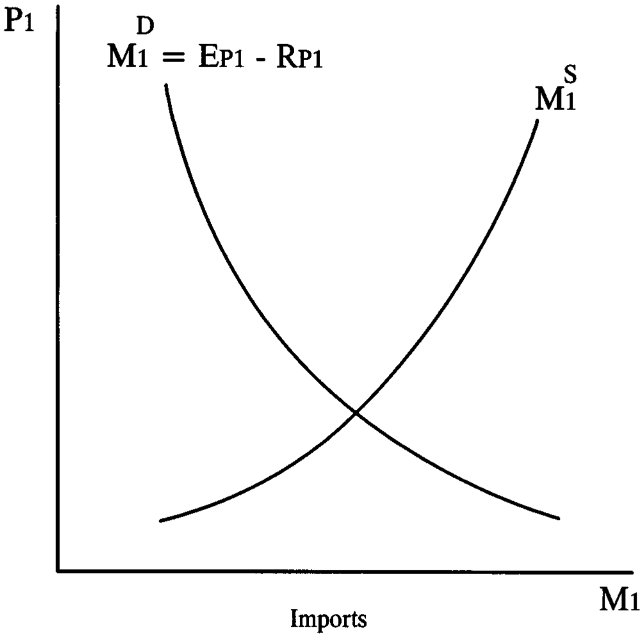


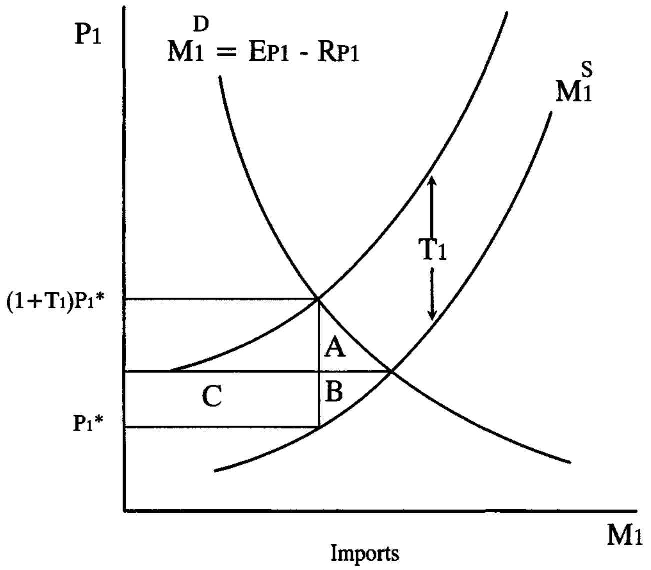
Figure 5.1. *Import market equilibrium*

The term $E_W dW$ provides a measure, at world prices, of the welfare/income effect of the tariff. Technically, it refers to the equivalent variation for small tariff changes around the region of the free trade equilibrium.[2] At free trade prices and income, it measures the additional income gain or loss necessary to achieve a change in welfare equivalent to that realized by the introduction of the tariff from free trade. The first term on the right side of equation (5.8) measures the cost of consumption distortions to intermediate and final consumers, while the second measures terms of trade effects.

For a large tariff T_1, the welfare impact of the tariff may be approximated from the condition represented by equation (5.8), where we treat the introduction of the tariff in "small," incremental steps. This is by no means an exact measure, though it is a common one, with deep theoretical roots in linearization through differential calculus. In particular, this approach yields a total welfare effect ΔW measured as follows:

$$\Delta W = \int_0^{T^1} \left[t^1 \cdot \frac{dM}{dt^1} \right] dt^1 - \int_0^{T^1} \left[M\left(t^1\right) \cdot \frac{dP^*}{dt^1} \right] dt^1 \qquad (5.9)$$

2 See Martin in Chapter 3 for a fuller discussion of alternative welfare measures under general equilibrium.



$$A + B = \int_0^{T1} t1\ [dM1/dt1]\ dt1$$

$$B + C = \int_0^{T1} M1(t1)\ [dP1^*/dt1]\ dt1$$

Figure 5.2. *Welfare and distributional effects of a tariff*

This has been represented in Figure 5.2, where

$$\int_0^{T^1}\left[t^1 \cdot \frac{dM^1}{dt^1}\right]dt^1 = A + B \tag{5.10}$$

and

$$\int_0^{T^1}\left[M^1\left(t^1\right)\cdot \frac{dP^{1*}}{dt^1}\right]dt^1 = B + C \tag{5.11}$$

Geometrically, the welfare impact of a tariff is defined, for very small changes in a tariff, by the total of areas $(C + B) = (A + B) = (C - A)$. For the case of real changes in tariffs, which in general are not infinitesimally small, the areas C and A are often assumed to serve as a reasonable approximation of welfare changes. For a small country, where world prices are assumed to be fixed, the second term in equation (5.8), which reflects terms of trade effects, will be zero, and the welfare impact of a tariff is then measured directly by area A in the second panel of Figure 5.2.

II.2 Welfare Triangles

The area A is commonly referred to as a welfare triangle. While we have grounded it in general equilibrium theory, in application the full general equilibrium definition of import demand found in equation (5.7) is usually replaced by a much simpler specification:

$$M^{D1} = M^{D1}\left(P^1, P^{S_1}\right) \tag{5.12}$$

In equation (5.12), P^{S1} represents a price index for close substitute products for the import i. In some cases, P^{SI} may also be dropped from the import demand equation. Given equation (5.12), and an appropriate import supply function M^{S1}, we can specify the complete equilibrium in a single market as follows:

$$M^{D1}\left(P^1\right) = M^{S1}\left(P^1\right) \tag{5.13}$$

Geometrically, the equilibrium condition still looks like Figure 5.2. The welfare effect of a tariff can be still be addressed by using the areas A and C as simple metrics. Rather than solving for exact areas, however, a further abstraction is often adopted, wherein we recognize that the area A is approximately equal to a triangle defined as follows:

$$A \approx \frac{1}{2} \cdot \left(M^1 - M^{1'}\right)\left(\left(P^{1*\prime} + T^1\right) - P^{1*}\right) \tag{5.14}$$

Even as such a model is expanded to include related domestic sectors, a basic sense of the welfare effects of a single tariff often can still be captured by equation (5.14) and related terms-of-trade effects in the primary market. As we introduce related markets, changes in tariffs and imports in those markets can also be used as a proxy for the secondary effects of changes in the primary market (see Chapter 3).

Equation (5.14) can also be derived from the balance of trade function (see Chapter 3). Returning to equations (5.3) and (5.4), and ignoring any net transfers, the balance of trade function for a small country is defined as

$$\begin{aligned} B &= z\left(\boldsymbol{p}, W, \boldsymbol{v}\right) - \left(\frac{\partial z}{\partial P}\right)\left(\boldsymbol{P} - \boldsymbol{P}^*\right) \\ &= z - \boldsymbol{z_P}\left(\boldsymbol{P} - \boldsymbol{P}^*\right) \end{aligned} \tag{5.15}$$

where we have defined $z(\cdot)=e(\cdot)-R(\cdot)$, and where external prices are fixed. The second term simply represents tariff revenues t. When considering the effect of discrete changes in the level of protection on the balance of trade function from a free-trade equilibrium, the second term can be dropped. Recall from Chapter 3 that the change in the balance of trade function provides a money measure of the change in welfare resulting from a tariff change. Using a second-order Taylor Series expansion (and ignoring third derivatives), we can approximate the discrete change in B for an arbitrary change in the tariff rate through a variation of equation (3.11):

$$\begin{aligned}\Delta B &\approx \boldsymbol{z_P}\Delta\boldsymbol{P} - \boldsymbol{z_{PP}}\left(\boldsymbol{P}-\boldsymbol{P}^*\right)\Delta\boldsymbol{P} \\ &\quad - \boldsymbol{z_P}\Delta\boldsymbol{P} - \left(\frac{1}{2}\right)\boldsymbol{z_{PP}}\left(\Delta\boldsymbol{P}\right)^2 \\ &\approx \left(\frac{1}{2}\right)\left(\frac{\partial M^{D1}}{\partial P_1}\right)\Delta P_1^2\end{aligned} \tag{5.16}$$

Equation (5.16) involves several simplifications. First, we have assumed that we start from an initial free trade equilibrium, so that $(\boldsymbol{P}-\boldsymbol{P}^*)=0$. We have also ignored secondary cross-price effects, so that the term z_P collapses to the net import function in equation (5.7).

