Adaptive Agent Modeling as a Tool for Trade and Development Theory

Timothy R. Gulden
University of Maryland
December; 2004

ABSTRACT

This paper makes use of an adaptive agent framework to extend traditional models of comparative advantage in international trade, illustrating several cases which make theoretical room for industrial policy and the regulation of trade. Using an agent based implementation of the Hecksher-Ohlin trade model, the paper confirms Samuelson's 2004 result demonstrating that the principle of comparative advantage does not ensure that technological progress in one country benefits its trading partners. It goes on to demonstrate that the presence of increasing returns leads to a situation with multiple equilibra, where free market trading policies can not be relied on to deliver an outcome which is efficient or equitable, with first movers in development enjoying permanent advantage over later developing nations. Finally, the paper examines the impact of relaxation of the Ricardian assumption of capital immobility on the principle of comparative advantage. It finds that the dynamics of factor trade are radically different from the dynamics of trade in goods and that factor mobility converts a regime of comparative advantage into a regime of absolute advantage, thus obviating the reassuring equity results which stem from comparative advantage.

Introduction

Of the many beautiful results which have emerged from economic theory over its long history, few are as elegant or have been as influential as Ricardo's principle of comparative advantage in international trade. This principle is often taken to prove that all nations, regardless of their level of development or productivity, can only benefit from increased international trade. Indeed, this argument is so counterintuitive on its face, but so convincing on further thought that it has come to dominate the thinking of those concerned with international trade, often leading them to overlook the assumptions on which the argument rests.

Every model rests on a set of assumptions. When modeling is conducted in the service of policy analysis, it is particularly important that these assumptions be made plain and that the result be recognized as the result of those assumptions. One critical assumption on which the comparative advantage argument depends is that there are constant or decreasing returns to scale in all industries. The relaxation of this assumption complicates analysis somewhat, leading to multiple equilibria and destroying the market's ability to deliver a unique outcome which can be considered to be "optimal" in some objective sense.

While an adaptive agent model is not strictly needed to explore the implications of relaxing this assumption, the adaptive agent approach can be used to build confidence in the insights generated through analysis and to communicate them to policymakers with limited background in economics. In this chapter, I will review two models which seek to realign the generalizations from trade theory with their underlying assumptions. I will then proceed to demonstrate how an adaptive agent model can be used to illustrate these

points in a way that clearly shows how the results follow from the assumptions about the behavior of the people and nations involved.

Gomory and Baumol's Model of International Trade

In their book, *Global Trade and Conflicting National Interests*, Ralph E. Gomory and William J. Baumol persuasively show that relaxing the assumption of decreasing returns to scale for national industries dramatically changes Ricardo's policy conclusions based on comparative advantage. With the introduction of startup costs and increasing returns, the situation goes from one of always coincident national interests in favor of openness, to a more nuanced picture where interests sometimes coincide and sometimes conflict.

A Place for Policy

A major result of their analysis is to move international trade theory out of the realm of pure efficiency analysis, making way for discussions of equity and the application of policy. In their analysis, it becomes clear that the market can not be expected to deliver a single, "optimal" pattern of production which allows each country to make the most of what God has given it. Rather, the market can produce myriad stable patterns of production. Some of these patterns are more efficient, some less, some distribute income relatively evenly among nations, some distribute income very unevenly. Gomory and Baumol argue convincingly that which one of these equilibria the market produces depends, to a great degree, on history and therefore on temporary policy measures such as the protection of infant industries.

Under the traditional assumption of decreasing returns, the market can be expected to produce a unique allocation of production and income based on each

country's natural endowments, which are given. This equilibrium is independent of history in that over the long run, the system can be expected to allocate production in the same way regardless of the order in which nations develop. Barring market failures, this also results in global production at the maximum scale which demand and technology allow at any given time.

If we relax the assumption of decreasing returns and allow some industries to display increasing returns over at least part of their range of production scale, natural endowments come to matter much less and have little to do with the distribution of productive capacity. Those who are first to enter an industry face falling costs as they increase production, making entry difficult even when the entrants have a lower wage bill. This means that it is often the first county – not always the best suited one – which ends up producing a given product.

In Ricardo's day, the assumption of decreasing returns was a reasonable one. Agriculture made up the largest share of even the most highly developed nation's utility. In many agricultural sectors decreasing returns still dominate: the best land is used first with production increases requiring the use of increasingly marginal lands and more intensive (and expensive) management techniques. Before the industrial revolution, this principle held even in manufactured goods: a hat maker could make only so many hats in a day, and there quickly came a point where supervising more apprentices became uneconomical.

During the industrial era, however, agriculture and hand crafts became relatively minor economic sectors while large scale manufacturing and high-skill services became the driving force behind the rapid growth of economic activity. These sectors, however,

display a different type of productivity curve. While the first tomato may be the cheapest to grow, the first automobile is far from the least expensive to manufacture. In many modern industries, economical production requires huge scale, and that huge scale requires tremendous investment, a high level of skill, and the reputation required to bring the resulting products to market. Gomory and Baumol refer to industries characterized by high startup costs due to significant economies of scale (like automobile manufacture), as "retainable" industries, because once a nation has developed such an industry and realized the resulting cost reductions it becomes very difficult for another nation – even one with lower labor costs and more plentiful raw materials – to take that industry away through competition.

For the sake of simplicity in the models that follow, we will use production functions which exhibit increasing returns throughout their range of production. This is, however, not essential to the argument. An industry is retainable so long as enough of the early part of its production cost curve is characterized by increasing returns that an entrant would be unable to coordinate sufficient capital to reach the later phases of constant or decreasing returns.

Multiple Equilibria

A world with retainable industries has the potential for a great many equilibria (in the two country case, there can be 2^n stable equilibria; where n is the number of industries). Gomory and Baumol observe that these equilibria are not arranged at random, but fall into definite patterns. In the extreme case, one nation may have all of the retainable industries and a high standard of living, while the other nation subsists in poverty. The poor nation is unable to purchase many of the goods produced in the rich

country, and it is also unable to develop its own industries because its costs of production are still higher than those in the rich country – so the products of its infant industries would not be competitive, even if they were produced. Because manufactures are less expensive to import than they are to make, the best that the poor nation can do (in the short run) is to produce its low-margin agricultural goods and trade them for small quantities of high value added manufactures from abroad.

