Chapter 4

GENERAL EQUILIBRIUM IN OPEN AND CLOSED ECONOMIES

4.1 General equilibrium in the closed (autarky) economy

The two previous chapters developed the tools of production and consumption theory. The purpose of this chapter is to combine the production and demand sides of the economy to arrive at an overall or *general-equilibrium* analysis. This section considers general-equilibrium in a closed economy; that is, an economy that is self sufficient and does not trade. Such an economy is said to be in *autarky*.

We will begin with a informal, graphical representation of general equilibrium, and move later in the chapter to a more rigorous formulation. Three sets conditions determine general-equilibrium in a closed economy. The first of these are *optimization* conditions for producers and consumers. Throughout this chapter producers and consumers are assumed to be competitive. In later chapters we will consider many cases of imperfect competition and other distortions. (1) Competitive, profit-maximizing producers pick outputs such that, at given commodity prices, the marginal rate of transformation is equal to the producer price ratio. This condition was given in equation (2.21) as $p_1/p_2 = MRT$. (2) Consumers pick commodities such that, at given commodity prices, their marginal rate of substitution in consumption is equal to the consumer price ratio. Assuming that consumer and producer prices are the same, this condition was given in equation (3.4) as $p_1/p_2 = MRS$. The next set of conditions are *market-clearing* conditions: (3) the supply and demand for each commodity must be equal. Let X specifically denote the production of a commodity and D denote consumption (demand) of a commodity. Our three conditions for a graphical representation of general-equilibrium are summarized by

$$\frac{p_1}{p_2} = MRT \qquad \text{producer optimization}$$

$$\frac{p_1}{p_2} = MRS \qquad \text{consumer optimization}$$

$$X_1 = D_1 \qquad X_2 = D_2 \qquad \text{market clearing} \tag{4.1}$$

Figure 4.1 shows an equilibrium for a closed economy that satisfies these three conditions. Producers produce optimally at point A where the slope of the production frontier is tangent to the price ratio $p^a = p_1^a/p_2^a$ (“a” for autarky: superscipts on variables generally denote particular values of those variables). Similarly, consumers consume optimally at point A where the slope of their indifference curve is tangent to the price ratio p^a. And finally, markets clear because the production and consumption points are the same. Note also that the equilibrium at A is *optimal* in the sense that the economy consumes on the highest possible community indifference curve, subject to the constraint that production is feasible.

Figure 4.1

Note for future reference that the equilibrium at point A in turn determines a factor allocation in the Edgeworth box in Figure 2.8 (if indeed the two-factor model is the underlying production structure). Thus factor prices are also determined in general-equilibrium. To the extent that consumers have different factor endowments, the factor prices in turn determine the distribution of income among consumers.

4.2 General equilibrium in the open (trading) economy

Now assume that an economy can engage in trade at a fixed world price ratio, which we will denote by $p^* = p_1^*/p_2^*$. The first two optimization conditions mentioned in the previous section remain unchanged. The only difference is that the values of world prices will in general be different from the values of the prices determined in autarky

The difference between the closed and open economy equilibria lies in the third condition: market clearing. With international trade, an economy is no longer constrained to consume only what it can produce itself. The loosening of this constraint is indeed the source of gains from trade as we shall see. A trading economy is able to sell some of one good at world prices and use the proceeds to buy the other commodity. Instead of market clearing, we have what we call a *trade balance* condition: the value of what a country sells on world markets must be equal to what it buys. We can define the *excess demand* for goods X_1 and X_2 as $(D_1 - X_1)$ and $(D_2 - X_2)$ respectively. If excess demand is positive, we are consuming more than we are producing, and so positive excess demand corresponds to an import good. If excess demand is negative, we are consuming less than we are producing and so this is an export good.

The trade-balance constraint requires that the value of our imports must be equal to the value of our exports. An alternative way of saying this is that the sum of the value of the country's excess demands must equal zero: the positive excess demand for the import good must equal the negative excess demand for the export good.[1] The trade-balance condition is given by

$$p_1^*(D_1 - X_1) + p_2^*(D_2 - X_2) = 0 \tag{4.2}$$

Note that this condition is completely general and does not depend on which good happens to be the import good and which happens to be the export good.

We can rearrange the terms in (4.2) and rewrite the equation in a different way.

$$p_1^* X_1 + p_2^* X_2 = p_1^* D_1 + p_2^* D_2 \tag{4.3}$$

The left-hand side of this equation is the value of production at world prices while the right-hand side is the value of the consumption at world prices. Thus a condition that is exactly equivalent to the trade-balance condition is the requirement that *the value of production equals the value of consumption*.

We can in turn think of the value of production as the income of the country. By placing a line with the slope of the world price ratio p^* through the production point, we then have the "national budget line". This budget line defines national income by evaluating domestic output at world prices. Consumers are then free to choose any point on this budget line, since the value of consumption will be equal to the value of production. This is shown in Figure 4.2, where the fixed world price ratio is given by p^*. Producers optimize by choosing to produce at point X. Consumers optimize by choosing consumption at point D. In the particular case shown, the country imports X_1 ($D_1 > X_1$) and exports X_2 ($D_2 < X_2$). Trade balances insofar as the value of production at world prices equals the value of consumption. To summarize, the conditions for general-equilibrium are given as follows.

$$\frac{p_1^*}{p_2^*} = MRT \qquad \text{producer optimization}$$

$$\frac{p_1^*}{p_2^*} = MRS \qquad \text{consumer optimization}$$

$$p_1^*(D_1 - X_1) + p_2^*(D_2 - X_2) = 0 \qquad \text{market clearing} \tag{4.4}$$

Note finally that the autarky market-clearing condition is a special case of trade balance. The former satisfies the trade-balance condition in that both terms in parentheses are zero. If world prices just happened to be the same as the country's autarky prices, then the trading equilibrium would be identical to the autarky equilibrium.