Note that, defining the elasticity of demand as $\eta=(\Delta M/\Delta P)(P/M)$, and defining quantities so that $P=1$, equation (5.14) (and identically equation [5.16]) can be respecified as follows:[3]

$$C \approx \Delta B \approx -\left(\frac{1}{2}\right)\eta M_0^{D1}\left(\Delta P_1\right)^2 \tag{5.17}$$

where M_0^{D1} is demand given free trade in the market for good 1.

At this point, it is worth summarizing some of the steps we have taken in moving from general equilibrium theory to partial equilibrium application. Our derivation of both equations (5.8) and (5.17) has followed from the assumption that we can ignore cross-price effects in other markets. In addition, in adopting specific functional forms for import demand and export supply functions that are only defined over certain key prices (as developed later), we are deliberately *not* modeling explicit linkages between the sector(s) modeled and the rest of the economy. In principle, the import demand function reflects underlying economywide linkages, which determine the local elasticity of the import demand function. In practice, however, such linkages are effectively sterilized when we turn to model implementation.

3 For further discussion of welfare measurement in partial equilibrium trade models, see Rousslang and Suomela (1984).

III A Perfect Substitutes Model

We now turn to two alternative approaches to implementing a partial equilibrium model. The differences between the two relate to the specification of linkages between imports in a particular market and competing domestic production. We start with the assumption of homogenous goods. In particular, we initially assume that imports are perfect substitutes for domestic production.

III.1 The Model

Assuming that elasticities are constant, we define the import and domestic market as follows:

$$\textit{Domestic demand:} \quad Q^D = Q^D(P) = K^D(P)^{\eta^D} \tag{5.18}$$

$$\textit{Domestic supply:} \quad Q^S = Q^S(P) = K^S(P)^{\varepsilon^S} \tag{5.19}$$

$$\textit{Import demand:} \quad M^D = Q^D(P) - Q^S(P) \tag{5.20}$$

$$\textit{Import supply:} \quad M^S = M^S(P^*) = K^{MS}(P^*)^{\varepsilon^{MS}} \tag{5.21}$$

$$\textit{Price equation:} \quad P^*(1+t+w) = P \tag{5.22}$$

where t represents a tariff wedge, and w represents a quota price wedge. The terms K^D, K^S, and K^{MS} are constants, while the exponential terms ε are elasticities. We have assumed quota rights held by exporters (such as a voluntary export restraint), with tariffs applied in addition to the quota price wedge.

If we are willing to accept a linear approximation, we can derive the following alternative specification in log form:

$$\textit{Import Supply:} \quad \ln(M^S) = \ln(K^{MS}) + \varepsilon^{MS}\ln(P) - \varepsilon^{MS}\ln(1+t+w) \tag{5.23}$$

$$\textit{Import Demand:} \quad \ln(M^D) = \ln(K^{MD}) + \eta^{MD}\ln(P)$$

$$\text{where} \quad \eta^{\mathrm{MD}} = \left[\frac{\left(\eta^D K^D - \varepsilon^S K^S\right)}{K^{MD}}\right] \tag{5.24}$$

$$\textit{Domestic Demand:}\qquad \ln\left(Q^{D}\right)=\ln\left(K^{D}\right)+\eta^{D}\ln\left(P\right) \tag{5.25}$$

$$\textit{Domestic Supply:}\qquad \ln\left(Q^{S}\right)=\ln\left(K^{S}\right)+\varepsilon^{S}\ln\left(P\right) \tag{5.26}$$

Note that, while we have specified the log-linear system in levels, the price and quantity system can also (identically) be specified in terms of differences, where ε^{i} measures relevant elasticities with respect to price. Without specifying particular functional forms, the linear system can then serve as a "locally general" linear approximation for more general functional forms for import supply and demand. In particular, when $g=g(P)$ and we define the elasticity $\eta^{gp}=(dg/dP)(P/g)$, then for small changes $\eta^{gp}=(d\ln(g)/d\ln(P))$, and hence $d\ln(g)=\eta^{gp}\,d\ln(P)$. Complex models, even general equilibrium models, are sometimes solved by using this type of linearization.[4] The advantage is that, for small policy changes around the region of an initial equilibrium, estimates can be obtained as part of a simple linear programming problem. An important shortcoming of this approach, even in single-market models, is the linearization error that can be introduced with large policy shocks.

From the non-linear system defined by equations (5.18)–(5.22), we can solve the system for price P, yielding the following non-linear equation:

$$K^{MS}\left(P\right)^{\varepsilon^{MS}}\left(1+t+w\right)^{-\varepsilon^{MS}}+K^{S}\left(P\right)^{\varepsilon^{S}}-K^{D}\left(P\right)^{\eta^{D}}=0 \tag{5.27}$$

Alternatively, we can solve equations (5.23)–(5.26) directly for the log of price P, yielding the following:

$$\ln\left(P\right)=\left[\varepsilon^{MS}-\eta^{MD}\right]^{-1}\left[\ln\left(K^{MD}\right)-\ln\left(K^{MS}\right)+\varepsilon^{MS}\ln\left(1+t+w\right)\right] \tag{5.28}$$

From either of these, a solution for the full system of equations can be obtained by first solving for the internal import price and then using the solution for price to solve for quantities. While the log-linear solution offers certain advantages related to generality and computational complexity, when compared to specific functional forms, such as constant elasticity demand and supply functions, linearization can include substantial linearization error. This is particularly true with large policy shocks.

Table 5.1 presents a spreadsheet implementation of the model, in both linear and non-linear form. The implications of linearization can be seen by comparison of the linear and non-linear results in the table, which can diverge dramatically as policy shocks increase. Corresponding to Table

4 For example, the SALTER/GTAP model, a large multi-region general equilibrium model, can be solved as a linearized system. See Hertel (1996).

Table 5.1. *A perfect substitutes model*

A	A	B	C–E	F	G
1		**Inputs**		**corrosion resistant steel**	
2					
3		6373	Benchmark sales of the domestic industry		
4		7800	Benchmark total sales (domestic origin and imported)		
5					
6		3	Es: Elasticity of domestic supply		
7		1.5	Ed: Elasticity of demand		
8		15	Ems: Elasticity of import supply		
9					
10		10.30%	Initial tariff		Solve
11		10.30%	New tariff		
12					
13		0.00%	Initial foreign-held quota price wedge		
14		27.60%	Final foreign-held quota price wedge		
15					
16					
17		Calibrated values			
18					
19		6.4E+03	Ks : domestic supply constant term		
20		7.8E+03	Kd: total demand constant term		
21		6.2E+03	Kms: import supply constant term		
22		1.4E+03	Kmd: import demand constant term		
23		1.4E+03	Md: Import demand		
24		2.2E+01	Emd: elasticity of import demand		
25					
26					
27		Counterfactual equilibrium price			
28					
29		1.096	Linear domestic price solution:		
30		1.043	Non-linear domestic price solution		
31			-9.0E-08 non-linear optimization constraint (excess supply)		
32		0.961	Free trade price (linear)		
33		0.951	Free-trade price (nonlinear)		
34			1.0E-07 non-linear free trade constraint		
35					
36		Welfare and Output Comparisons			
37					
38				linear	nonlinear
39		National income effects: old regime			
40		welfare triangle		-38.83	-36.67
41		terms-of-trade effect		133.26	133.26
42		quota rent transfers		0.00	0.00
43		Total national income effect		94.43	96.58
44					
45		National income effects: new regime			
46		welfare triangle		-226.10	-131.99
47		terms-of-trade effect		16.53	15.73
48		quota rent transfers		-12.03	-11.45
49		Total national income effect		-221.61	-127.71
50					
51		Net welfare effect		-316.04	-224.29
52					
53		percent change in border price of imports		9.59%	4.29%
54		percent change in internal price		9.59%	4.29%
55		percent change in imports		-96.15%	-96.34%
56		percent change in domestic output		31.60%	13.44%
57					
58		old tariff revenues		$133.26	$133.26
59		new tariff revenues		$4.49	$4.27
60					

note: Border prices are f.o.b., and measure prices prior to the application of the quota premium. Terms-of-trade effects are also prior to quota rent deductions.

5.1, Appendix Table 5A.1 presents the programming structure of the spreadsheet, including cell references and formulas. In the spreadsheet, the system is first calibrated, meaning that the constant terms in the various equations are derived from the benchmark equilibrium data. We have employed a common normalization, which involves defining quantities so that price is equal to 1. This means that, when calibrating the model, most of the relevant constant terms are simply equal to initial benchmark dollar values. Welfare comparisons involve using welfare triangles – see equation (5.17) – and the corresponding terms-of-trade effect term. Quotas imply some transfer of rents, which are also included in the calculations. The spreadsheet uses the "Solve" option of Quattro Pro, a commercially available spreadsheet package. Other commercial spreadsheets offer similar utilities for solving a non-linear equation, or for solving a simple system of equations subject to a set of constraints. An alternative would be to use the non-linear optimizer, which is also included with most spreadsheet packages, where equation (5.27) defines the objective function. Other options involve programming the model in a non-linear optimization package, such as GAMS/MINOS or GAMS/MPSGE (Rutherford 1994a,b).