Because one country with a high standard of living is making all of the industrial products in this scenario, its labor costs are high and its workforce is fragmented between many industries. Meanwhile, the labor force of the poor country sits in idle poverty, producing next to nothing. In this situation, world output is lower than it would be if the retainable industries were divided between the two countries, employing their combined labor force to produce tradable goods. On a graph with income share on the x axis and world output on the y axis, the various mixes of production form an inverted "U", with low output associated with a high concentration in either country and higher output associated with a more balanced division of industries.

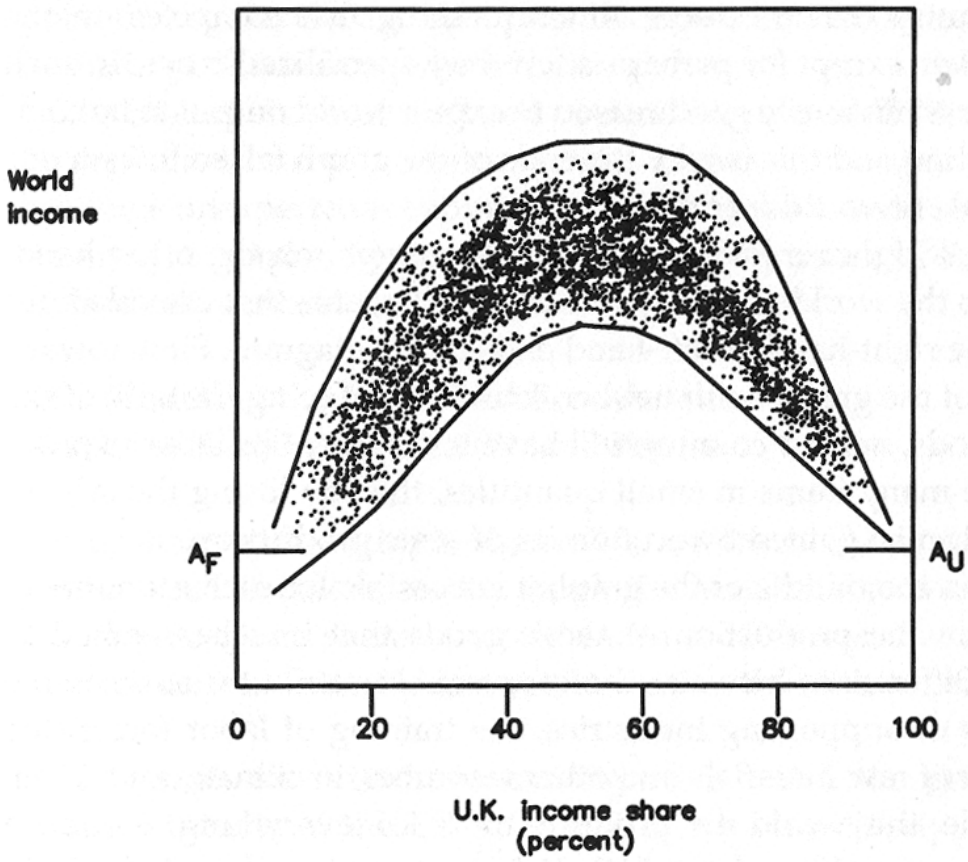


Figure 2.1: Multiple equilibria in a world with increasing returns to scale. Reproduced from Gomory and Baumol [2000].

Gomory and Baumol further point out that this possibility space is actually slightly more complex than a simple inverted "U" because of both natural advantage and synergies between industries. While natural advantage does not play the large role that it did in Ricardo's theory, there is still a place for it in the world of retainable industries. Some countries are simply better suited to produce some things. If, by accident of history, industries develop in countries where they are not particularly well suited, it is possible to produce an even division of industries between countries which produces less than the maximum possible because the industries are located in the "wrong" countries.

Synergy between industries (or the lack thereof) can also lead to different levels of output given the same percentage division of industries between nations. Some industries work well together (e.g. steel making and automobile manufacture) while others do not (e.g. paper making and destination tourism). A division that keeps synergistic industries together while separating those that clash will be more productive than one that does the reverse.

Natural advantage and industrial synergy both lead to a range of possible outcomes for each division of industries between countries. The curve of possibilities, therefore spreads from an inverted "U" to an inverted boomerang which is thin at its tips (because there is only one way for the industries to be packed into a single country) and thicker in the middle, where the industries can be divided in many ways, some more efficient than others (figure 2.1).

Cooperation and Conflict

Gomory and Baumol proceed to unpack this distribution, analyzing the implications of this way of looking at things for the output of each country individually. Using essentially the same logic with which they produced the inverted boomerang for world output, but changing the y axis to reflect national output, they now produce a crossing pair of skewed boomerangs, one for each country. These shapes resemble the shape for world output, but are asymmetrical, with a higher peak on the side of the graph which reflects the larger share of industries for the nation in question.