Figure 4.2

4.3 The excess demand function

We now turn to the larger question of the determination of world prices and an international general equilibrium (our world will consist of two countries). Consider Figure 4.3. The autarky price ratio p^a is shown for reference. At the price ratio $p^{*1} < p^a$, the country produces at X^{*1} and consumes at D^{*1}. Excess demand for good X_1 is positive; i.e., X_1 is imported (recalling $p = p_1/p_2$) . If the relative price of X_1 is lower on the world markets than on the domestic market then the country should buy from the low cost source and hence import the good. Similarly, if X_2 is relatively more valuable on the world market than at home, then exports of Y are in order. At the price ratio $p^{*2} > p^a$ in Figure 4.3, producers pick point X^{*2} and consumption at D^{*2}. With the price ratio greater than the autarky price ratio, the home country exports X_1 (the relatively valuable good on the world markets) and imports X_2 (the relatively cheap good on the world market).

Figure 4.3

This is indeed a general result. If the world price ratio exceeds the domestic price ratio ($p^* > p^a$) then X_1 is exported and there is a negative excess demand for X_1. If the world price ratio is less than the autarky price ratio ($p^* < p^a$) then X_1 is imported and there is a positive excess demand for X_1.

In Figure 4.4, we construct an excess demand curve for good X_1 for the country, where excess demand is given by $M_i = D_i - X_i$ ('*M*' for imports) At the autarky price ratio p^a, there is zero excess demand. Price ratios p^{*1} and p^{*2} in Figure 4.4 correspond to the similarly labeled price ratios in Figure 4.3. The excess demand curve for X_1 is labelled M_1 in Figure 4.4. The excess demand curve is thus much like a conventional demand curve, except that the quantity demanded may be either positive or negative. A negative excess demand is simply a desire to supply (export) the good to the world market at that price.

Figure 4.4

4.4 The shape of the excess demand curve, welfare interpretation

What are the factors that lead to the specific shape that an excess demand curve assumes? As in the case of the standard consumer-choice problem, there are both substitution and income effects. The substitution effect here is always negative: an increase in the price of a good decreases demand and increases production, so $M_i = D_i - X_i$ is negatively related to the relative price of p_i. However, the income effect is more complicated than in the standard consumer problem (even under the assumption that all goods are normal). If a good is imported, then an increase in its price generates a negative income effect.

But if it is exported, a rise in its price is a good thing and the income effect is positive. A potential subtlety thus exists in constructing the excess demand curve comes when $p^* > p^a$. In this case, the curve may bend backward (its slope becomes positive) in the exporting section (negative excess demand) of the curve. Intuitively, as the price of the export good continues to increase, the country gets richer from the sales of that good. This leads consumers to want to devote some of their additional income to purchases of that good. Thus at some point, this "income effect", which leads consumers to demand more of the export good, may outweigh the substitution effect which leads consumers to want less of a good when its price rises.

Finally, movement along the excess demand curve away from p^a in either direction is welfare improving because any change in price leads to an increase in the consumption choices for consumers. As prices fall from p^a, for instance, the previous combination of X_1 imports and X_2 exports now generates a trade surplus, so consumers can buy more imports for less exports (retaining the previous exports as consumption). Similarly, as the price of an export good rises, consumers could maintain their consumption levels of the export, but have the choice of buying more imports as an alternative. In short, the further a country can trade from its autarky price ratio the better.

4.5 International general equilibrium

Now introduce a second country referring to it as country f, and to the original country as h. Figure 4.5 shows an excess demand curve for country f, M_{f1}, placed arbitrarily above the excess demand curve for country H, M_{h1}. The autarky price in the country f is $p_f^a = p_{f1}^a / p_{f2}^a$, greater than country h's autarky price ratio, p_h^a.

General-equilibrium in the world economy is then determined at an international price ratio where the excess demands of the two countries are equal and opposite. In Figure 4.5, this occurs at price ratio p^*. At that price, the positive excess demand (imports) of the foreign country are equal to the negative excess demand (exports) of the home country. The market for X_1 clears, which is a condition for international equilibrium: $M_{h1} + M_{f1} = 0$.[2] Note for future reference that the equilibrium price lies *between* the autarky prices of the two countries.[3] This is a general result, at least in competitive models, and it makes economic sense. If, for example, the world relative price of X_1 was greater than the autarky prices of both countries, then both countries would want to export X_1. But this cannot be an equilibrium.

Figure 4.5

The *direction of trade* (which countries import and export which goods) at this equilibrium in Figure 4.5 makes economic sense. With the relative price of X_1 higher in country f in autarky, f will import X_1 and h will export X_1 in international equilibrium. We will see many times in the chapters that the direction of trade follows the differences in autarky prices. A major topic of Part II of the book is determining how underlying characteristics of economies, such as technologies and factor endowments, lead to differences in autarky prices.

What about the market for X_2? When we have only two goods and impose a trade-balance condition, we need only examine one market to find international equilibrium. Suppose that both countries are satisfying their trade balance conditions and that the market for X_1 clears. These three equations must then imply that the market for X_2 also clears. The need to find equilibrium in only one of two markets is known as Walras' Law in economics (more generally, if n-1 markets are clearing where n is the number of markets, the nth market must clear as well). If

$$p_1^* M_{h1} = -p_2^* M_{h2} \qquad p_1^* M_{f1} = -p_2^* M_{f2} \qquad M_{h2} = -M_{f2} \quad \text{then} \quad M_{2h} = -M_{2f} \tag{4.5}$$

4.6 An introduction to computing solutions to numerical general-equilibrium models[4]

The treatment of general-equilibrium to this point has been informal and intended to develop a simple intuition about trade and gains from trade. But it is a long way from a methodology that could be implemented with numbers (whether from real data or a straight simulation analysis). The principal problem is that it assumes that we know a lot about the production set and an equation for the production frontier in particular. However, it unfortunately turns out the even for many relatively simple production functions, it is impossible to solve for an equation for the production frontier. This in turn means that it is not possible, for example, to solve for the relationship between product and factor prices.