In structuring the spreadsheet, we have assumed that quotas are binding and can be modeled as export taxes. Tariffs and quota premiums are applied additively to world prices. This means that, when tariffs are used to recapture quota rents fully, one simply replaces the binding quota with an equally binding tariff. In general, attention must be paid to whether or not a quota is the binding constraint, and the extent to which tariffs recapture quota rents.

III.2 Welfare Calculations in a Second-Best World

Recall from our discussion of equations (5.8) and (5.17) that we assumed that we were starting from an undistorted equilibrium. In the presence of an initial distortion, the welfare impact of a new tariff or quota is complicated by the existence of the initial distortion. This is illustrated in Figure 5.3. In the figure, we assume an initial tariff for a small country at t_1, such that the internal price is $P=(1+t_1)P^*$, where P^* is world price. If we introduce an additional tariff t_2, so that $P=(1+t_1+t_2)$, the welfare impact will include the welfare triangle A. However, the new tariff also magnifies the impact of the initial distortion, resulting in additional welfare loss B. This highlights an important point. In many instances, it is difficult to justify comparing one tariff to another in isolation from related trade policies in the same market. To account for this, the spreadsheet in Table 5.1 calculates the welfare

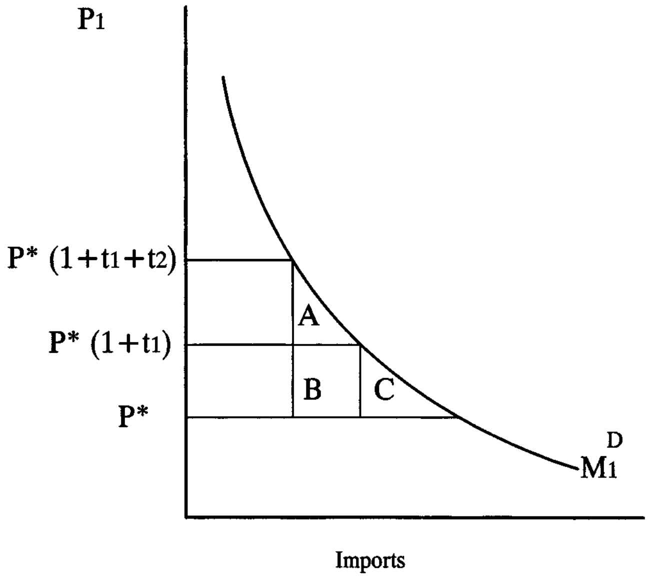


Figure 5.3. *The incremental effect of a tariff with an existing distortion*

implications of the benchmark regime relative to free trade and compares it to the counterfactual regime's implications relative to free trade. In terms of Figure 5.3, we compare triangle C, derived from tariff t_1, to triangle $(A+B+C)$, derived from tariff (t_1+t_2). Hence, in Table 5.1, the welfare equations in the spreadsheet are based on these calculations with reference to a non-distorted trade equilibrium and reflect a comparison of compensating variations for free trade options. Of course, it is not necessary to include these calculations within the spreadsheet itself. As an alternative, one could simply calculate and compare the welfare implications of various regimes, including the status quo, relative to free trade. With relatively large spreadsheet models, such an approach may allow more flexibility in implementing other aspects of the model.

In the world of second best, underlying distortions can carry very important implications for policy initiatives. In the presence of a quota, for example, a tariff may improve welfare by re-capturing quota rents. This is illustrated in Table 5.2, which reports simulation results, for a set of hypothetical import data, when a new 10 percent tariff or an equally restrictive voluntary export restraint is introduced. The trade flow data and elasticities are the same in all examples. The only difference is the initial underlying protection. For the new tariff, note that when the tariff replaces an existing voluntary

Table 5.2. *Impact of a new 10 percent tariff*

perfect substitutes model

	Case 1	Case 2	Case 3	Case 4	Case 5
Benchmark data					
Benchmark sales of the domestic industry	1000.00	1000.00	1000.00	1000.00	1000.00
Benchmark total sales	2000.00	2000.00	2000.00	2000.00	2000.00
Es: Elasticity of domestic supply	3.00	3.00	3.00	3.00	3.00
Ed: Elasticity of demand	2.00	2.00	2.00	2.00	2.00
Ems: Elasticity of import supply	10.00	10.00	10.00	10.00	10.00
Initial tariff	0.00	0.10	0.00	0.10	0.50
New tariff	0.10	0.20	0.10	0.20	0.60
Initial foreign-held quota price wedge	0.00	0.00	0.10	0.10	0.00
Final foreign-held quota price wedge	0.00	0.00	0.00	0.00	0.00
Counterfactual simulation results					
National income effects: old regime					
welfare triangle	0.00	-12.29	-12.29	-48.38	-271.93
terms-of-trade effect	0.00	90.91	90.91	166.67	333.33
quota rent transfers	0.00	0.00	-90.91	-83.33	0.00
Total national income effect	0.00	78.62	-12.29	34.96	61.40
National income effects: new regime					
welfare triangle	-15.52	-52.26	-12.29	-48.38	-376.94
terms-of-trade effect	39.01	77.01	90.91	166.67	211.70
quota rent transfers	0.00	0.00	0.00	0.00	0.00
Total national income effect	23.49	24.76	78.62	118.29	-165.24
Net welfare effect	23.49	-53.86	90.91	83.33	-226.64
percent change in border price of imports	-4.34%	-3.93%	-9.09%	-8.33%	-2.84%
percent change in internal price	5.22%	4.80%	-0.00%	-0.00%	3.63%
percent change in imports	-59.43%	-56.10%	-0.00%	-0.00%	-45.65%
percent change in domestic output	16.50%	15.11%	-0.00%	-0.00%	11.30%
old tariff revenues	0.00	90.91	0.00	83.33	333.33
new tariff revenues	39.01	77.01	90.91	166.67	211.70

Case 1: No initial underlying protection.
Case 2: Initial 10% tariff.
Case 3: Quota-rent recapture, no initial tariffs.
Case 4: Quota rent recapture, with initial tariff.
Case 5: Initial 50% tariff.

export restraint, the tariff improves welfare for the importer by capturing quota rents. In the example, when the initial equilibrium involves free trade, a small tariff improves welfare through terms-of-trade effects. However, when there is already a large initial tariff, the effect of the new 10 percent tariff is to reduce welfare. Because of quota rent transfers, the new "equivalent" quota carries more adverse welfare implications than the new tariff.[5]

The interaction of existing distortions illustrated in the table highlights the importance of underlying distortions. When working in a single-market model, we are limited to the interaction of various distortions within the market being examined. At the same time, there may be other distortions that, while significant and related to the present market, carry important implications for equilibria in other markets. This may justify movement away from a single-market model, and toward a multi-market partial equilibrium model (Chapter 8) or a simple general equilibrium model (Chapter 6). At a minimum, these issues must be taken into account when the modeling framework is first chosen.

IV Armington Models

A common alternative to the perfect substitutes model involves more complex specification of the markets for related products. Two tacks are often followed here. One involves the analysis of upstream and downstream markets; the other involves the analysis of competing products. Upstream and downstream linkages are explored in later chapters, both in partial and in general equilibrium. We focus in this section on horizontal linkages between markets.

We follow Armington (1969) in assuming well behaved preferences over a weakly separable product category that comprises similar, but not identical products. These imperfect substitutes are differentiated by their country of origin. The first version of the model is a log-linear version with constant own and cross-price elasticities of demand. This type of approach is relatively standard, and is followed in a number of spreadsheet-based partial equilibrium models, including the CADIC dumping model (Boltuck, 1991) and the COMPAS model (Francois and Hall, 1993). The second version of the model is specified as a non-linear system with a constant elasticity of substitution between products.

