Specific Factors, Learning, and the Dynamics of Trade *

Claustre Bajona †

University of Miami, USA

Abstract

In the postwar period, the volume of trade among developed countries has increased at a much higher rate than GDP. This paper presents a dynamic general equilibrium model of trade between developed countries that accounts for this pattern of trade dynamics. Countries trade in goods that use good-specific skilled labor and unskilled labor as factors of production. Specific skills are learned on-the-job and there exists positive effects in learning. Small initial differences in the distribution of experts in each country generate an increasing pattern of specialization over time. Knowledge spillovers across sectors are crucial determinants of the trade pattern.

Key words: volume of trade, good-specific knowledge, dynamic general equilibrium, accumulation of factors.

JEL: F1, E.

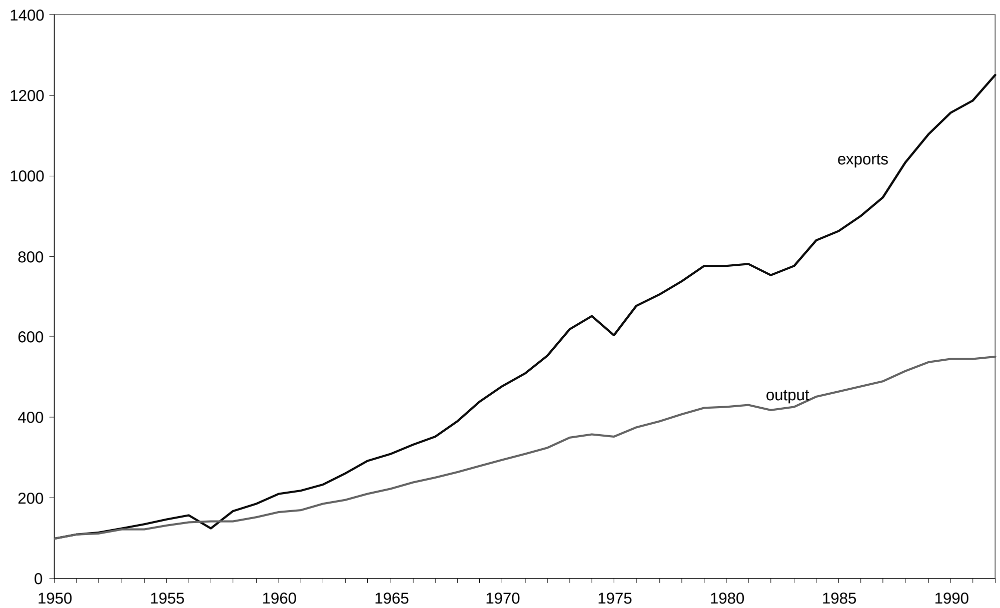
---

*Submitted October 2000. Revised July 2002. This version February 2003.

†Please send comments to cbajona@miami.edu. I would like to thank Timothy J. Kehoe and Edward C. Prescott for their continuous help and support while developing this paper. I also thank Kei-Mu Yi, whose comments substantially improved earlier versions of this paper. I am grateful to Andrés Erosa, Luisa Fuster, David Kelly, Narayana Kocherlakota, Lee Ohanian, Terry Roe, Jim Schmitz, and an anonymous referee as well as participants of the Macroeconomics Workshop at the University of Minnesota, the Research Department at the Federal Reserve Bank of Minneapolis and the SED meetings for their insightful comments . All remaining errors are my own.

1. Introduction

The rapid increase in commercial interaction between countries has attracted considerable attention in the past decades, both in political and academic arenas (Feenstra 1998, Krugman 1995, Ishii and Yi 1997 among others). As figure 1 shows, merchandise trade has increased 2.5 times faster than income in the postwar period. The rapid growth in trade raises new issues that cannot be resolved without knowledge of the precise nature of the trade pattern and the domestic effects of a more open economy.



Source: GATT International Trade, various issues.