One approach to solving for general-equilibrium that often occurs to students is to treat it as an optimization problem, essentially exploiting what we called the first theorem of welfare economics earlier in the book: competitive equilibria are Pareto optimal. This is indeed a possible approach, but it is really only viable for a single economy with a single "representative" household on the demand side. If there are multiple household types, characterized by different endowments and/or preferences, or if there is more than one country, the optimization approach breaks down. It is not clear what to optimize subject to what constraints. There are infinitely many Pareto optimal allocations with two household types, but generally only one of those is a competitive equilibrium (e.g., a Pareto allocation in which each household's consumption is equal to its factor income).

The modern approach to general-equilibrium is to formulate a system of equations and inequalities, embedding the optimization at the level of the industry and household, creating a system of n weak inequalities in n unknowns. General equilibrium is then a solution to a square system, not a solution to a single constrained optimization problem. It is actually a bit more complicated than that. In order to accommodate corner solutions in which, for example, not all goods are produced (quantities and prices must be non-negative), it is necessary to associate each equation/inequality with a particular non-negative variable. If the relationship holds as a strict equality, the associated variable is positive. If, in equilibrium, the relationship holds as a strict inequality, the associated variable is zero. A problem of this type is referred to as a (non-linear) complementarity problem in mathematical programming terminology: each (weak) inequality has an associated complementary variable. Economic theory provides the correct association of inequalities and unknowns and the correct direction of the inequality (e.g., cost can exceed price in equilibrium, the good is unprofitable and is not produced, but price cannot exceed cost in equilibrium).

There are several possible approaches to formulating general-equilibrium as a complementarity problem, but one that seems very robust to the inclusion of lots of added features is the Mathieson-Rutherford approach, which formulates a model as composed of four blocks of inequalities and unknowns. (1) *zero-profit or optimization* conditions for all production and trade activities. (2) *market-clearing* or supply-equal-demand relationships for all commodities and markets. (3) *income or budget balance* conditions for all agents (consumers, governments, and so forth). (4) *auxiliary equations* such as equations that determine things like endogenous tax rates, markups and so forth. The last of these will not be treated in this chapter.

Let's see how this works in practice with our two-good, two-factor, closed economy with a single representative consumer. The first task is to solve for cost functions for each sector, and the consumer's expenditure function. Alternatively Marshallian demand functions may be used. Either way, optimization is embedded at the sectoral and household level. Here is a specification using Marshallian demands.

weak inequality	description	complementary variable	
$c_1(w_1, w_2) \geq p_1$	zero profits in X_1	X_1	(4.6)
$c_2(w_1, w_2) \geq p_2$	zero profits in X_2	X_2	(4.7)
$X_1 \geq D_1(p_1, p_2, I)$	market clearing, X_1	p_1	(4.8)
$X_2 \geq D_2(p_1, p_2, I)$	market clearing, X_2	p_2	(4.9)
$\bar{V}_1 \geq c_{11}(w_1, w_2)X_1 + c_{21}(w_1, w_2)X_2$	market clearing, V_1	w_1	(4.10)
$\bar{V}_2 \geq c_{12}(w_1, w_2)X_1 + c_{22}(w_1, w_2)X_2$	market clearing, V_2	w_2	(4.11)
$I = w_1\bar{V}_1 + w_2\bar{V}_2$	budget balance	I	(4.12)

The first two inequalities (4.6)-(4.7) involved prices and costs and have quantities as complementary variables: if, in equilibrium, marginal cost is strictly greater than price, production is unprofitable and output is zero. All of the market-clearing equations (4.8)-(4.11) are in terms of quantities, and have prices as complementary variables: if, in equilibrium, supply exceed demand then the good/factor is free, its price is zero. The last equation is income-expenditure or budget balance. Note the use of Shepard's lemma in the market-clearing inequalities for factors to get the factor demands on the right hand side of (4.10) and (4.11).

There is one extra equation in the system, another manifestation of Walras' Law: if n-1 markets clear, then the nth does as well. This is generally interpreted as an indeterminacy of the price level. Note that if we find a set of prices and income that solves (4.6)-(4.12), then any multiple scaling these prices and income up or down proportionately also solves the model. This problem is usually dealt with by choosing a numeraire, typically setting one price equal to one and dropping the corresponding equation from the model. This is essentially what we were doing in our graphical presentation above: the solution only determines the relative prices of goods 1 and 2; any multiple of their absolute prices is also a solution. Showing that every relationship in (4.6)-(4.12) remains unchanged with a doubling of prices and income is left to you as an exercise.

While the above system seems simple and intuitive, in many applied problems it turns out to be more useful to work with Hicksian demand and to model utility as though it was a produced good: utility (U) is *produced* with inputs of X_1 and X_2, and it has a *price* associated with it, p_u, which in equilibrium must be the cost of producing one unit of utility, the unit expenditure function. One advantage of this approach is that welfare and the real consumer price index p_u (the price of a unit of utility) are automatically computed as part of the solution. The same model as above can be written as follows.

weak inequality	description	complementary variable	
$c_1(w_1, w_2) \geq p_1$	zero profits in X_1	X_1	(4.13)
$c_2(w_1, w_2) \geq p_2$	zero profits in X_2	X_2	(4.14)
$e(p_1, p_2) \geq p_u$	zero profits in U	U	(4.15)
$X_1 \geq e_1(p_1, p_2)U$	market clearing, X_1	p_1	(4.16)
$X_2 \geq e_2(p_1, p_2,)U$	market clearing, X_2	p_2	(4.17)
$U = I/p_u$	market clearing for U	p_u	(4.18)
$\bar{V}_1 \geq c_{11}(w_1, w_2)X_1 + c_{21}(w_1, w_2)X_2$	market clearing, V_1	w_1	(4.19)
$\bar{V}_2 \geq c_{12}(w_1, w_2)X_1 + c_{22}(w_1, w_2)X_2$	market clearing, V_2	w_2	(4.20)
$I = w_1\bar{V}_1 + w_2\bar{V}_2$	budget balance	I	(4.21)

As in the case of using Shepard's lemma to get factor demands, Shepard's lemma is used in (4.16) and (4.17) to get commodity demands. In this square system, p_u, the real consumer price index is often chosen as numeraire. This has the advantage that all other prices, especially factor prices, are "real" values: a ten-percent increase in a factor price is relative to the cost of the consumer's consumption bundle.