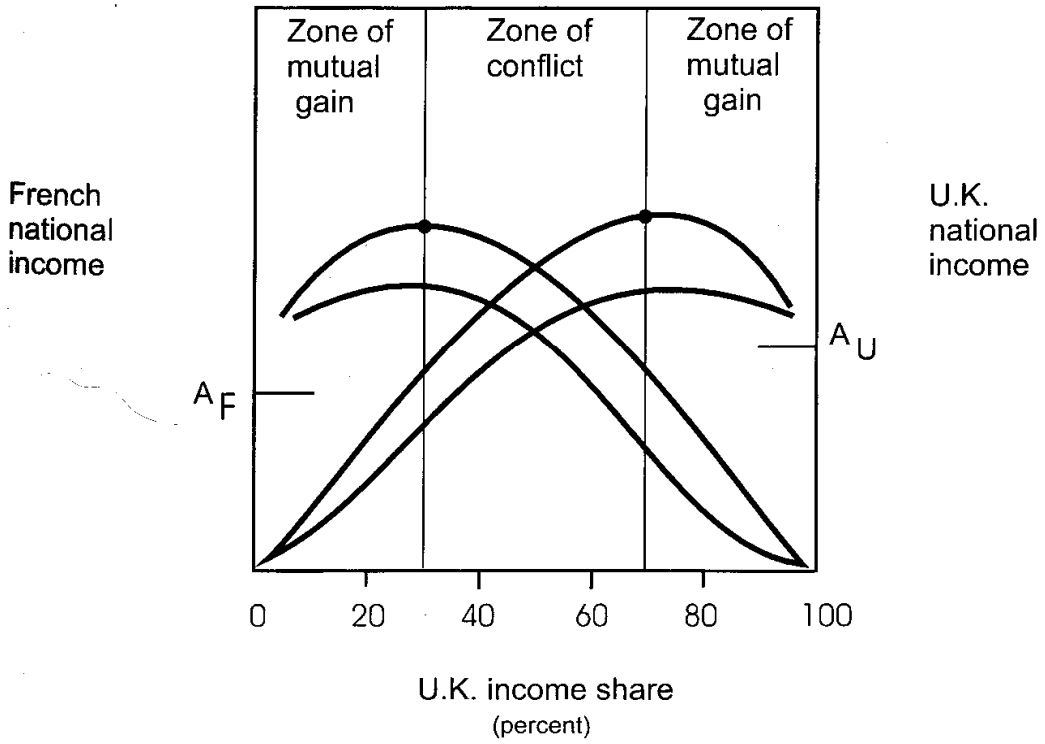


Figure 2.2: Zones of mutual gain and zone of conflict in bilateral trade. Reproduced from Gomory and Baumol [2000].

From this graph (figure 2.2) one can see that there are zones where the interests of the countries either coincide or conflict. In the zones of mutual gain, the curves of both countries slope in the same direction. This indicates coinciding interests. If one partner has a great many industries while the other has very few, both can improve their position by transferring some industries from the richer to the poorer country. This benefits the poorer country by allowing it to produce goods for export and to enjoy the resulting increase in income. It also benefits the richer country by creating a market for its exports and allowing it to purchase low priced goods from its trading partner. In these zones of mutual gain, both partners benefit from increased trade. There is also, however, a zone of conflict where the curves slope in opposite directions. This indicates that one partner

benefits from increased trade at the expense of the other. In this central region of the graph, any movement toward more balanced development leads to greater income for the poorer partner, but less income for the richer one.

It is important to remember here that all of the points within the curves are stable equilibria. If the system finds itself outside of these curved areas, it can be expected to work its way back into them. However, once the market is within these areas, it can not be expected to move the balance in any particular direction, or even to find the maximum output position for a given balance. Instead of market forces, movement within these areas is due to policy decisions: trade policy, development policy, industrial policy, etc.

Revisiting the Infant Industries Argument

Having developed this model of trade in a world with retainable industries which exhibit increasing returns to scale over at least the early part of their development cycle, Gomory and Baumol go on to develop a similar model for industries with linear returns to scale, but where productivity improves with experience. Though some of the details of the analysis differ, the upshot is the same: first movers have a substantial advantage and the market can produce myriad stable outcomes that differ greatly in their equity and efficiency. This conception indicates that the often maligned "infant industries" argument for protectionism in underdeveloped nations has a good deal of merit. Once a country with low wages attains a competitive position in such a skill based industry, its low wage bill will keep it competitive. However, such entry is only possible once the industry has become efficient enough (through experience) to compete.

This way of looking at development and trade puts the plight of underdeveloped nations in new perspective. Under the traditional assumption of decreasing returns,

capital would be expected to flow from wealthy nations to poor ones, eventually equalizing incomes all around and producing high level of world output. To the extent that differences in income remain, in the traditional view, these should be due to differences in the natural endowments of the nations. This world view absolves market participants from any concerns about equity in trade or development because the market is basically egalitarian. Though the developed world may have gained its wealth by having the good fortune to develop first and by exploiting other areas during the colonial era, the market is always working to erase these historical flukes and iniquities. If the market is only allowed to function without impediments, it will eventually allow every nation to produce at the highest level at which its land and people are capable.

Gomory and Baumol make it clear that over a broad range of industries – particularly those which drive the modern economy – this picture is extremely misleading. Underdeveloped countries are not underdeveloped because they are somehow inferior in terms of either land or people. Rather, the operations of the modern international economy work to lock them into their historical patterns of poverty.

Policy Implications

While this finding would seem to be bad news for the developing world, the analysis also offers hope for the most underdeveloped places. While the analysis makes it clear that the market will not automatically improve the lot of Sub-Saharan Africa (for example), it also makes it clear that it is in the interest of wealthy nations to assist the poorest nations to gain a foothold in industries where they have the potential to succeed. Any job transferred from the US to Liberia can be expected not only to make Liberia better off, but to generate more than one job in the US because the reduction in aggregate

demand in the US (from the lost job) will be more than offset by an increase in aggregate demand for US imports in Liberia, as well as a reduction in price in the good that is now manufactured abroad. This should result in a more jobs and more consumption in both countries.

They estimate that the ideal trading partner for a wealthy nation is one which has a GDP per capita of about one quarter of its own. This makes Mexico something close to an ideal trading partner for the United States in the sense that the US could not improve its lot by seizing industries from or conceding industries to Mexico. If this analysis is correct and Mexico defines the border between the zone of cooperation and the zone of conflict for the US, then those nations with per capita GDP lower than Mexico (approximately two thirds of the world's nations) fall into the zone of cooperation, where the US could only benefit by helping them.

An Adaptive Agent Model of International Trade

In an effort to gain insight into the mechanisms involved with international trade and development, we can construct a simple adaptive agent model of production and trade. This model will follow the basic outline of the classic Hecksher-Ohlin trade model, but will further disaggregate the model, resting it on the behavior of individuals and firms. The model is capable of reproducing a contemporary analysis of trade from Paul Samuelson as well as verifying the retainability of industries as described by Gomory and Baumol and demonstrating how recognition of this retainability has important implications for the long discredited infant industries argument for protection of developing markets.

Model Specification

We begin by defining the agents. We define two types of agents: citizens and nations. Citizens are each associated with one nation and possess one unit each of labor and capital, which they choose to deploy in one of two national industries depending on which pays the higher wage or higher return to capital (they may choose to work in one industry and invest in the other). They use these wages and returns to demand goods.

Nations possess national industries (we can follow convention by thinking of them as wine and cloth) which produce goods according to Cobb-Douglass production functions using the labor and capital which the citizen agents provide. They calculate wages and returns to capital along with prices for each of the goods produced. When trade is enabled, they also engage in trade, importing more of a good if its price is lower in the other country and paying for these imports by bartering with goods from the industry where their price is lower.