Figure 1.1: Indices of world merchandise exports and output. (1950 = 100)

The analysis of trade patterns reveals other interesting features of international trade in the postwar period. In particular, about 70% of the trade flows are originated by developed countries trading with each other. Furthermore, developed countries mostly trade in manufactures. This is a striking feature, since the consumption share of manufactures in developed countries decreased sharply in the period of study. Most of the increase in trade is apparently accounted for by goods that are becoming less and less important in the consumption basket.

Tariffs and transportation costs where substantially reduced in the postwar period. Despite this fact, several studies like Baier and Bergnstrand (1998) and Rose (1991) find that tariffs and transportation costs are not the main force behind the increase in trade.

The increase in the trade-to-income ratio represents a puzzle for existing trade theories. Standard static formulations of the Heckscher-Ohlin and Ricardian models predict little trade among countries with similar capital-labor ratios and technologies (both characteristics of developed countries).[1] Markusen (1986) uses a "new trade theory" model[2] with non-homothetic preferences where the trade volume increases as countries become richer. Even though the model delivers increases in trade to income over time, Bergoeing and Kehoe (2001) find, in a qualitative study of Markusen's model, that in order to replicate the increase in the trade-to-income ratio observed in the data they need extremely high elasticities of substitution between goods. Furthermore, the model implies an increase in the consumption share of income over time, contrary to what we observe in the data. Yi (2002) obtains huge increases in trade in short periods of time through increases in vertical specialization driven by tariff reductions. He uses a Ricardian framework, with exogenously given technological differences across countries. Given that developed countries have access to the same technology and similar levels of development, this is, in my opinion, a strong assumption. I am convinced that the effects of international trade in the industrial structure of an open economy are significant. The observed differences in technology could very well be a *result* of the international interaction, in which case assuming them away leaves unexplained a very important aspect of the effects of trade in the economy.

In this paper I develop a general equilibrium model of trade between developed countries that

[1] Chipman (1992) and Rodgers (1987) present models in the Heckscher-Ohlin framework in which they get significant intra-industry trade (trade between commodities in the same industry) between countries with similar capital-labor endowments. Both models are static.

[2] see Helpman and Krugman (1985) for a survey on new trade theory models.

specifically introduces dynamic effects of trade in the economy. Countries that are open to trade gradually specialize over time in the production of the specific goods in which they have comparative advantage. Comparative advantage is, in turn, intensified over time by the accumulation of specific factors of production. Two factors are needed for the production of any good: good-specific specialized labor, called *experts* in the model, and non-specialized labor, called *workers*. The skills needed to become an expert are learned on-the-job. Trading countries export the goods for which they have comparative advantage in their endowment of experts.

A country's production pattern determines how the distribution of skills among its population evolves over time. The stock of experts in each industry produces a positive effect in the ability of workers to acquire the expertise in the industry. The higher the proportion of experts in the industry, the easier the workers learn. The positive effects in the ability to learn on-the-job, together with the ability to trade, magnify any initial comparative advantages across countries, and create a pattern of gradual specialization. The intuition for the gradual specialization is clear: the possibility of learning and becoming a skilled worker creates a trade off between wages today and income possibilities tomorrow. Workers are willing to accept lower wages today in exchange for a higher probability of becoming skilled in the future. Therefore, the industry with relatively lower proportion of skilled workers has to pay relatively higher wages and, thus, hire less workers than the industry in which the country has comparative advantage. Less workers hired implies that less workers learn the skills in the industry and, as a result, the stock of experts in the industry grows at a relatively slower pace until it reaches a point where the stock of experts in the industry cannot be sustained and the industry starts decaying. Countries gradually concentrate their expertise in different industries, according to their initial comparative advantage, gradually specializing in the production of different goods.