The above indicates that there are often several ways to formulate general equilibrium as a complementarity problem. The second approach has two more equations than unknowns and so seems more complicated (not to mention getting your head around the notion of utility as something that is produced and carries a price, since neither are observed in data). However, it is clear that even the first approach is going to defy analytical solutions, except in extremely simple cases due to the number of dimensions of the model and to the fact that the solution itself determines which weak inequalities hold strictly and which hold with equality (e.g., which goods are actually produced). Thus modelers typically turn to numerical solutions, picking functional forms and parameters for the general model. The computer doesn't care how many dimensions the model has, so the formulation of a model for numerical solution depends on the flexibility it carries and easy of interpretation. Often, more equations and unknowns are preferred.

With this thought in mind, let us now consider an open economy model, and in particular a "small" economy, defined as one that faces fixed world prices. There are several ways to do this, some of which result in smaller-dimension models than the closed economy case: think of our graphical treatment in which two market-clearing equations are replaced by a single balance-of-trade equation. Intuitively, the open economy has fewer *constraints*. However, the other way to think about it is that the open economy offers more *opportunities*. Trade effectively allows a country to transform one good into another through international exchange. Thus our above models can be modified by adding additional activities, import and export activities, with associated quantity variables of imports and exports. This generally turns out to be the more productive approach.

Let ρ_1^* and ρ_2^* be *fixed parameters* for the small economy, giving world prices of X_1 and X_2

respectively. (In a simulation below, we choose X_2 as numeraire and so $\rho_2^* = 1$.) Let E_i and M_i denote the number of units of X_i exported and imported respectively. To allow for either direction of trade depending on world prices, we add four trading activities and four unknowns: E_i and M_i for each good. Our model is extended to the open economy by adding four inequalities (four trading activities, although only two will be strict equalities in equilibrium) and revising the market-clearing equations for X_1 and X_2: production minus exports plus imports equals consumption. The trading activities are represented by zero-profit conditions as in the case of production activities, with the complementary variables being quantities of imports and exports.[5] Here are the added and revised inequalities and variables.

weak inequality	description	complementary variable	
$p_1 \geq \rho_1^*$	zero profits, exports of X_1	E_1	(4.22)
$\rho_1^* \geq p_1$	zero profits, imports of X_1	M_1	(4.23)
$p_2 \geq \rho_2^*$	zero profits, exports of X_2	E_2	(4.24)
$\rho_2^* \geq p_2$	zero profits, exports of M_2	M_2	(4.25)
$X_1 - E_1 + M_1 \geq e_1(p_1, p_2)U$	market clearing, X_1	p_1	(4.16 revised)
$X_2 - E_2 + M_2 \geq e_2(p_1, p_2,)U$	market clearing, X_2	p_2	(4.17 revised)

This surely seems a lot to take in, but analytical solutions are not possible beyond extremely restrictive cases. Once one goes to simulation, the number of inequalities and unknowns is immaterial, and the researcher/student or whomever can analyze much more complex situations than is possible with strictly analytical methods.

In an appendix to this book, we present computer code for this model. In order to catch your interest in this, Figures 4.6 and 4.7 present some simple simulation results for changing the terms of trade, the (fixed) relative price of X_1 in terms of X_2. Figure 4.6 plots the excess demand curve for X_1; it becomes vertical in the export section once specialization is reached but does not bend back (this is a property of Cobb-Douglas preferences assumed in the model). Figure 4.7 plots welfare as a function of the terms of trade. The horizontal axis of Figure 4.7 is the same as the vertical axis of Figure 4.6: by convention, prices are put on the vertical axis of excess demand diagrams, even when they are the exogenous variable as is the case here. Welfare gains from trade are 30 percent of autarky welfare in Figure 4.7 when the relative price of X_1 is 2.5 (X_1 exported in Figure 4.6) or its reciprocal 0.4 (X_1 imported in Figure 4.6).

Figure 4.6 **Figure 4.7**

In the appendix, we will generalize this model to include tariffs and transport costs. Learning to build and compute simulation models requires quite an investment of your time to master as is true of any technique and software, but it is immensely educational to actually build a workable model rather than simply look at graphs and qualitative properties of comparative statics exercises; indeed the latter are only solvable for extremely special cases. In addition to being educational, it is just plain good fun to see theorems verified numerically or see the optimal tariff idea in action for example.

4.7 Summary: what you should know

The chapter begins with a simple and intuitive contrast between the conditions for equilibrium between for a closed (autarkic) economy and an open or trading economy. Trade can be thought of as *removing a constraint*: the requirement that anything that is consumed must be produced domestically. Or it can be thought of as *creating an opportunity*: the ability to essentially transform one good into another by exporting the first and importing the second. We showed how an economy may be graphically summarize by an excess demand function, discussed its shape and its welfare interpretation. In the two-good case, Walras' law allows us to find equilibrium in one market only, then the other market must clear as well.

The world prices (or just price ratio in the two-good case) is then determine as the price ratio at which the sum of all country's excess demands are zero. In the two-country case, the import demand of one country must balance the exports (negative excess demand) of the other country. The world price ratio must lie between the two autarky price ratios, and each country will export the good it produces relatively cheaply in autarky and import the good which is relatively costly in autarky.