More specifically, the citizen agents have three basic state variables: a job, an investment, and a demand function. In each round, each agent does these things:

- Asks the nation for the current price of both wine and cloth.
- Asks the nation for the current wage in the industry where the agent works.
- Asks the nation for the current return on capital in the industry where the agent has invested.
- Calculates its demand for both wine and cloth based on its income (from wages and investments) and the prices of the two goods using the simple hyperbolic demand function $D_w = Y/2P_w$. This amounts to saying that each agent spends half of its income on each good – buying less and more of the good as the price goes up and down.
- With a probability of one percent, the agent reexamines its job and investment choice, changing jobs or shifting its investment to the industry which provides the higher wage or return to capital. The low rate of turnover in employment

and investment insures that the model is able to adjust to each change, thus avoiding stampedes from one industry to another which dramatically overshoot the required correction in the employment or investment level.

The nation agent also has several state variables. The structure of the nation's two industries is given by a pair of Cobb-Douglas production functions of the form $Q_w = A*L^{\alpha}_w*K^{\beta}_w$, where the quantity of wine produced Q_w is the product of an efficiency A, the amount of labor devoted to wine L_w to some exponent α and the amount of capital K_w devoted to wine to some exponent β. These parameters (A, α, and β) are state variables.

Because the model relies on barter rather than money, the price of one good (wine) is fixed at 1, while the price of the other good (cloth) adjusts to reflect its relative scarcity. The price of cloth is adjusted upward by a small amount when demand for cloth exceeds its supply and down by a similar amount when supply exceeds demand. Because wages and returns on investment are calculated as shares of current production, Walras' law ensures that if the cloth market clears, the wine market will also clear. The price of cloth is a state variable.

Finally, when trade is opened, the nations barter goods. Cloth flows from the country in which its price (relative to wine) is lower to that where its price is higher, with compensation being made in wine according to the current price of cloth. When the international market is out of equilibrium (i.e. when the price of cloth differs between the two countries) the trade price of cloth is taken to be the average price between the two countries. The amount of cloth exported is increased by a small amount when the nation's partner has a higher relative price for cloth and is decreased by a small amount when the partner has a lower relative price for cloth. This level of trade is the nation's final state variable.

In each round, each nation does these things:

- Counts the number of citizens working and investing in each industry.
- Determines the quantity of each good which it will produce using each industry's production function and the current level of employment and investment in each industry.
- Determines the wage for each industry by calculating the marginal product of labor in that industry by subtracting the current level of production from the production that would result from the addition of one additional unit of labor.
- Determines the return to capital for each industry by subtracting the wage bill for that industry from the total output of the industry (at current prices) and dividing by the number of investors in the industry.
- Adjusts the price of cloth as described above.
- Adjusts the level of trade to reflect the new price level in both countries as described above.

These straightforward behavioral rules are adequate to reproduce the primary features of the Hecksher-Ohlin trade model in a dynamic context. This model is implemented in Java using the Ascape (Parker 2000) modeling framework. The agents are represented by Java object classes, while Ascape handles the randomized agent activation regime (i.e. agents activate in a changing, randomized order) while also facilitating the collection of statistics and the production of graphical output.

Samuelson's Analysis of Outsourcing

Paul Samuelson, who is widely considered to be the Dean of neoclassical trade theory, has recently published a paper [Samuelson, 2004] which takes mainstream trade theorists to task for over generalizing the benefits of free trade by demonstrating that there are situations where the gains from trade for one nation can be undone by technological developments in a second nation. Because Samuelson sets up his simple analytical model in a way that is compatible with our agent analysis, it serves nicely to

validate our model. If the model is correctly specified, it should be able to produce results which agree with Samuelson's mathematically rigorous analysis.

Samuelson asks us to consider two countries designed to look something like the US and China. His stylized US has 100 citizens while his stylized China has ten times that population with 1000 citizens. For the sake of symmetry, he further assumes that the US average productivity is ten times as high as Chinese productivity, thus producing equal amounts of total production in the two countries (though Chinese per capita productivity is only $1/10^{th}$ that of the US). These productivities are asymmetrically distributed between industries, however, with the US having Ricardian productivity parameters of 2 and 1/2, while China has parameters of 1/20 and 2/10.

One problem with models of this sort, which represent the economy in barter terms, is that it has traditionally been difficult to compare outcomes in absolute terms. Samuelson overcomes this problem by pointing out that there is a definite relationship between demand and utility functions. He assumes a J. S. Mill style pair of hyperbolic demand functions: $D_c = Y/2P_c$ and $D_w = Y/2P_w$. These demand functions imply that consumers spend half of their income on each good. He the shows that these are the logical outgrowth of a utility function $U = (C*W)^{0.5}$ which takes the geometric mean of the consumption of the two goods as a measure of welfare. This relationship allows us to measure the total utility of each nation. In the absence of money, this utility measure allows us to assess the value of the nation's consumption. It can thus be used as a fair measure of the nation's utility.

Samuelson refers to this measure as a proxy for GDP, but this is not necessary or entirely correct. Generally, GDP is taken as a proxy for total utility, which is difficult to

measure. GDP is, however, a poor proxy for a variety of reasons [Daly, 2003]. Because we are working with a theoretical system, it is possible for us to work directly with utility rather than resorting to the poor proxy of GDP. In the current specification of the model, we would assume that GDP and utility would be highly correlated but other interesting formulations would weaken this link. To avoid confusing the end (utility) with its means (GDP), we will break from Samuelson's usage and refer to the geometric mean of consumption as utility rather than GDP.

Using these production and demand functions, Samuelson demonstrates that there are substantial gains to be had when the countries specialize and trade the product in which they are relatively strong for that in which they are relatively weak. In autarky, the US can produce 100 units of cloth and 25 units of wine. This gives a utility of $(100*25)^{0.5}$ or 50. China, similarly, can produce 25 units of cloth and 100 units of wine to achieve the same utility level of 50. US utility per capita is therefore 50/100 or 0.5, while China's is 50/1000 or 0.05.