Given the way wages are determined, the model has some implications for the wage differentials across sectors and skill levels that are consistent with wage patterns on industries involved in trade between developed countries (see Lovely and Richardson, 1998). In particular, the model predicts that exporting industries should have higher wage differentials and a higher rate of growth of unskilled wages. Furthermore, the overall wage gap decreases over time.[3]

Skills, or expertise, are understood in a broad sense in this model. Skills, embodied in people, are meant to capture all the knowledge that is specific to the production of a certain good. Part of this knowledge involves the acquisition of managerial capital. The production of a specific good involves a managerial sector that controls the production process and a marketing sector that distributes the product to the public. The skills of these managers are specific to the good produced. Workers, by working at the firm, are exposed to these managerial capital, learn how the firm is run, and become capable of setting up a new firm on their own.

A specific study of the importance of on-the-job learning in the transmission of know-how is Rhee (1990).[4] Rhee traces the success of garment exports in Bangladesh to a collaboration between a Korean firm, Daewoo, and a local firm, Desh. Even though Bangladeshi workers were trained in Daewoo in the performance of very specific tasks the trainees were exposed to the managerial and marketing systems used by Daewoo, allowing them to leave Desh and set up their own garment export firms in Bangladesh, making it one of the most successful export industries in the country.

The idea of introducing learning in models of trade is not new. Young (1991), Boldrin and Scheickman (1988), and Devereux (1997) are some examples of dynamic models of trade and learning. These papers differ from mine in two aspects: they all use a learning-by-doing framework and learning

[3]These results follow from the fact that wages in the skilled sector depend on the scarcity of skilled workers. Wages of unskilled workers in each sector depend on two factors: their scarcity and the value of the skills in the sector. The higher the need for unskilled labor, the higher their wages. The higher the value of acquiring the sector's skills, the lower the unskilled wages in the sector.

[4]I thank Amy J. Glass for pointing out this case study.

increases total factor productivity in the country (Ricardian-type of learning). Higher differences in productivity increase technological differences across countries and, thus, increase trade. These models, given the mechanisms that drive international trade, are more suitable to study trade among countries at different levels of development than to study trade between developed countries, which have similar educational and technological levels. Feeney (1999) introduces industry-specific learning-by-doing in a trade model. Her model, like the one in this paper, delivers gradual specialization over time, but her learning mechanism is different from mine, since it also affects total factor productivity.

The importance of external effects in the acquisition of knowledge is the subject of a vast economic literature (e.g., see Lucas, 1988, 1998). The existence of agglomerations of the type of Silicon Valley, the importance of cities as centers of economic activity, and universities as centers of transmission of knowledge accounts for anecdotal evidence in this respect.

The paper is organized as follows: I present the model in section 2. In section 3 I define equilibrium and characterize it for a simplified version of the model. Section 4 contains a simulated version of the model economy as well as some sensitivity analysis on the parameters of the model. The effects of tariffs on the model are studied in section 5 and section 6 concludes.

2. The model

Two factors are needed to produce any consumption good: experts and workers. Expertise is good-specific; workers are not. Following Rhee's (1990) case study, managerial and marketing skills in the garment industry are specific to the industry (even to the specific type of garments goods produced).

People in this model are of different types. Some people possess specific skills for the production of one of the goods, whereas other people are unskilled. A person's type, which will change over time, determines his occupational choices. Skilled people work as experts in the industry in which they have the skills. Unskilled people work as raw labor in any of the industries. In what follows it is crucial to distinguish between a person's type and his actual occupation. I use the terms skilled/unskilled to denote type, and expert/worker to denote occupation.

Expertise is acquired on-the-job. While being taught how to operate the technology, the workers from Bangladesh were also exposed to other fundamentals of the industry's know-how– it was precisely this knowledge what they used to set up their own industries. Expertise depreciates in this model, capturing the fact that knowledge needs to be updated. The constant evolution of technology changes industrial practices. Only the firms that can adapt to the changes remain competitive.

There is a positive external effect on the acquisition of expertise. The more experts employed in the industry, the easier it is for a worker to gain the expertise. This external effect creates a disparity in the ratio of accumulation of experts over time.