The graphical approach and its analytical counterpart has great appeal. It is unfortunately the case that it is not very useful in practice and, even in very simple models past two goods and two factors, it does not permit a full characterization of equilibrium and of the response of the economies outputs and factor prices to changes in world prices for example. This is largely due to the fact that we generally cannot characterize much about the production frontier other than concavity from knowing sectoral production functions. Even in the two-good, two-factor case, the graphical and analytical approaches can say little quantitatively; e.g., what are the aggregate welfare and distributional effects of at 20% import tariff?

On account of these difficulties, we have sketched the outline of a methodology used to solve for general equilibrium in more complex situations. This methodology embeds the optimization problems at the sectoral level, that of industries and households. These industry/household results are then used to build square models of n weak inequalities in n unknowns. These are roughly characterized in terms of "blocks": (1) optimization conditions, with outputs and demands as complementary variables, (2) market clearing inequalities with prices as complementary variables, and (3) income balance conditions. A forth set, auxiliary equations and variables such as determining markups, endogenous tax rates and so forth are left to more advanced treatments.

Endnotes

1. In a dynamic model with many time periods, trade need not balance in any one time period. A country can consume more than it producers by selling *assets* which can be thought of as claims to future consumption. The United States has been in a position of *trade deficit* for years, indicating that foreigners are accumulating US assets and hence have a claim on future US production. This is an important topic in international finance, but we will also discuss it in the last chapter of the book.

2. Because of the possibility of backward bending sections of excess demand curves in the exporting region (i.e., negative excess demand) mentioned in the previous section, there is a possibility of multiple equilibria. This will be ignored in this book.

3. Later in the book we show that with imperfect competition, the free-trade price for a good need not lie between the autarky prices of the two countries. Additional competition induced by trade may lead to a fall in the price of the good in both countries.

4. Professors may wish to skip this section, and the numerical appendices in the book. We have tried to make it possible to do this without loss of continuity. The general set up for a method of actually creating a solvable model is instructive however, and all of the tools needed to understand this section (cost and expenditure functions, Shepard's lemma) have already been introduced. There will be a number of general references to this section later in the book but again, we have tried to write subsequent material so that this section is not crucial to things later on.

6. An astute reader might note below that both the export and import equation can hold with equality for a given good. It is possible that a good could be both imported and exported, with only net trade being determined in equilibrium (there are infinitely many gross trade patterns consistent with a given net trade). This indeterminacy is broken in numerical models by imposing a very small trade cost (0.01% will do). For example, equation (4.25) below could be written $p_1(1.0001) \geq \rho_1^* p_{fx}$. We have ignored this problem here, but it is important in actual computable models to add this small trade cost.