Samuelson then demonstrates that, under free trade, the US is able to specialize in cloth, producing 200 units of cloth, whereas China is able to specialize in wine, also producing 200 units. Because of the symmetry of the example, each country is able to trade and consume 100 units of each good, thus raising total utility in each country to $(100*100)^{0.5}$ or 100 units. Both countries have thus doubled their real utility by specializing and trading.

Finally, Samuelson demonstrates that not all technological changes need be beneficial for both nations. For the sake of this example, he posits a tremendous technological improvement in China's cloth sector (where the US had previously been

stronger) from 0.05 to 0.8. This leaves cloth productivity substantially below the US level of 2, but much higher than it had been. This change serves to equalize the factor prices in both countries (the ratio of the efficiencies in both nations is now 4). This equalization removes all incentive to trade, reducing the problem to calculating the output of each country in autarky.

The result is a boon for China and a plague for the US. China is now capable of producing 400 units of cloth and 100 units of wine for a total utility of $(400*100)^{0.5}$ or 200 (0.2 per capita), while US once again can produce (100*25)0.5 or 50 (0.5 per capita). Chinese consumption thus expands by a factor of four while US consumption is halved.

Samuelson uses this model to argue that outsourcing of high technology jobs from the US to India and China is not automatically good for both nations. Indeed the transfer of jobs in a sector where the US was once a leader to countries which did not previously participate heavily in such industries has the potential to make the economies of various nations more alike in their productivity, thus eroding gains from trade to which the US has become accustomed.

Verifying the Agent Model

We can gain some confidence in both the agent model and in the soundness of Samuelson's analysis by verifying that they both produce the same result. Because our modeling approach is compatible with Samuelson's analysis, it is easy to translate his numbers into parameters which can be plugged into the agent model.

The "US" nation agent begins with 100 citizens. It has two industries specified by these production functions which (following Samuelson) exhibit constant returns to scale:

- $Q_c=2*L_c^{0.5}*K_c^{0.5}$
- $Q_w = 0.5*L_w^{0.5}*K_w^{0.5}$

The "China" nation agent begins with 1000 citizens. Its industries are similarly specified with these production functions:

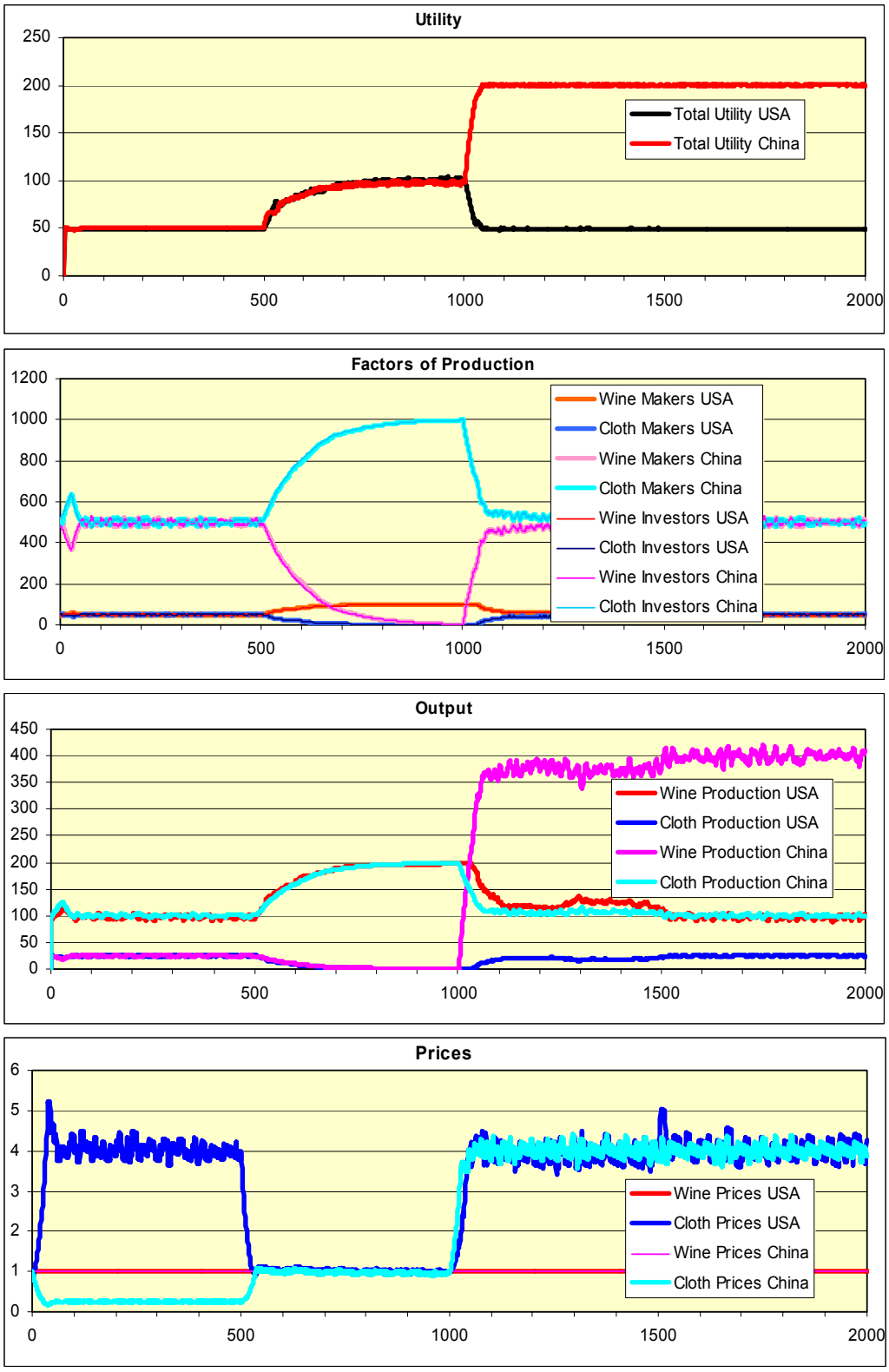
- $Q_c=0.05*L_c^{0.5}*K_c^{0.5}$
- $Q_w = 0.2*L_w^{0.5}*K_w^{0.5}$

The citizen agents of each country are initially randomly assigned a job, an investment and a demand function as described above. This demand function is identical for each agent.

We begin the model run in autarky. After 500 rounds, both nations have established equilibrium production at 50 units of utility. At 500 rounds, we open trading which allows the nations to import a good if its relative price is lower in the other country. This results in a major restructuring of each economy.