IV.1 A Log-Linear Specification

We start with an n good model, separating the product category into market segments by country of origin: domestic products (good 1) and imports (goods $2 \ldots n$). Further, all price elasticities of demand are assumed con-

5 One compelling reason for shifting from single-market models to multi-market models (partial or general equilibrium) is the type of policy interaction demonstrated in Table 5.2. Other policy variables, such as consumption or factor income taxes, can carry similar, though more complex, implications.

stant as in the preceding perfect substitutes model and may therefore be represented in log-linear form as follows:

Price Equation: $$P_i = P_i^*\left(1+t_i+w_i\right), \qquad i \neq 1 \tag{5.29}$$

Domestic Supply: $$\ln\left(Q_1^S\right) = K_1^S + \varepsilon_1^S \ln\left(P_1\right) \tag{5.30}$$

Import Supply: $$\ln\left(Q_i^S\right) = K_i^S + \varepsilon_i^S \ln\left(P_i^*\right), \qquad i \neq 1 \tag{5.31}$$

Domestic Demand: $$\ln\left(Q_1^D\right) = K_1^D + N_1 \ln\left(P_1\right) + \sum_{j\neq 1} N_{1j} \ln\left(P_j\right) \tag{5.32}$$

Import Demand: $$\ln\left(Q_i^D\right) = K_i^D + N_i \ln\left(P_i\right) + \sum_{j\neq 1} N_{ij} \ln\left(P_j\right), \qquad i \neq 1 \tag{5.33}$$

where each K is a constant and N_{ij} is the total price j elasticity of demand for product i.

Separability For the price elasticities of demand to be constant, we assume that demand for each product within the industry is a function of industry prices and total expenditure alone:

$$Q_i^D = D_i\left(P_i, P_{j,j\neq 1}, y\right) \tag{5.34}$$

where y is total industry expenditure. In individual consumer theory, this would result from the assumption of weakly separable preferences.[6] Differentiating with respect to price j we get

$$\frac{dD_i}{dP_j} = \frac{\partial D_i}{\partial P_j} + \frac{\partial D_i}{\partial y}\frac{\partial y}{\partial P_j} \tag{5.35}$$

This can be rearranged to describe total price elasticity of demand as a function of the partial price elasticity of demand holding industry expenditures fixed:

$$N_{ij} = \eta_{ij} + \eta_{iy}\eta_{yj} \tag{5.36}$$

where N_{ij} is the total price elasticity of demand, η_{ij} is the partial price j elasticity of demand for product i (holding y fixed), η_{iy} is the industry

6 Note that there is no utility function from which log-linear demand functions can be generally derived for all commodities. See Green (1978).

expenditure elasticity of demand for product i, and η_{yj} is the price j elasticity of industry expenditure.

With well behaved preferences, we can convert the partial price elasticities of demand into substitution elasticities using the Slutsky decomposition of partial demand

$$\eta_{ij} = \eta_{ij}^{*} - \theta_j \eta_{iy} \tag{5.37}$$

(where η_{ij}^{*} is the compensated partial price j elasticity of demand for product i and θ_j is the product j share of industry expenditures) and conditional Allen elasticities of substitution[7] to get

$$N_{ij} = \theta_j \sigma_{ij} + \eta_{iy}\left(\eta_{yj} - \theta_j\right) \tag{5.38}$$

From the zero homogeneity property of Hicksian demand (see Henderson and Quandt, 1980, p. 33) we can use the fact that

$$\sum_j \eta_{ij}^{*} = 0$$

to substitute

$$-\sum_{j \neq 1} \eta_{ij}^{*}$$

for η_{ii} to obtain

$$N_{ii} = -\left(\sum_{j \neq i} \theta_j \sigma_{ij}\right) + \eta_{iy}\left(\eta_{yi} - \theta_i\right) \tag{5.39}$$

Two-Stage Budgeting Equation (5.39) can be further simplified with the additional assumption of homothetic preferences for industry expenditures, which, along with the assumption of weak separability, is sufficient for two-stage budgeting (see Shiells et al., 1986). We can therefore define price and quantity indexes P and $Q(P)$ over all prices P_i from the first stage utility maximization problem, and substitute them into the definition of the price j elasticity of industry expenditures as follows:

$$\begin{aligned} \eta_{yj} &\equiv \frac{\partial y}{\partial P_j}\frac{P_j}{y} \\ &= \frac{\partial (PQ)}{\partial P_j}\frac{P_j}{y} = \left(\frac{\partial P}{\partial P_j}Q + \frac{\partial Q}{\partial P}\frac{\partial P}{\partial P_j}P\right)\frac{P_j}{y} \end{aligned} \tag{5.40}$$

7 Allen elasticities are defined as $\sigma_{ij} = \eta_{ij}/\theta_j$.

Homotheticity of preferences implies that income elasticity of demand for every product is 1 (again see Shiells et al.), so that if we define NA as the aggregate demand elasticity for products in the industry with respect to industry price index P, Shepard's Lemma leads to

$$\frac{\partial P}{\partial P_j} = \frac{Q_j}{Q} \tag{5.41}$$

which can be substituted into the previous equation to obtain

$$\eta_{yj} = \theta_j (1 + NA) \tag{5.42}$$

Both results can be substituted into (5.37) and (5.38) to obtain

$$N_{ij} = \theta_j (\sigma_{ij} + NA) \qquad for\ i \neq j \tag{5.43}$$

$$N_{ii} = \theta_i NA - \sum_{j \neq i} \theta_j \sigma_{ij} \tag{5.44}$$

Constant Industry Expenditures Alternatively, rather than adding the assumption of homothetic preferences for industry expenditures we could assume that industry expenditures are fixed ($\eta_{yj}=0$) and obtain the following:

$$N_{ij} = \theta_j (\sigma_{ij} - \eta_{iy}) \qquad for\ i \neq j \tag{5.45}$$

$$N_{ii} = -\theta_i \eta_{iy} - \sum_{j \neq i} \theta_j \sigma_{ij} \tag{4.46}$$

Implementation Working with either equations (5.43)–(5.44) or alternatively equations (5.45)–(5.46), the elasticity parameters in equations (5.29)–(5.33) can be calculated from a relatively small number of parameters: the elasticity of substitution σ, the composite demand elasticity NA, and market share data. If we scale quantities so that prices are unity, then the constant terms are simply equal to market revenues.

A warning is called for here. Examination of equation (5.43) should make it apparent that theory suggests an important relationship between composite demand elasticities and low-tier substitution elasticities. In particular, if the lower-tier substitution elasticity is *smaller* than the upper-tier composite demand elasticity NA, then "competing" goods will be net complements instead of net substitutes. Basically, with relatively low substitution elasticities, the composite price effects related to trade liberalization will dominate cross-price effects. Hence, while there may be some substitution away from the domestic product and toward imports, the net effect of a tariff reduction will be an increase in demand for the domestic product caused by increased expenditures on the category. This result is the "Henning conundrum," which refers to cases where models yield increased demand for domestic goods when tariffs on competing imports are reduced. Equation (5.43) identifies a constraint (the Henning conundrum constraint) sufficient to rule out such results, particularly $\sigma > |NA|$.

IV.2 A Non-Linear Specification

As an alternative, we can also specify an Armington model as a system of non-linear equations. We first define the Armington composite good, q, as a CES composite of the domestic good $X1$, and of imports Xi from countries $i=2 \ldots n$.

$$q = \left[\sum_{i=1}^{n} \alpha_i X_i^{\rho} \right]^{1/\rho} \tag{5.47}$$

In calibrating the model, we again scale quantities so that internal prices are all unity in the benchmark. This includes the price for the Armington composite good q. The price index for the composite good can be shown to equal

$$P = \left[\sum_{i=1}^{n} \alpha_i^{\sigma} P_i^{1-\sigma} \right]^{1-1/\rho} \tag{5.48}$$

At the same time, from the first-order conditions, the demand for good Xi can be shown to equal

$$\begin{aligned} x_i &= \left[\frac{\alpha_i}{P_i} \right]^{\sigma} \left[\sum_{i=1}^{n} \alpha_i P_i^{1-\sigma} \right]^{-1} Y \\ &= \left[\frac{\alpha_i}{P_i} \right]^{\sigma} P^{\sigma-1} Y, \qquad where\ \rho = 1 - \left(\frac{1}{\sigma} \right) \end{aligned} \tag{5.49}$$

Combined with supply equations, these terms can be used to define a simple non-linear system in terms of prices. In particular, if we specify supply as a function with constant supply elasticity ε_{si}, then excess demand conditions in each market are defined as follows:

$$\left[\frac{\alpha_i}{P_i} \right]^{\sigma} P^{\sigma-1} Y - K_{si} P_i^{\varepsilon_{si}} = 0 \tag{5.50}$$

At the same time, the composite price equation can be re-written as follows:

$$\left[\sum_{i=1}^{n} \alpha_i^{\sigma} P_i^{1-\sigma}\right]^{1-1/\rho} - P = 0 \tag{5.51}$$

Finally, if we define demand for the composite good as

$$q = k_A P^{NA} \tag{5.52}$$

where NA is the elasticity of demand for the composite good, then we can specify excess demand for the composite good as follows: Note that, in equation (5.53), $Y = Pq$.

$$k_A P^{NA+1} - Y = 0 \tag{5.53}$$

Equations (5.50), (5.51), and (5.53) define a system of $(n+2)$ equations and $(n+2)$ unknowns. The system can be solved for prices, and solution prices can then used to solve for quantities and welfare measures.