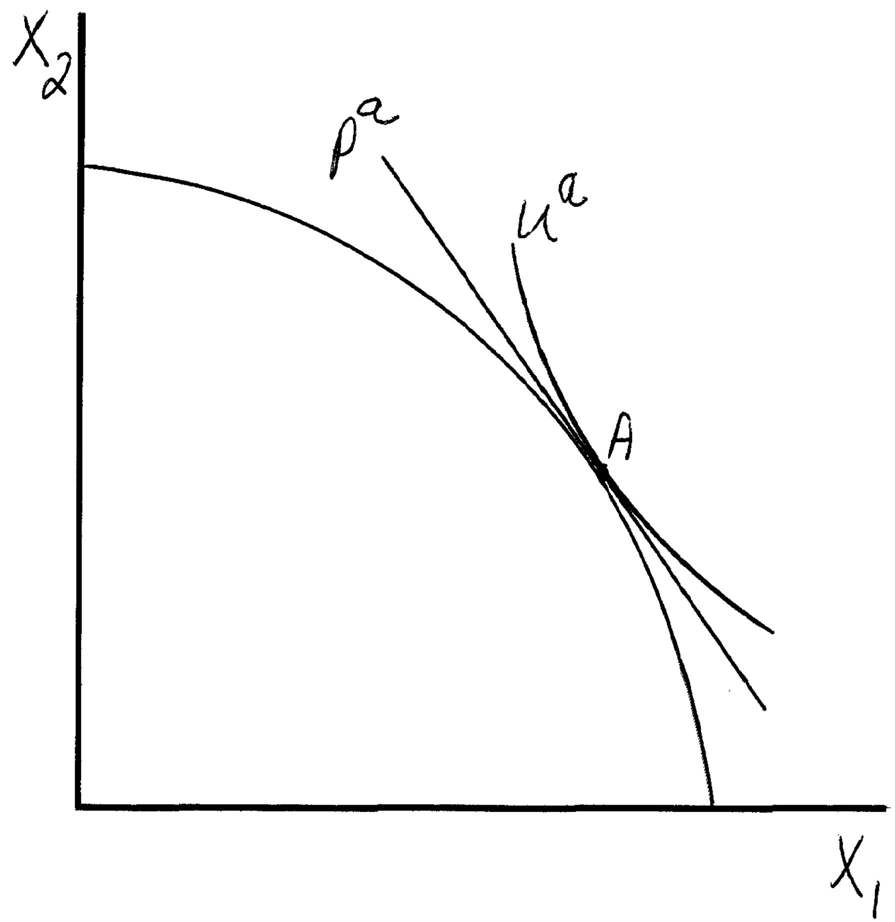

Figure 4.1

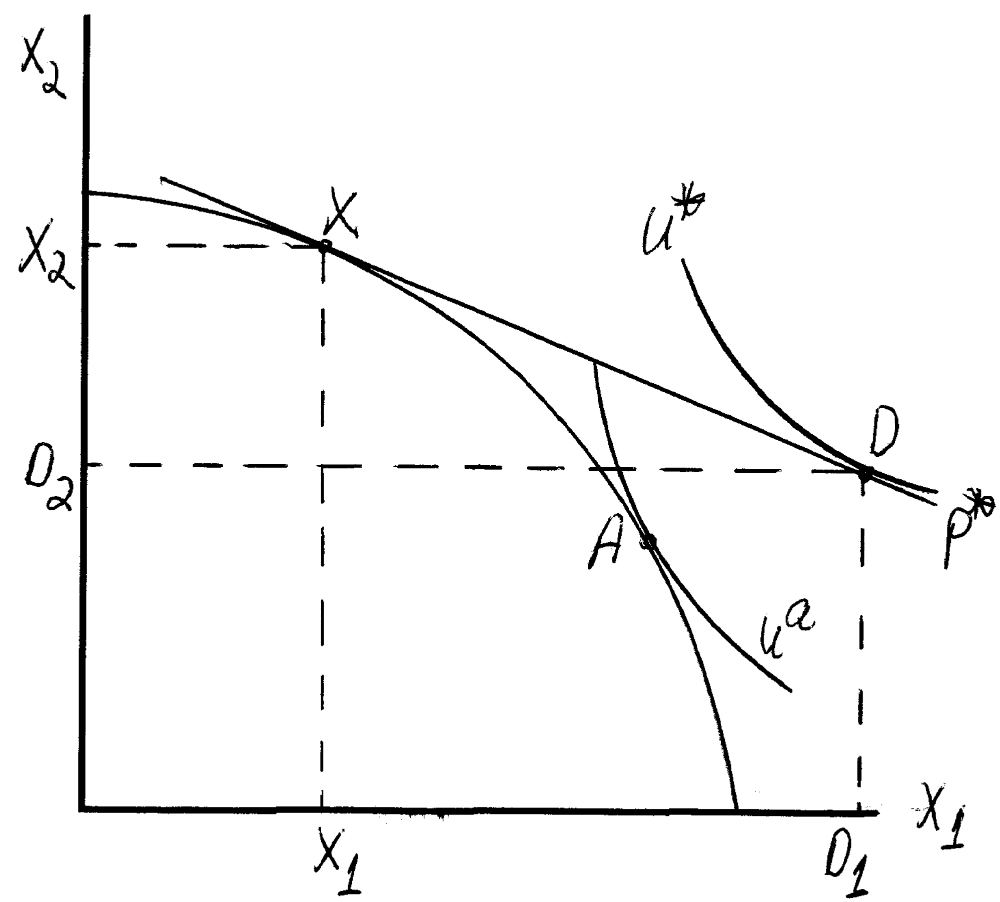

Figure 4.2

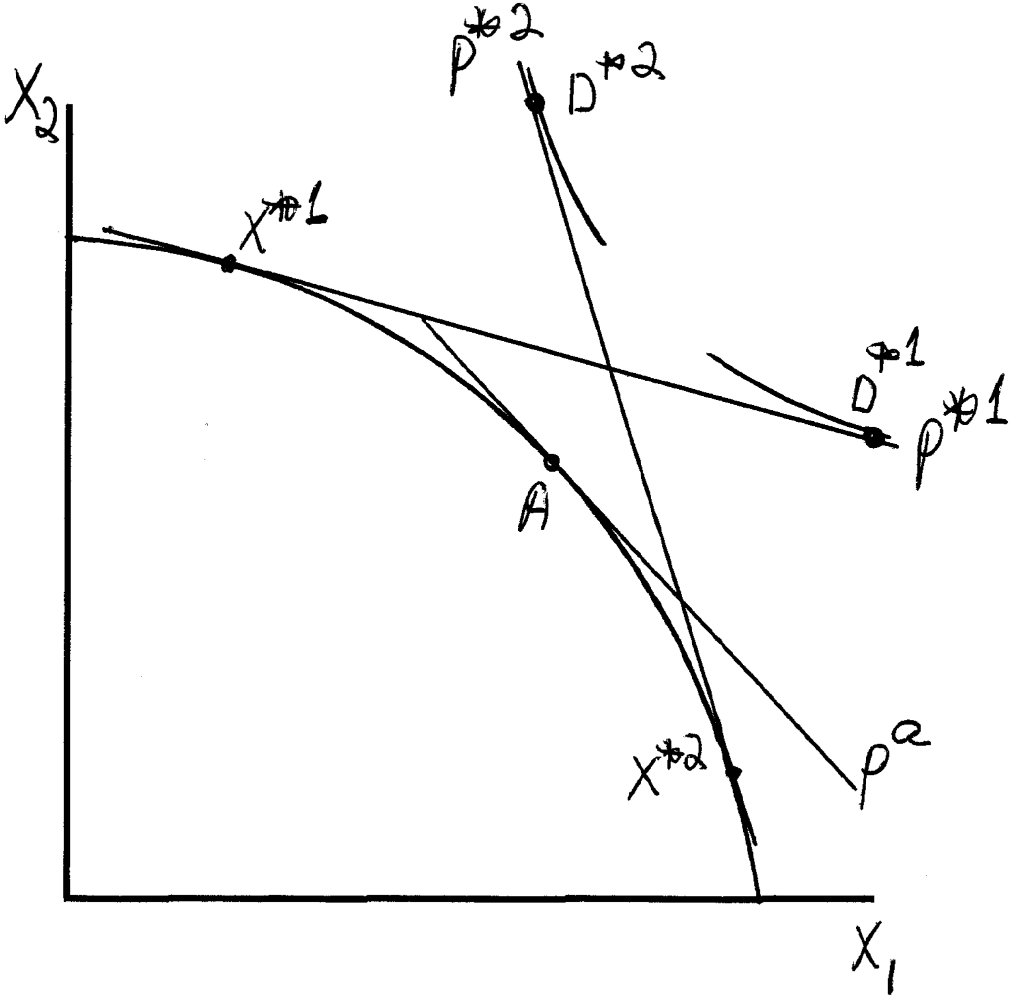