After another 500 rounds, at round 1000, China undergoes its remarkable invention in the cloth industry, raising its productivity there from 1/20 to 8/10. As Samuelson's analysis indicates, Chinese utility jumps to 200, while US utility falls back to its previous autarkic level of 50. After yet another 500 rounds, trade is stopped and the model shows no major difference, thus demonstrating that these productivity levels produce trade terms which are functionally equivalent to autarky.

Figure 2.3: Adaptive Agent Realization of Samuelson Trade Model



Verifying Gomory and Baumol's Retainable Industries

Now that we have established the basic functioning of the model, we can use it to look at what happens when we explore the more interesting case where we relax the assumption of constant returns to scale, shifting instead to the combination of increasing and decreasing returns examined by Gomory and Baumol.

As discussed above, one of the foundations of Gomory and Baumol's argument is that relaxing the standard assumption of constant or decreasing returns to scale to allow for increasing returns to scale in some industries changes the complexion of trade theory dramatically. With constant or decreasing returns, the Hecksher-Ohlin (along with its various Ricardian cousins) indicates that the market will always deliver a better result for each country with trade than it will without. Though the standard model is not dynamic, it also implies that changes in productive capacity will be reflected in the market – as we saw in Samuelson's stylized treatment of the US and China.

Gomory and Baumol observe, however, that in a world where some industries produce increasing returns to scale, these industries can be "retainable" by a nation which develops them early. Because costs fall as more units are produced, it may be possible for a nation with a less efficient production function to retain an industry over a later entry which would be able to produce the good more cheaply if only it could attain the required scale of production. As we will see shortly, a late developing country may, under some circumstances, be able to do better in the long run by abandoning trade in some industries all together.

The recognition of the importance of increasing returns is not entirely new, having been explored by such authors as Kenneth Arrow [1962] by Paul Krugman [1979,

1983], Brian Arthur [1989], among others. It has, however, failed to make a real dent in the policy discourse concerning trade and development

We can illustrate the existence of retainability by running our adaptive agent trade model with an appropriate set of parameters. In this case, we imagine a large (500 citizen), industrialized nation and a smaller (100 citizen) "third world" nation which develops later. Once again we have two industries, but this time they are industries of a specific character. One is a basic agricultural industry which exhibits low productivity and decreasing returns to scale. The other is a high productivity industry – let's generically call it manufactures – which exhibits increasing returns to scale. We will assume for the moment that this industry exhibits increasing returns over its whole range of production.

With the exception of levels of productivity, these production functions are identical in both countries:

- $Q_a = A*L_a^{0.4}*K_a^{0.4}$
- $Q_m = B*L_m^{0.7}*K_m^{0.7}$

As in Samuelson's case, the nations differ only in their production efficiency in each industry. The developed nation is more efficient in both industries, having an efficiency in agriculture of A=0.5 and an efficiency in manufactures of B=1.0. The developing nation begins with equal efficiency in both industries: A=0.2 and B=0.2. This gives the developing nation a comparative advantage in agriculture and the industrialized nation a comparative advantage in manufactures.

We run the model forward as we did in the Samuelson case. For the first 500 rounds, both countries produce and consume as best they can in autarky. For the next

500 rounds, the nations trade, both realizing gains because they are able to specialize in the area where they are most efficient.

As in the Samuelson case, at round 1000, we introduce a substantial exogenous change in productivity in one of its industries. In this case, the developing country drastically increases its productivity in manufactures from a paltry 0.2 to an impressive 1.5, jumping from 20% of the developed nation's productivity to 150%. At this point, however, we observe a marked contrast to Samuelson's giant increase in productivity: nothing happens.

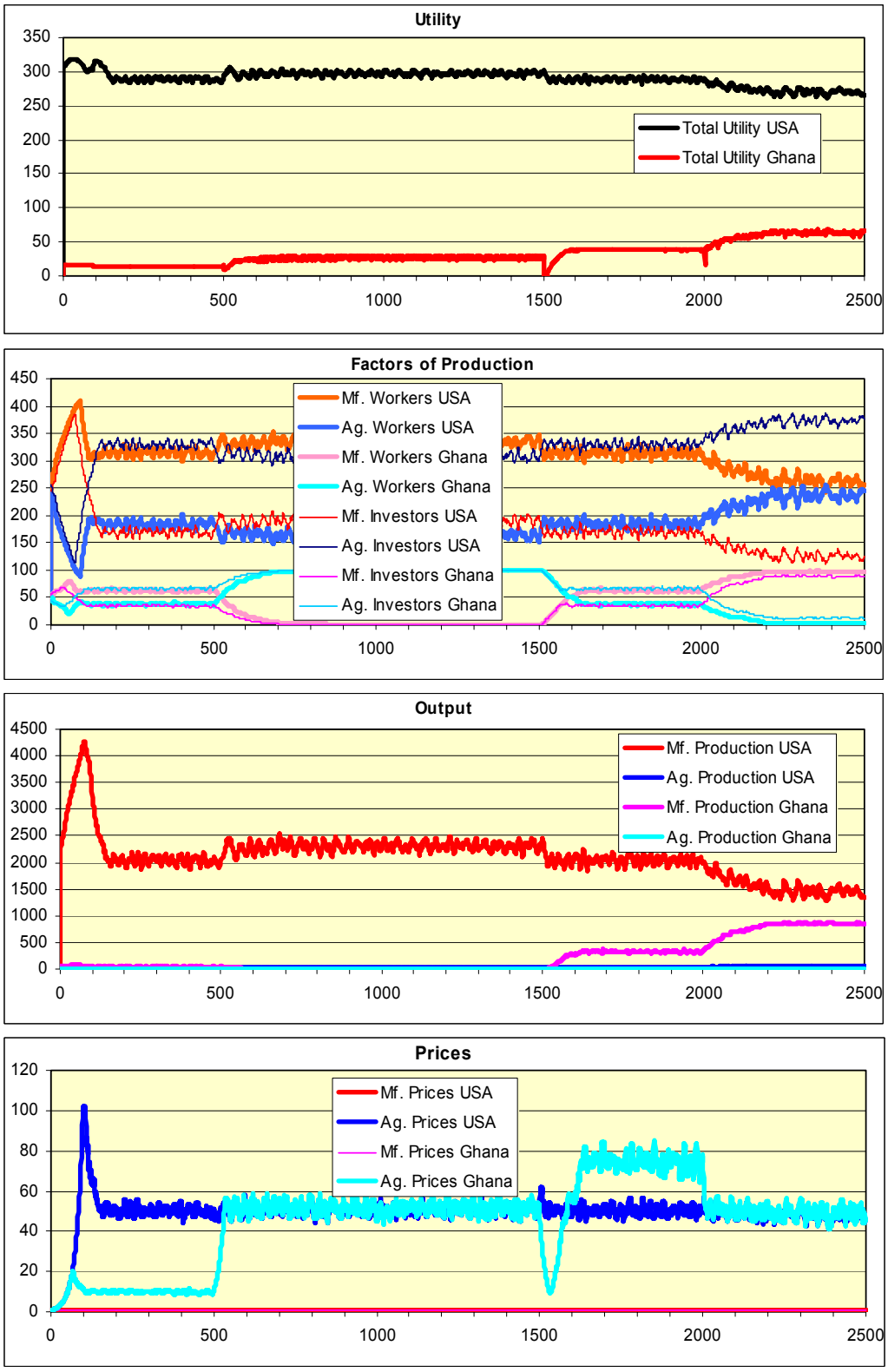
Because the developing nation has specialized in agriculture, it has virtually no industry in manufactures. Any attempt to start such an industry is bound to fail because the industrialized country has attained a scale such that it can produce manufactures more cheaply than the developing nation – even given the developing nation's new, superior productivity at any given point on the production functions. In each round, the citizens and investors of the developing nation examine the feasibility of moving into manufactures, and in each round they find that they can do better by sticking to agriculture. The industrialized nation is thus able to retain the industry despite the fact that, all else being equal, it is no longer the most efficient producer in either absolute or relative terms.