The rapid growth of the garment industry in Bangladesh after the creation of Desh is a clear evidence of the existence of these external effects. Before Desh was created, the garment industry was almost non-existent in Bangladesh and clearly not competitive in international markets. Four years after Desh started operations, garments became one of the most successful exports industries in the country. The explanation of this evolution is simple: most of the people originally trained in Daewoo left Desh to operate their own firms. Other workers acquired the know-how while working in these newly established firms and decided to set up their own firms too. As the number of new firms (and, thus, experts) proliferated, the know-how was widely spread among workers in the industry, making it easier for the newcomers to succeed.

A characteristic of knowledge in this model is that it is "free" in the sense that no resources are devoted to training workers or to acquiring the knowledge. Expertise is acquired as a by-product of working. From the point of view of the worker, though, knowledge is not free. The worker accepts lower wages today for a better opportunity of learning and, thus, higher wages tomorrow. The static cost of learning is measured by the period's wage differential across sectors. A similar type of learning is found in Park (1997). In that model, young workers also learn from expert old workers through their every day interactions. No resources are used in the learning process, and workers are willing to accept lower wages to work with more knowledgeable workers. In Park's model people learn the skills with certainty, experts in the same industry have different levels of expertise and workers with different levels of expertise are perfect substitutes in production. The idea of learning on-the-job used in this paper is in the same spirit as the learning-by-doing literature, started by Arrow (1962) and emphasized as an engine of growth in Lucas (1988, 1993), where expertise increases through the production activity, without any resources devoted to it. The learning in my model differs from learning-by-doing in several aspects. First, a worker's learning does not increase total factor productivity in the industry. Learning implies becoming a different type of input (a skilled worker). A worker's learning also affects the ability of future workers to learn the skills. Second, given that the stock of experts affects the productivity of learning and not total productivity, there are no social benefits from learning that are not internalized by the worker and, therefore, the equilibrium in this model is efficient.

In our model, the productivity of the unskilled labor in each sector depends on the amount of experts in the industry (stock of industry-specific expertise), which is a function of the previous period expertise and the number of workers hired in the previous period:

$$x'_s = \pi x_s + \eta(x_s)n_s.$$

2.1. The environment

There are two countries in the model, indexed by k. There are two goods: an homogeneous good and a differentiated good. The differentiated good contains several sectors. The sectors are numbered by $s \in S = \{1, 2, ..., S\}$.

There is a measure l of infinitely-lived people in each country. Country size may be different across countries and people cannot move between countries. People are endowed with one unit of time which they supply inelastically. In any period, there are $S + 1$ types of people, $m \in \{0, 1, ..., S\}$. A person's type indicates his endowment of skills. A person that at a point in time is of type m, with $m \neq 0$, has the specific skills needed for the production of good $s = m$. This person works as an expert in the production of good s (s-expert). A person of type $m = 0$ has no skills, and becomes a worker in any sector.

People's endowment of skills changes over time, depending on their occupation. A worker in sector s acquires the skills in the sector with probability $\eta(x_s/l)$, where x_s/l is the fraction of experts of type s in the country. I take the function $\eta(\cdot)$ to be increasing and concave, to represent the positive effect of the number of experts in the workers' chances of gaining the skills. Specifically, I assume that learning the skills of a specific industry is difficult when the country has few experts in the industry, it increases with the number of experts, but it has diminishing returns. This assumption is meant to capture the way in which knowledge spreads. If an industry in a country is very small, like the garment industry in Bangladesh before the creation of Desh, it is hard for workers to learn the industry's know-how: they are exposed to the managerial skills of their own firm, but they do not obtain any information on how effective the skills are in the market. Once the industry starts growing and becoming successful, workers are not only exposed to the practices of their firm, but also to those of competing firms in the industry. There is a general knowledge about the industry that makes the assimilation of the organizational skills easier.

Knowledge is perishable in the sense that it needs to be updated. I capture this fact by assuming that each expert retains the skill to the next period with some probability π and loses it with probability $1-\pi$.

Technology:

1. Differentiated good: production takes place at production units (plants). The optimal size of a plant is small relative to the economy. Each plant is suited to produce only one of the goods. A plant that produces good s, has as inputs to the production process s-experts, h_s, and workers, n_s. During the production process, some learning will occur. Workers capture all the rents from learning.