Tariffs or other price-based measures of import protection can be added to the system through the import supply functions. This requires a slight modification of equation (5.50), as follows:

$$\left[\frac{\alpha_j}{P_j}\right]^{\sigma} P^{\sigma-1} Y - K_{si}\left(\frac{P_j}{\left(1+t_j\right)}\right)^{\varepsilon_{sj}} = 0 \qquad for\, j = 2 \ldots n \tag{5.54}$$

Table 5.3 presents a spreadsheet implementation of a non-linear Armington model with two import sources. The programming structure of the spreadsheet is detailed in Appendix Table 5A.2. Calibration is based on unit price normalization, so that all constants are equal to benchmark expenditures. The model is solved by using a spreadsheet-based non-linear solver provided with Quattro Pro (this feature is now common to most commercial spreadsheets). The non-linear solver is used to solve for the price of the composite good – equation (5.52) – subject to the constraint that all excess demands must equal zero (equations (5.50)–(5.51), and (5.54)). As constructed, the spreadsheet model must first be benchmarked, by means of a macro routine that sets initial guess values for the counterfactual value of variables on the basis of benchmark equilibrium values.

In Table 5.3, welfare measures are calculated on the basis of changes in trade policy regarding imports from country 2. This includes comparison of welfare triangles and terms-of-trade effects for the benchmark and counterfactual equilibrium, both with respect to a free trade equilibrium. As described in Chapter 3, the measure of the welfare effect of induced changes in

Table 5.3. *A non-linear imperfect substitutes (Armington) model*

C	A	B	C–G	H	I	J
1		**Inputs**	**corrosion resistant steel**			
2						
3		1716	Benchmark sales of X1 (i.e. domestic) industry			
4		228	Benchmark sales of country 2 imports			
5		56	Benchmark sales of country 3 imports			
6		2000	Benchmark total sales (domestic origin and imported)			
7						
8		1.5	NA: Composite elasticity of demand		(RE)CALIBRATE	
9		3	Es1: Elasticity of domestic supply			
10		15	Es2: Elasticity of country 2 import supply			
11		15	Es3: Elasticity of country 3 import supply			
12		3.08	σ: Elasticity of substitution		SOLVE	
13						
14		10.30%	t2,0: Initial tariff on country 2 imports			
15		10.30%	t3,0: Initial tariff on country 3 imports			
16		10.30%	t2,1: Final tariff on country 2 imports			
17		10.30%	t3,1: Final tariff on country 3 imports			
18						
19		0.00%	w2,0: Initial export tax/quota price wedge on country 2 imports			
20		0.00%	w3,0: Initial export tax/quota price wedge on country 3 imports			
21		55.70%	w2,1: Final export tax/quota price wedge on country 2 imports			
22		0.00%	w3,1: Final export tax/quota price wedge on country 3 imports			
23						
24						
25		**Calibrated values**				
26						
27	1.72E+03	Ks1 : domestic supply constant term		1.00	P1: calibrated domestic product market	
28	9.92E+02	Ks2 : country 2 import supply constant term		1.00	P2: calibrated internal price for good 2	
29	2.44E+02	Ks3 : country 3 import supply constant term		1.00	P3: calibrated internal price for good 3	
30	2.00E+03	KD : composite demand constant term		0.91	P2*: calibrated country 2 border price	
31	0.95	$\omega 1$:	CES weight for domestic good	0.91	P3*: calibrated country 3 border price	
32	0.49	$\omega 2$:	CES weight for country 2 import	1.00	PA: calibrated composite good price	
33	0.31	$\omega 3$:	CES weight for country 3 import			
34						
35						
36		**Counterfactual solution values**				
37	counterfactual	free-trade in X2		internal prices and Y		
38	Excess demands	excess demands		free trade in X2	counterfactual	
39	5.3E-10	1.4E-10	P1: domestic product market	1.00	1.01	
40	2.7E-07	7.0E-08	P2: good 2 market	0.92	1.41	
41	2.0E-11	5.1E-12	P3: good 3 market	1.00	1.00	
42	3.3E-12	3.7E-13	PA: composite good price	0.99	1.04	
43	-2.3E-10	-6.2E-11	Y: total expenditure	2013.07	1962.55	
44						
45		**Results**				
46						
47		**National income effects of policy change in market for X2:**				
48				old regime	new regime	change
49		welfare triangle		-32.55	-155.74	-123.19
50		terms-of-trade effects		3.24	6.10	2.86
51		quota rent transfers		0.00	-39.84	-39.84
52		secondary effects for X3		*	0.27	0.27
53		Net welfare effect				-159.90
54						
55						
56		**Price, quantity and tariff revenue effects of policy change in X2 market:**				
57						
58		percent change in internal price of domestic good				0.99%
59		percent change in shipments of domestic good				2.99%
60						
61		percent change in border price of good 2				-6.42%
62		percent change in internal price of good 2				40.84%
63		percent change in imports of good 2				-63.03%
64						
65		percent change in border price of good 3				0.33%
66		percent change in internal price of good 3				0.33%
67		percent change in imports of good 3				5.08%
68						
69		Change in tariff revenue				
70		tariffs in market for X2				-13.92
71		tariffs in market for X3				0.28
72		total change in tariff revenue				-13.64
73						

note: Border prices are measured f.o.b., and are net of quota markups.

demand for imports of good 3 is based on induced changes in tariff revenue in the import market for good 3.

V An Application to U.S. Steel Protection

We turn to an applied example, focusing on U.S. steel imports. Since the early 1980s, U.S. steel imports have been subjected to a variety of import restraints (USITC, 1993a). In 1984, negotiations began on voluntary export restraints (VERs) on steel. Agreement was eventually reached with nineteen countries (including Portugal and Spain) and the European Community; these are listed in Table 5.4. The VER negotiations followed an episode where the U.S. steel industry threatened to file literally hundreds of antidumping and countervailing duty complaints. These involved the threat of massive litigation over alleged unfair pricing of imports. These unfair trade cases were terminated when the series of bilateral VERs were imposed. Because these quotas were "voluntary," they escaped GATT strictures on most favored nation (MFN) treatment and discriminatory protection. With exchange rate changes, the binding effects of these quotas were gradually eroded, and by the end of the 1980s, they had largely ceased to be binding. In 1989, the president announced his intention to phase out the VERs by March 31, 1992. With the loss of protection through quotas, the U.S. steel industry again pursued antidumping and countervailing duty actions. The result this time was not new VERs, but rather the imposition of antidumping and countervailing duty orders. Table 5.4 provides a comparison of the VERs and their subsequent replacement with antidumping and countervailing duties. This episode, with the transition from bilateral quotas to bilateral tariffs, offers an opportunity to compare and contrast the implications of importer and exporter administered protection.

Table 5.5 presents data on U.S. import trade in steel and existing tariffs in 1992. The results of the dumping investigations are also presented, as a set of trade-weighted tariffs. Simulation results are also presented in Table 5.6, under alternative assumptions about model structure and about the policy options undertaken. In particular, we have modeled the actual imposition of antidumping and countervailing duties, and the alternative imposition of identical restraints. Because we model quotas as an export tax, export quotas or price undertakings are operationally identical in this type of model.[8]

8 An alternative approach involves the explicit modeling of quotas, initially specified as slack constraints on imports. The constraint can then be tightened until it is binding. Under this type of approach, the import quantity is exogenously specified, while the resulting quota price wedge or export tax equivalent is endogenous. This can be done with a slack-complementarity solver, like GAMS/MPSGE (Rutherford, 1994a,b).

Table 5.4. *The expiration of VERs and the imposition of antidumping and countervailing duties*

Country	VER on exports of certain steel products 1984-92	Anti-dumping duty orders on certain flat-rolled steel products, 1993	Countervailing duty orders on certain flat-rolled steel products, 1993	Antidumping and/or countervailing orders on flat-rolled steel, 1993
Australia	yes	yes	no	yes
Austria	yes	no	no	no
Brazil	yes	yes	yes	yes
China	yes	no	no	no
Czechoslovakia	yes	no	no	no
European Community	yes	yes	yes	yes
Finland	yes	yes	no	yes
German Democratic Republic	yes	no	no	no
Hungary	yes	no	no	no
Japan	yes	no	no	no
Korea, Republic of	yes	yes	yes	yes
Mexico	yes	yes	yes	yes
Poland	yes	yes	no	yes
Romania	yes	yes	no	yes
Trinidad and Tobago	yes	no	no	no
Venezuela	yes	no	no	no
Yugoslavia	yes	no	no	no

Source: GATT secretariat (1994), Table IV.4.