In the Samuelson case, we cut off trade at round 1500 and found that there was no impact on utility in either country because their proportional productivities had become similar. If we cut off trade in this case, something even more surprising happens. After an initial plunge in utility, the developing country begins to restructure its economy. Where its manufactures had been unable to compete with cheap, mass produced imports

in its domestic market, they are now the only game in town. Workers and investors begin to shift away from agriculture and into manufactures. Initially, this sector is not terribly productive, but with experience and scale, it becomes more and more productive. In time, given the parameters we have chosen, the manufacturing sector becomes so productive that the small nation is actually able to do better in autarky than it previously did through trade!

Finally, in round 2000, we reopen trade. The newly industrialized country is now in a much stronger position to compete on the international market and sees a substantial gain. The larger, more established country actually looses more utility as a result of this trade over autarky. It is forced to restructure its economy to produce the lower productivity agricultural good. Because this good has decreasing rather than increasing returns, its productivity erodes as it becomes more specialized, leading to a long term decline in income as compared to autarky.

Figure 2.4: Retainability of Industries with Increasing Returns



Discussion

This case is admittedly highly stylized; however, it makes good sense in terms of development and has important implications for development policy. In the constant or decreasing returns world of neo-classical trade theory, the productivities of nations in different industries determine a unique set of equilibria in trade and utility unless some sort of trade policy intervenes to interfere with trade and lower that utility. A poor country is poor either because it is not very productive, or because it is not making good use of its comparative advantages in productivity through trade.

The policy prescription that comes out of the neo-classical model is simple. Poor nations should try to improve their productivity in areas where they have a chance to compete – keeping wages low and focusing on low skill sectors such as agriculture (the stereotypical example would be bananas). Furthermore, they should seek to increase trade in every situation. The standard set of assumptions about trade indicate that this is the very best they can hope to do. If such a country is unable to compete in any of the more modern industries which are characterized by increasing returns, that is simply because they as a nation are no good at them. Their best strategy for obtaining these high value added goods, in both the sort and long terms, is to grow ever more bananas and look for additional markets in which to trade them.

The introduction of increasing returns into this picture changes everything. A poor country no longer faces a simple policy prescription, and the invisible hand can no longer be counted on to deliver the industrial structure which will give the country its highest long-run level of consumption. The multiple equilibrium situation introduced by increasing returns leaves the country with difficult choices. In the short run, protecting a domestic industry will almost certainly hurt them. In the long run, however, this

protection might allow the protected industry to attain sufficient scale that the country would be better off. Even if the long run autarkic equilibrium utility would be lower than the free trade equilibrium, a period of protection and domestic development might allow the protected industry to develop to the point where it could become a competitive producer on the world market, thus allowing the nation to reopen to substantially improved terms of trade and higher consumption. The Asian "tiger" economies come to mind as nations which achieved tremendous development by following this kind of strategy. [UNIDO, 2004]

Next Steps

In this essay, we have used the adaptive agent approach to illustrate a result which can be obtained more simply (but perhaps less convincingly to some) using analysis. This approach, however would lend itself nicely to variations which would be much more difficult to handle analytically.

We have held to the standard economic convention of using consumption as the sole measure of well being. Though this convention is almost universally followed, this probably has more to do with its analytical convenience than it does with any attempt to reflect economic reality. Economic analysis generally assumes a preference curve for goods (as we do in our hyperbolic demand curve and geometric mean welfare function), but assumes that workers are uniformly indifferent about their employment. This adaptive agent modeling framework would make it relatively simple to work with a heterogeneous population of agents who possess different talents for different kinds of work and different preferences for different kinds of work. Not everyone is cut out to be a banana farmer – and not everyone with the abilities required would want to be one.

Such a formulation could reflect not only the efficiencies associated with having a diverse economy which is able to take advantage of people's differing talents, but also reflect the subjective (but very real) welfare gains which would result from people being able to spend their time at jobs which they prefer [Daly, 1996].

Because the current model assumes equal wages and returns within an industry and works to equalize these returns between industries, it can have nothing to say about the impacts of trade on income distribution. While a full scale model capable of reproducing national patterns of income distribution would be more than a minor extension of this model, the ability of the adaptive agent approach to work with heterogeneous agents would make it ideal for this kind of work.