Figure 4.3

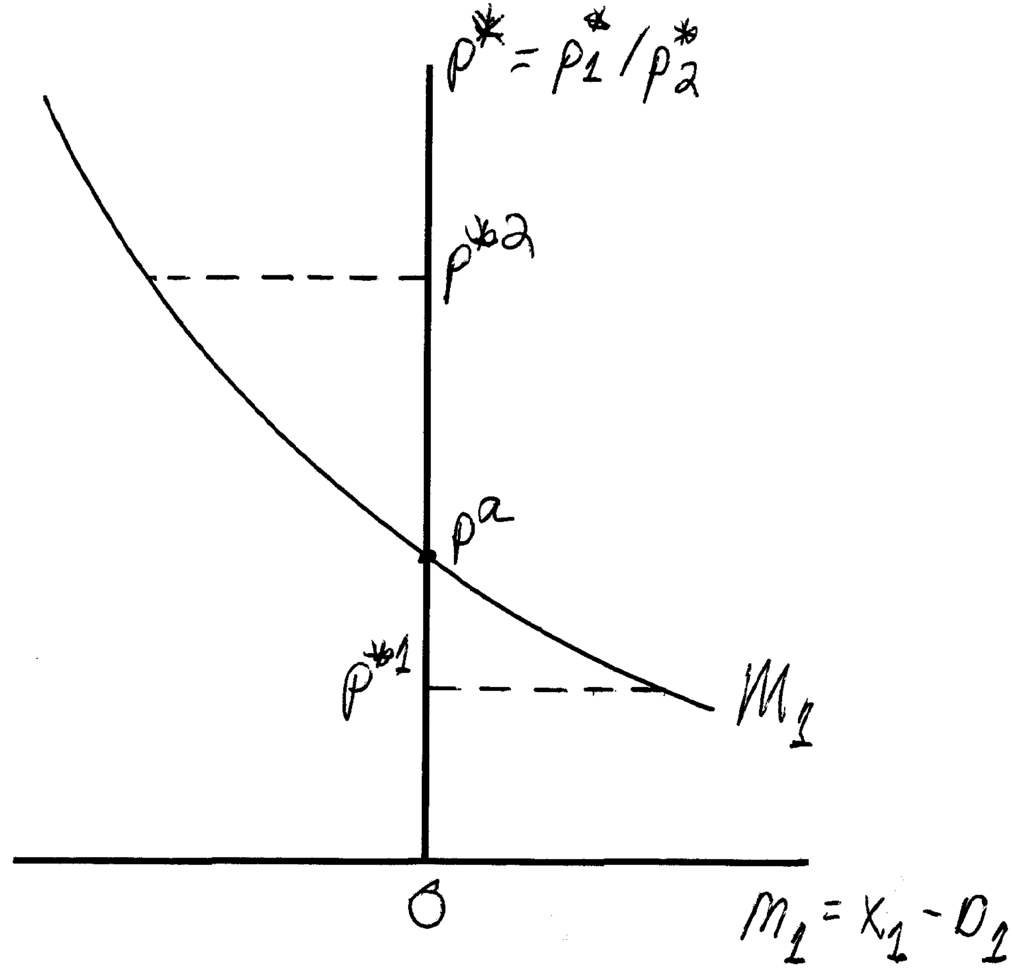

Figure 4.4

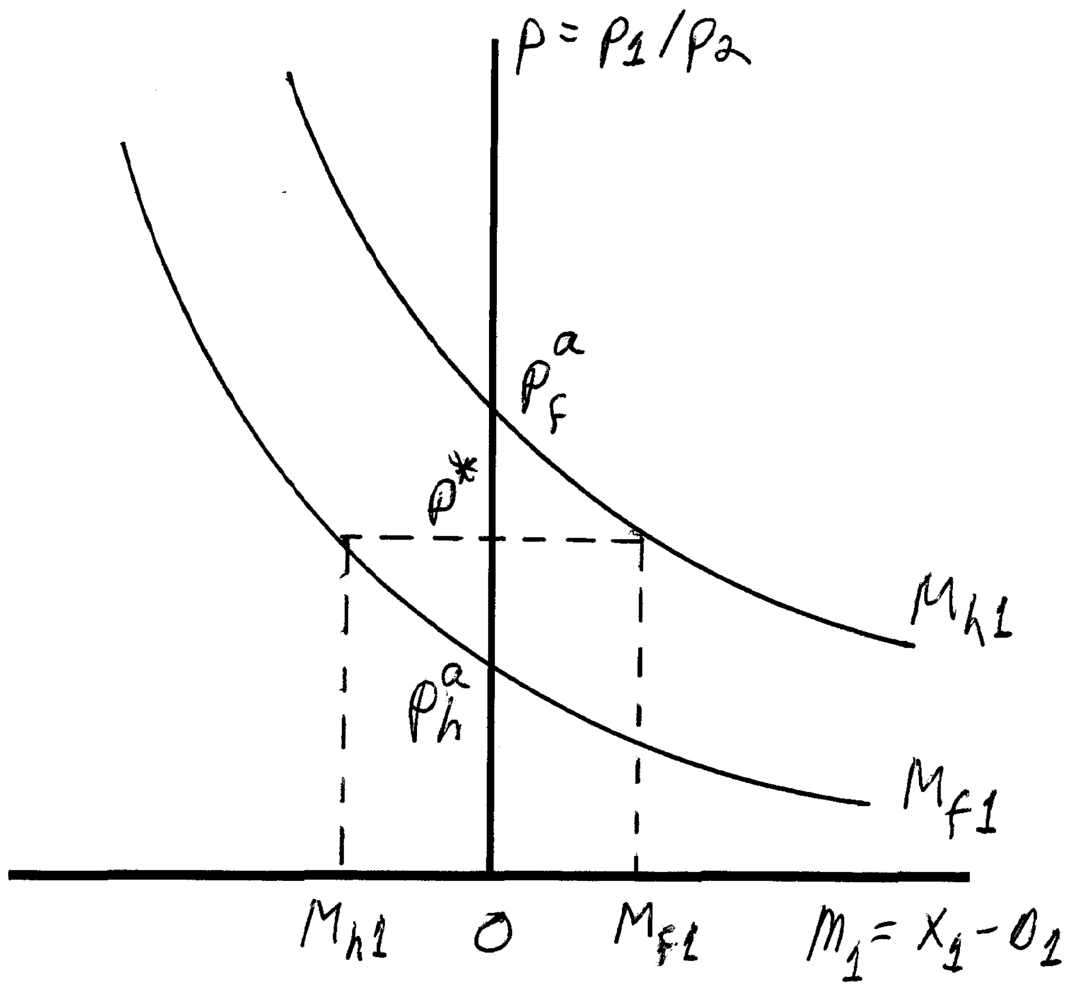

Figure 4.5

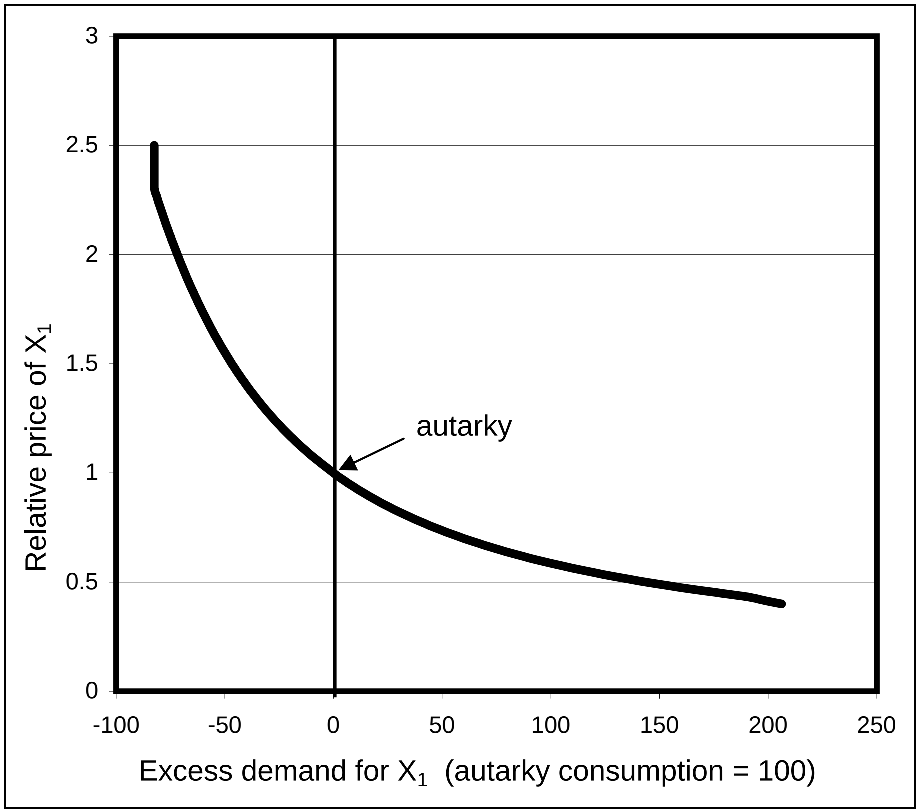