Table 5.5. *Flat rolled steel products, 1992: summary of U.S. antidumping and countervailing duty actions*

	Plate	Hot-rolled	Cold-rolled	Corrosion resistant
Benchmark sales of domestic industry, 1992	1,716	13,369	10,318	6,373
Benchmark total sales (domestic and foreign)	2,000	14,500	11,300	7,800
Initial tariff on imports				
subject imports	0.103	0.103	0.103	0.103
non-subject imports	0.103	0.103	0.103	0.103
Benchmark subject imports, c.i.f.	228	1,021	884	1,308
Benchmark non-subject imports, c.i.f.	56	110	98	120
Trade weighted AD/CVD duties				
weighted by all imports	0.447	0.000	0.063	0.276
weighted by subject imports	0.557	0.000	0.070	0.302

note: imports are in millions of dollars for 1992, valued at internal market prices
Final duties were published in July 1993. See USITC (1993).

Table 5.6. *Comparison of tariffs and quotas*

national income effects, millions of dollars

	imports as perfect substitutes		imports as imperfect substitutes	
	tariffs	quotas	tariffs	quotas
cut-to-length steel plate	-42.3	-43.4	-120.6	-159.9
cold-rolled products	-49.5	-73.1	-72.32	-120.9
corrosion resistant product	-212.8	-224.3	-401.5	-596.5
Total	-304.6	-340.8	-594.42	-877.3

import effects, percent

	imports as perfect substitutes	imports as imperfect substitutes	
		subject imports	non-subject imports
cut-to-length steel plate	-99.4	-63	5.1
cold-rolled products	-56.1	-13.9	0.7
corrosion resistant products	-96.3	-43.4	5

note: Trade and domestic production data are all from Table 5.5. Application examples are shown in Tables 5.1 and 5.3, including the elasticities used. A substitution elasticity of 3.08 is used in the Armington model, based on Reinert and Roland-Holst (1992).

The implications of alternative model structures are highlighted in Table 5.6. The results are calculated by using the non-linear models presented in Tables 5.1 and 5.3. For a given policy shock, the largest trade impacts are realized in the perfect substitutes model. In contrast, the largest welfare impacts are identified under the imperfect substitutes model. As suggested by the relative trade impact, as we move to an imperfect substitutes framework, the impact of protection on the domestic industry is substantially less. This is because the degree of competition between imports and the domestic like product has been limited by the degree of substitution, which is now less than infinite.

While not highlighted in Table 5.6, it is important to recognize that the results generated by Armington models are particularly sensitive to the value of the parameter σ. This should be apparent from our earlier discussion of equation (5.43) and the Henning conundrum constraint. This can also be seen by comparing the results when $\sigma=3$ (the right set of results in Table 5.6) with the results when $\sigma \to \infty$ (the left set of results). We have drawn our Armington parameters from Reinert and Roland-Holst (1992). Other sources of estimates include Shiells and Reinert (1993) and Shiells, Deardorff, and Stern (1986). Estimates from Reinert and Roland-Holst are reproduced in Appendix Table 5A.3. The sensitivity of Armington parameters to the substitution elasticity carries over to large, general equilibrium models as well. In general equilibrium, the implications are more complex and carry over to the factor market and economywide terms-of-trade effects of trade liberalization. However, the roots of this central role for the substitution elasticity can be identified even in a simple partial equilibrium setting.

There are some qualitative results that are largely invariant to model structure. In particular, the imposition of tariffs is welfare superior, for the United States, to the imposition of identical protection through quotas or a price undertaking. This is because the latter involves the transfer of some of the rents generated by protection to the exporter. This also illustrates why, politically, export restraints are easier to agree on with an exporter than import restraints. Such rents offer partial "compensation" for reduced market access. When threatened with high, discriminatory tariffs (such as antidumping duties), an exporter may prefer to impose protection itself. Depending on the size of the rents at stake, an exporter may even prefer such "voluntary" restraints to free trade.

While not developed here, the welfare implications of alternative policy instruments can vary with extensions to the analytical framework employed in Table 5.6. For example, if we assume that domestic firms have market power, the imposition of a quota will have different implications for domestic production than a tariff (see Chapter 11). With quotas and a domestic monopolist, for example, protection may actually lead to a reduction in domestic production, as the monopolist raises his prices to take advantage of the protection offered by the quota.[9] Alternatively, shifts in the terms of trade due to exchange rate swings may also cause tariffs to carry different welfare implications than quotas.

VI Extensions

In this chapter, we have presented basic techniques for relatively simple, partial equilibrium modeling of commercial policy. The techniques are quite

9 See Chapters 2 and 10 for further discussion. Also see Krugman and Helpman (1989, Chapter 3) for a comparison of tariffs and quotas when protected domestic firms have market power.

flexible, and can be applied relatively quickly, and with a limited amount of information on trade flows and relevant parameter values. At the same time, the limitations of this type of analysis must also be taken into account. While the simplicity of these models implies relative transparency when compared to more complex models, such simplicity also limits the scope of the analysis.

The welfare measures we offer emphasize the trade-off between domestic distortions in consumption and terms-of-trade effects. However, these are not likely to be the only variables in an inherently political objective function. National income effects may, in fact, enter relatively far down the list of relevant factors considered by trade officials. More "immediate" trade and production effects may, for various reasons, be ranked higher. Still, as our applied example of U.S. steel protection illustrates, the tools developed here can identify options that help to minimize costs when protection is to be chosen from a range of policy instruments. These tools may also allow some exploration of the distributional implications, production effects, and terms-of-trade effects of various policy options.

The basic framework developed here can be extended in a number of directions, while still offering relative simplicity and transparency. The example of vertical market linkages and multi-region models is covered in Chapter 8. The basic framework developed here is also employed in the suite of spreadsheets that constitute the COMPAS model (Francois and Hall, 1993) for assessment of trade remedies. As long as limitations are kept in mind, this type of approach can also be employed for assessment of the welfare and production effects of trade regimes. Examples include research on U.S. import protection (USITC, 1989), the MFA (Martin and Suphachalasai, 1990; Cline, 1987), and the European Union's single market program (Commission of the European Communities, 1988).

Appendix 5.1

Table 5A.1. *Spreadsheet structure for Table 5.1*

```
A:B3:   6373
A:B4:   7800
A:B6:   3
A:B7:   1.5
A:B8:   15
A:B10:  0.103
A:B11:  0.103
A:B13:  0
A:B14:  0.276
A:B19:  (B3)
A:B20:  (B4)
A:B21:  (((1+B10+B13))^B8)*B23
A:B22:  (B23)
A:B23:  (B4-B3)
A:B24:  -(-(B7*B20)-(B6*B19))/(B22)
A:B29:  @EXP((1/($B$8+$B$24))*(@LN($B$22)-@LN($B$21)+($B$8*@LN((1+$B$11+$B$14)))))
A:B30:  1.0429239642158
A:C31:  ($B$21*($B$30^$B$8)*(((1+$B$11+$B$14))^(-$B$8)))+(($B$19)*($B$30^$B$6))-($B$20*($B$30^(-$B$7)
        ))
A:B32:  @EXP((1/($B$8+$B$24))*(@LN($B$22)-@LN($B$21)+($B$8*@LN((1)))))
A:B33:  0.95108669942967
A:C34:  ($B$21*($B$33^$B$8)*(((1))^(-$B$8)))+(($B$19)*($B$33^$B$6))-($B$20*($B$33^(-$B$7)))
A:F40:  ((($B$21*($B$32^$B$8))-$B$23))*($B$32-1)*0.5
A:G40:  ((($B$21*($B$33^$B$8))-$B$23))*($B$33-1)*0.5
A:F41:  (((1+B10+B13)-1)/((1+B10+B13)))*B23
A:G41:  (((1+B10+B13)-1)/((1+B10+B13)))*B23
A:F42:  -(B13/((1+B10+B13)))*B23
A:G42:  -(B13/((1+B10+B13)))*B23
A:F43:  @SUM(F40..F42)
A:G43:  @SUM(G40..G42)
A:F46:  ((($B$21*($B$32^$B$8))-($B$23*(1+$F$55))))*($B$32-$B$29)*0.5
A:G46:  ((($B$21*($B$33^$B$8))-($B$23*(1+$G$55))))*($B$33-$B$30)*0.5
A:F47:  (B29/((1+B11+B14)))*((1+B11+B14)-1)*(1+F55)*B23
A:G47:  (B30/((1+B11+B14)))*((1+B11+B14)-1)*(1+F55)*B23
A:F48:  -(B29/((1+B11+B14)))*(B14)*(1+F55)*B23
A:G48:  -(B30/((1+B11+B14)))*(B14)*(1+F55)*B23
A:F49:  @SUM(F46..F48)
A:G49:  @SUM(G46..G48)
A:F51:  (F49-F43)
A:G51:  (G49-G43)
A:F53:  ((($B$29/(1+$B$11))-(1/(1+$B$10)))*(1+$B$10))
A:G53:  ((($B$30/(1+$B$11))-(1/(1+$B$10)))*(1+$B$10))
A:F54:  ($B$29-1)
A:G54:  ($B$30-1)
A:F55:  (($B$21*($B$29/((1+$B$11+$B$14))^$B$8))-$B$23)/$B$23
A:G55:  (($B$21*($B$30/((1+$B$11+$B$14))^$B$8))-$B$23)/$B$23
A:F56:  (($B$19*($B$29^$B$6))-$B$3)/$B$3
A:G56:  (($B$19*($B$30^$B$6))-$B$3)/$B$3
A:F58:  (F41+F42)
A:G58:  (G41+G42)
A:F59:  (F47+F48)
A:G59:  (G47+G48)
A:A64:  'SOLVE MACRO
A:A65:  '{SolveFor.Formula_Cell A:C31}
A:A66:  '{SolveFor.Variable_Cell A:B30}
A:A67:  '{SolveFor.Target_Value 0}
A:A68:  '{SolveFor.Max_Iters 10}
A:A69:  '{SolveFor.Accuracy 5E-06}
A:A70:  '{SolveFor.Go}
A:A71:  '{SolveFor.Formula_Cell A:C34}
A:A72:  '{SolveFor.Variable_Cell A:B33}
A:A73:  '{SolveFor.Target_Value 0}
A:A74:  '{SolveFor.Max_Iters 10}
A:A75:  '{SolveFor.Accuracy 5E-06}
A:A76:  '{SolveFor.Go}
```