Along these lines, Samuelson [2004] states, "My most important omission, for realism and for policy, is treating all people in each region as different homogeneous Ricardian laborers. That inhibits our grappling with the realistic cases where some Americans (capitalists and skilled computer experts) may be being helped by what is decimating the real free-trade wage rates of the semi-skilled or the blue-collar factory workers." He goes on to discuss ways in which factor price equalization models might predict declining median income even in the face of increasing average income due to increasing inequality. In so doing, he points out that, in a factor price equalization model such as this one, the US unskilled wage would be expected to drop in the face of low wage foreign competition. While it might be possible for the winners in such situation to compensate the losers, he observes that there is no evidence that this has happened or will happen. If citizens were fully aware that this could happen, a democratic society might well choose to increase median income at the expense of the average (or total) income.

The adaptive agent approach used here would be ideally suited to relaxing the assumption of homogeneous Ricardian laborers. Workers could be endowed with differing abilities in different industries and different levels of effort or energy. Different industries could have various requirements for more and less skilled laborers, with wages reflecting the market for such work. This approach would allow for the rigorous treatment of such issues as offshoring and outsourcing without adding major complexity.

Another way that the adaptive agent approach could contribute to trade modeling would be by providing a natural modeling framework for capturing industrial synergies. A significant part of Gomory and Baumol's analysis rests on the idea that many industries can not operate in isolation, but are dependent on other industries for efficient production. We could further illustrate this point by elaborating production functions to make the output of some industries dependent on the supply of goods produced by others. In the presence of transport costs (which could easily be introduced), this would make some combinations of industries more efficient than others.

It would also be straightforward to generalize this model to include many industries and many nations. This would be useful in evaluating policy issues such as the validity of Gomory and Baumol's claim that it could be in the interest of a wealthy nation to transfer an industry to a poor nation. While their analysis demonstrates that such a transfer would increase global utility, it is not entirely clear, in a many nation situation, under what circumstances the benefits to the wealthy nation would actually outweigh the costs it incurs. In the two nation case, the wealthy nation sacrifices an industry but is able to reap all of the benefits of lower prices from the lost industry. In the many nation

case, the wealthy nation would still incur all of the costs of sacrificing an industry, but the benefits would be distributed among many nations.

This would seem to complicate the self-interest based argument for helping poor nations to take over some of the industries which are currently retained by wealthy nations. While such a move would increase global utility to the point where the winners could, in principle, compensate the losers, this would almost certainly never happen. A multi-nation adaptive agent treatment of this problem could be a useful tool in differentiating the kinds of situations where a pure self interest argument would apply from those which would rely on appeals to the common good (where global welfare would be increased at the expense of national welfare) or to economic justice (where the poor would benefit at the expense of the aggregate).

Finally, the agent framework presented here would be well suited to exploring Daly's [1996] observation (also mentioned by Samuelson [2004]) that the mechanism of the comparative advantage argument depends on internationally immobile capital.

This assumption is explicitly stated by Ricardo [1817], but is generally omitted from modern discussions. Given the realities of early 19th century international travel and communication, Ricardo found this assumption reasonable:

> Experience, however, shews, that the fancied or real insecurity of capital, when not under the immediate control of its owner, together with the natural disinclination which every man has to quit the country of his birth and connexions, and intrust himself with all his habits fixed, to a strange government and new laws, checks the emigration of capital. These feelings, which I should be sorry to see weakened, induce most men of property to be satisfied with a low rate of profits in their own country, rather than seek a more advantageous employment for their wealth in foreign nations.

In the early 21st century, international investment is a much simpler matter and the increasing trend toward globalization continues to make national borders less relevant to

investment decisions. Daly points out (following Ricardo closely) that mobile capital shifts the situation from one of comparative advantage – where all nations benefit – to one of absolute advantage. Under absolute advantage total global output can be expected to increase (as capital moves to find its maximum return), but more efficient nations benefit while less efficient nations suffer. In a decreasing returns world, this would lead to equalization of incomes among nations, as capital moved to the places where it was in shortest supply (and thus produced the highest marginal return). In the more complex world that we inhabit, with increasing returns, industrial synergies, critical infrastructure, etc., the effects of relaxing the assumption of international capital immobility are harder to identify with certainty.

An initial exploration of this principle could be conducted by allowing the agents of our model a broader choice of investments. Currently, agents examine the marginal return to capital in the two domestic industries – moving their investments to maximize this return. By allowing the agents to invest in any of the four industries, we should be able to reproduce the basic difference between comparative and absolute advantage.

In its simplest form, the model would pay the return to capital directly to the investor. This would be equivalent to allowing the complete repatriation of revenues (not just profits). Thus, investment abroad would generate considerable demand at home. The actual fate of revenues from foreign investment is considerably more complex than this [Gomory and Baumol, 2000] and modeling it well enough to make specific policy recommendations would be a non-trival task. Even a simple model along these lines would, however, make the point that the rosy picture pained by the comparative advantage argument no longer applies. It would make it clear that unless winning nations

are prepared to compensate losing nations (which is unlikely), nations would do well to proceed with caution with regard to capital mobility because there is no assurance that each will benefit.

Arrow, Kenneth. 1962. “The economic implications of learning by doing.” *Review of Economic Studies* 29: 155-73.

Arthur, W. Brian. 1989. “Competing technologies, increasing returns and lock in by historical events.” *Economics Journal* 99: 116-31

Herman E. Daly, 1996. *Beyond Growth.* Beacon Press, Boston

Daly, Herman and Joshua Farely, 2003. *Ecological Economics: Principles and Applications.* Island Press, Washington, DC.

Gomory, Ralph E. and William J. Baumol. 2000. *Global Trade and Conflicting National Interests*. Cambridge, Mass.: MIT Press.

Krugman, Paul R. 1979. “Increasing returns, monopolistic competition and international trade.” *Journal of International Economics*. 9:469-79

Krugman, Paul R. 1983. “Targeted industrial policies: Theory and evidence.” *Industrial Change and Public Policy.* Kansas City, MO: Federal Reserve Bank, pp. 123-55.

Marshall A., 1890, *The Principles of Economics*, McMillan (N.Y.), re-edition 1925.

Samuelson, Paul A. 2004. “Where Ricardo and Mill Rebut and Confirm Arguments of Mainstream Economists Against Globalization.” *Journal of Economic Perspectives.* Vol. 18, No. 3. Summer 2004. pp 161-180.

UNIDO, 2004. *Industrial Development Report 2004*, Vienna: United Nations Industrial Development Organization.