Figure 4.6: Simulated excess demand curve

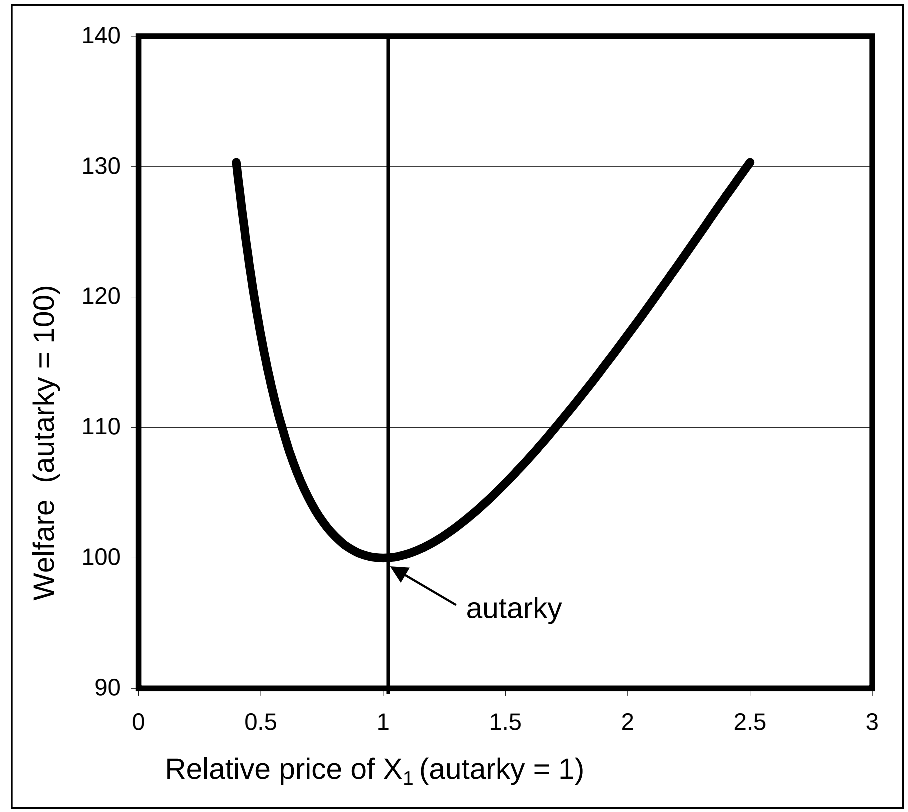

Figure 4.7: Welfare and the terms of trade