note: Quota rents are included in calculation of "gross" terms-of-trade effects. These are then backed out of net welfare calculations.

Table 5A.2. *Spreadsheet structure for Table 5.3*

C:B3:	1716
C:B4:	228
C:B5:	56
C:B6:	@SUM(B3..B5)
C:B8:	1.5
C:B9:	3
C:B10:	15
C:B11:	15
C:B12:	3.08
C:B14:	0.103
C:B15:	0.103
C:B16:	0.103
C:B17:	0.103
C:B19:	0
C:B20:	0
C:B21:	0.557
C:B22:	0
C:A27:	(B3)
C:A28:	(B4)*(((1+B14+B19))^(B10))
C:A29:	(B5)*(((1+B15+B20))^(B11))
C:A30:	(B6)
C:A31:	(B3/A$30)^(1/B$12)
C:A32:	(B4/A$30)^(1/B$12)
C:A33:	(B5/A$30)^(1/B$12)
C:G27:	1
C:G28:	(1+B14+B19)*G30
C:G29:	(1+B15+B20)*G31
C:G30:	(1/((1+B14+B19)))
C:G31:	(1/((1+B15+B20)))
C:G32:	(((A31)^B12)+((A32)^B12)+((A33)^B12))^(-1/(B12-1))
C:A39:	(((A31/I39)^(B$12))*(I$43)*(I$42^(B$12-1)))-(A27*(I39^B9))
C:A40:	(((A32/I40)^(B$12))*(I$43)*(I$42^(B$12-1)))-(A28*(((I40/((1+B16+B21)))^B10)))
C:A41:	(((A33/I41)^(B$12))*(I$43)*(I$42^(B$12-1)))-(A29*(((I41/((1+B17+B22)))^B11)))
C:A42:	(((A31)^(B$12))*(I39^(1-B$12))+((A32)^(B$12))*(I40^(1-B$12))+((A33)^(B$12))*(I41^(1-B$12)))^(1/(1-B12))-I42
C:A43:	(A30)*(I42^(-B8+1))-I43
C:C39:	(((A31/H39)^(B$12))*(H$43)*(H$42^(B$12-1)))-(A27*(H39^B9))
C:C40:	(((A32/H40)^(B$12))*(H$43)*(H$42^(B$12-1)))-(A28*(((H40/((1)*(1)))^B10)))
C:C41:	(((A33/H41)^(B$12))*(H$43)*(H$42^(B$12-1)))-(A29*(((H41/((1+B17+B22)))^B11)))
C:C42:	(((A31)^(B$12))*(H39^(1-B$12))+((A32)^(B$12))*(H40^(1-B$12))+((A33)^(B$12))*(H41^(1-B$12)))^(1/(1-B12))-H42
C:C43:	(A30)*(H42^(-B8+1))-H43
C:H39:	0.996621077741846
C:H40:	0.920837680437056
C:H41:	0.998862448733529
C:H42:	0.987059999394282
C:H43:	2013.06695303149
C:I39:	1.00987375148887
C:I40:	1.40839392451381
C:I41:	1.00330955595646
C:I42:	1.03853269183699
C:I43:	1962.54629206507
C:G49:	(((B4)-(((A32/H40)^(B$12))*(H$43)*(H$42^(B$12-1))))*(1/H40))*0.5
C:G50:	(H40-G30)*B4
C:G51:	-((1/(1+B19+B14)))*B19*B4
C:G52:	^*
C:H49:	(((B4*(1+I63))-(((A32/H40)^(B$12))*(H$43)*(H$42^(B$12-1))))*(I40/H40))*0.5
C:H50:	(H40-(I40/(1+B21+B16)))*(1+I63)*B4
C:H51:	-(I40/(1+B21+B16))*B21*B4*(1+I63)
C:H52:	(G31*(1+I67)*B5*B17)+H71-(B5*G31*B15)
C:I49:	(H49-G49)
C:I50:	(H50-G50)
C:I51:	(H51-G51)
C:I52:	(H52-G52)
C:I53:	@SUM(I49..I52)
C:I58:	(I39-1)
C:I59:	((((A31/I39)^(B$12))*(I$43)*(I$42^(B$12-1)))-B3)/B3
C:I61:	((I40/((1+B16+B21)))-G30)/G30
C:I62:	(I40-1)
C:I63:	((((A32/I40)^(B$12))*(I$43)*(I$42^(B$12-1)))-B4)/B4
C:I65:	((I41/((1+B17+B22)))-G31)/G31
C:I66:	(I41-1)
C:I67:	((((A33/I41)^(B$12))*(I$43)*(I$42^(B$12-1)))-B5)/B5
C:I70:	((1+I61)*G30*(1+I63)*B4*B16)-(B4*G30*B14)
C:I71:	((1+I65)*G31*(1+I67)*B5*B17)-(B5*G31*B15)
C:I72:	@SUM(I70..I71)

Table 5A.2. *(cont.)*

C:N1:	'(RE)CALIBRATE MACRO
C:N2:	'{HLine -5}
C:N3:	'{VLine 24}
C:N4:	'{SelectBlock g27..g29}
C:N5:	'{EditCopy}
C:N6:	'{SelectBlock H39..H41}
C:N7:	'{PasteSpecial "",Values,"",""}
C:N8:	'{SelectBlock I39..I41}
C:N9:	'{PasteSpecial "",Values,"",""}
C:N10:	'{SelectBlock g32..g32}
C:N11:	'{EditCopy}
C:N12:	'{SelectBlock H42..H42}
C:N13:	'{PasteSpecial "",Values,"",""}
C:N14:	'{SelectBlock I42..I42}
C:N15:	'{PasteSpecial "",Values,"",""}
C:N16:	'{SelectBlock a30..a30}
C:N17:	'{EditCopy}
C:N18:	'{SelectBlock H43..H43}
C:N19:	'{PasteSpecial "",Values,"",""}
C:N20:	'{SelectBlock I43..I43}
C:N21:	'{PasteSpecial "",Values,"",""}
C:N22:	'{SelectBlock A1..A1}
C:R1:	'SOLVE MACRO
C:R2:	'{Optimizer.Reset}
C:R3:	'{Optimizer.Solution_Cell A42}
C:R4:	'{Optimizer.Solution_Goal "Target Value:"}
C:R5:	'{Optimizer.Variable_Cells I39..I43}
C:R6:	'{Optimizer.Add 1,"A39..A39","=","0"}
C:R7:	'{Optimizer.Add 2,"A40..A40","=","0"}
C:R8:	'{Optimizer.Add 3,"A41..A41","=","0"}
C:R9:	'{Optimizer.Add 4,"A43..A43","=","0"}
C:R10:	'{Optimizer.Solve}
C:R11:	'{Optimizer.Reset}
C:R12:	'{Optimizer.Solution_Cell C42}
C:R13:	'{Optimizer.Solution_Goal "Target Value:"}
C:R14:	'{Optimizer.Variable_Cells H39..H43}
C:R15:	'{Optimizer.Add 1,"C39..C39","=","0"}
C:R16:	'{Optimizer.Add 2,"C40..C40","=","0"}
C:R17:	'{Optimizer.Add 3,"C41..C41","=","0"}
C:R18:	'{Optimizer.Add 4,"C43..C43","=","0"}
C:R19:	'{Optimizer.Solve}
C:R20:	'{SelectBlock A1..A1}

note: Quota rents are included in calculation of "gross" terms-of-trade effects. These are then backed out of net welfare calculations.

Table 5A.3. *Estimated elasticities of substitution between imports and domestic competing goods (based on U.S. imports)*

Sector No.	Elasticity	t-statistic		Sector Name
1	1.22	1.63		Iron and ferroalloy ores mining
4	0.16	0.23		Coal mining
5	0.31	2.3	*	Crude petroleum and natural gas
6	0.97	17.84	*	Stone, sand, and gravel
8	1.13	1.78		Chemical and fertilizer mineral mining
9	1.68	3.3	*	Meat packing plants and prepared meats
11	1	33.92	*	Creamery butter
12	1.99	6.74	*	Cheese, natural and processed
15	0.67	3.1	*	Fluid milk
17	1.16	2.84	*	Flour and other grain mill products
18	0.35	8.04	*	Cereals and flour
19	1.88	7.9	*	Dog, cat, and other pet food
20	1.26	6.24	*	Prepared feeds, n.e.c.
21	0.59	1.67		Wet corn milling
22	1.11	7.68	*	Bread, cake, cookies, and crackers
24	0.13	6.57	*	Chocolate and other confectionary products
25	0.02	0.8		Malt and malt beverages
26	3.49	6.95	*	Wine, brandy, and brandy spirits
27	0.15	8.46	*	Distilled liquor, except brandy
28	1.49	4.75	*	Soft drinks, flavorings, and syrups
29	0.93	2.82	*	Vegetable oil mills
30	0.06	0.14		Animal and marine fats and oils
32	1.85	4.12	*	Shortening and cooking oils
33	0.27	5.16	*	Sea foods, ice, and pasta
34	0.69	1.52		Cigarettes
35	0.15	3.28	*	Cigars
36	0.99	6.21	*	Tobacco
37	0.54	3.96	*	Yarn, thread, and broadwoven fabric mills
38	0.82	7.41	*	Narrow fabric mills
39	1.21	2.55	*	Floor coverings
40	0.57	1.91		Felt, lace and other textile goods
41	2.53	9.8	*	Hosiery
43	0.45	3.55	*	Apparel made from purchased materials
44	2.18	3.74	*	Housefurnish., textile bags, canvas
45	0.64	2.6	*	Logging camps and logging contractors
46	0.58	0.64		Sawmills
47	1.73	8.53	*	Hardwood dimension and flooring mills
48	0.06	2.1	*	Millwork, wood kitchens and cabinets
50	1.02	20.13	*	Wood pallets, skids, and containers
52	0.49	9.92	*	Wood preserving and particleboard
53	0.05	0.91		Household furniture
56	0.97	16.6	*	Paper mills, except building papers
57	1.5	6.92	*	Paperboard mills

Table 5A.3. *(cont.)*

Sector No.	Elasticity	t-statistic		Sector Name
59	1.42	8.19	*	Sanitary paper products
60	0.97	1		Building paper and board mills
61	1.68	10.15	*	Paper coating and glazing
62	1.48	4.57	*	Paperboard containers and boxes
63	0.98	9.26	*	Newspapers
64	1	43.12	*	Periodicals, books, and greeting cards
65	0.8	11.48	*	Printing
66	0.48	4.17	*	Industrial inorganic and organic chemicals
67	0.31	3.62	*	Agricultural chemicals
68	0.96	18.73	*	Chemical preparations
69	1.71	11.55	*	Plastics materials and resins
70	0.87	4.47	*	Synthetic rubber
71	0.66	2.31	*	Organic fibers
72	1.09	6.49	*	Drugs
73	0.58	1.44		Soap, detergents, and sanitation goods
76	0.4	1.53		Paving mixtures,blocks, asphalt felts
77	0.02	0.34		Tires and inner tubes
78	0.29	4.32	*	Rubber and plastics footwear
79	0.01	0.14		Other rubber products
80	1.46	1.71	*	Miscellaneous plastics products
81	1.07	1.89	*	Leather tanning and finishing
83	1.27	14.85	*	Other leather goods
84	0.36	11.95	*	Glass and glass products, exc. containers
85	0.23	1.13		Glass containers
86	1.09	12.73	*	Cement, hydraulic
87	1.04	28.48	*	Brick and structural clay tile
88	0.88	24.13	*	Ceramic wall and floor tile
90	0.84	8.94	*	Ceramic plumbing and electrical supplies
91	1.45	7.38	*	China and earthenware products
93	0.82	16.13	*	Stone and nonmetalic mineral products
94	0.76	7.75	*	Primary steel
95	3.08	4.06	*	Iron and steel foundries
96	0.69	2.17	*	Metal heat treating and primary metal
97	0.91	0.98		Primary copper
103	0.16	1.3		Other nonfer. rolling, drawing, insulating
106	1.03	2.76	*	Metal barrels, drums and pails
107	0.45	1.47		Metal plumbing fixtures, heating equipment
108	0.74	6.26	*	Fabricated metal work
109	1.07	2.34	*	Fabricated plate work (boiler shops)
110	0.22	2.34	*	Screw machine products and bolts, etc.
111	1.17	23.65	*	Forgings and stampings
112	0.2	0.48		Cutlery
113	0.22	8.87	*	Hand tools
115	0.24	2.75	*	Other fabricated metal products
116	0.3	1.25		Pipe, valves, and pipe fittings
117	0.99	21.77	*	Turbines and turbine generator sets
118	0.3	17.75	*	Internal combustion engines, n.e.c.
119	1.06	11.08	*	Farm and garden machinery and equipment
120	0.97	7.6	*	Construction, mining, oil field machinery

Table 5A.3. *(cont.)*

Sector No.	Elasticity	t-statistic		Sector Name
121	0.94	10.79	*	Elevators, conveyors, cranes
122	0.79	8.01	*	Machine tools and power driven hand tools
123	0.69	7.05	*	Special industry machinery
124	0.26	2.77	*	Pumps, compressors, blowers, fans, furnaces
125	0.83	10.89	*	Ball and roller bearings transmiss. equip.
127	0.85	5.6	*	Electrical computing equipment
128	1.22	9.67	*	Service industry machines
129	0.2	2.13	*	Transformers, switchgear and switchboard
130	0.72	3.3	*	Electrical industrial apparatus
131	2.69	2.6	*	Household cooking equipment
132	1.13	5.91	*	Household refrigerator and freezers
133	1.01	19.66	*	Household laundry equipment
134	1.97	11.77	*	Electric housewares and fans
135	1.99	3.92	*	Household vacuum cleaners
136	0.09	1.12		Sewing machines, household appliances
137	0.82	3.59	*	Electric lamps, lighting, wiring devices
138	1.41	3.52	*	Radio, TV, phonograph records and tapes
139	0.63	4.18	*	Telephone and telegraph apparatus
140	1.42	16.54	*	Radio and TV communication equipment
141	0.62	9.8	*	Electron tubes
143	2.65	11.6	*	Storage batteries
144	0.36	5.99	*	Electrical equipment and supplies
145	1.16	12.02	*	Motor vehicles parts and accessories
146	0.76	3.3	*	Aircraft
147	0.62	3.24	*	Aircraft and missile equipment, n.e.c.
149	0.3	2.47	*	Boat building and repairing
150	0.92	5.07	*	Railroad equipment
151	1.73	6.3	*	Motorcycles, bicycles, and parts
153	0.65	2.31	*	Transportation equipment, n.e.c.
155	0.89	1.64		Ordnance and accessories
157	0.89	22.52	*	Engineering, scientific, optical equipment
158	1.05	18.18	*	Measuring devices, environmental controls
159	0.66	2.61	*	Surgical, medical and dental equipment
160	0.28	2.26	*	Watches, clocks, and ophthalmic goods
162	0.14	4.13	*	Jewelry, musical instruments, toys

* Indicates that the estimated elasticity is statistically significant at the 5 percent level.

Source: Kenneth A. Reinert and David W. Roland-Holst (with permission), "Disaggregated Armington Elasticities for the Mining and Manufacturing Sectors" Journal of Policy Modeling, 4:5, 1992.

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