2. Homogeneous good: The inputs are unskilled labor and a fixed factor, land, in a constant returns technology. I normalize the amount of land to 1 in both countries and I assume that all the individuals in the country own an equal share of the fixed factor.

Accumulation of expertise: Let $x^k \equiv (x_1^k, ..., x_S^k)$ be the distribution of experts in country k, at time t, and $x \equiv (x^1, x^2)$. Then, next period's distribution of skilled people will be:

$$x_s' = (\pi x_s + \eta(x_s) n_s)\, v_s,$$

where v_s is the number of plants producing good s this period, x_s' is next period's number of experts in sector s. This is just saying that the number of people with s-skills in the next period is equal to the experts in this period that maintain their skills plus the workers that learn the skill. In what follows, time and country subscripts are omitted unless necessary.

2.2. The economy

2.2.1. Preferences and consumer's problem

Consumers are infinitely lived and derive utility from the consumption of the different goods in the economy. They choose consumption and occupation streams to maximize their lifetime discounted expected utility. Their period preferences are homothetic, represented by the utility function:

$$u(c) = \frac{\left[\left(\sum_{s=1}^{S} a_s c_s^{\gamma}\right)^{\frac{b}{\gamma}} c_H^{1-b}\right]^{\rho} - 1}{\rho},$$

where γ, $0 \leq \gamma \leq 1$, governs the elasticity of substitution $1/(1-\gamma)$ between varieties of the differentiated good, b, $0 \leq b \leq 1$, is the consumption share of the differentiated manufactured good, and, ρ, $\rho \leq 1$, governs the intertemporal elasticity of substitution. I normalize $\sum a_s = 1$. Consumers discount the future at a rate β, $0 < \beta < 1$. For simplicity, to keep the number of types fixed over time, borrowing and lending are not allowed. Therefore, individuals consume their entire income every period. This assumption makes the consumption choice static, and lets us concentrate on the occupational choice, which is a key feature of the dynamics of this model.

The occupational choice is driving the dynamics in the consumer's problem. When deciding among different occupations, workers take into account the effect that their decision will have in their future earnings. A worker in an sector with a lot of experts is willing to accept a lower wage today since his probability of becoming skilled in the industry is higher.

Define the sequence of prices and wages in the economy as $P = \{p_{st}, w_{st}^k, e_{st}^k, p_{Ht}, w_{Ht}^k, e_{Ht}^k\}_{s,k,t}$ and let x be the time sequence of distribution of experts in both countries. I denote by $V_{0t}(P, x)$ the discounted expected utility of an unskilled individual at time t, given the sequence of prices and distribution of skills. Since this individual has no skills, his choice is to decide in which sector to work.

If $W_{st}(P,x)$ is the expected discounted utility of a worker in sector s in period t, and $W_{Ht}(P,x)$ is the expected discounted utility of a worker producing the homogeneous good, an unskilled individual chooses to work in any industry that gives him the maximal expected utility:

$$V_{0t}(P,x) = \max_{s}\{W_{st}(P,x), W_{Ht}(P,x)\}.$$

Let $V_{st}(P,x)$ be the discounted expected utility of an individual with s-skills. This individual works as an expert in sector s.

Notice that since workers in different industries have different probabilities of learning the skills, they earn different wages. Workers in sectors with higher possibilities of learning are willing to accept lower-than-average wages in the hope of benefiting from the learning.

A person who has decided to be a worker in sector s chooses a level of consumption. Since I do not allow borrowing or lending, the individual spends all of his income in consumption goods. Occupation is, therefore, the only real choice for consumers in this model. Notice that an individual's level of income depends on his occupation, since different industries pay different wages.

The discounted expected utility for a worker in sector s in period t is:

$$\begin{aligned} W_{st}(P,x) = \quad & \max_{c}\left\{u(c_t) + \beta\left[\eta(x_{st})V_{st+1}(P,x) + (1-\eta(x_{st}))V_{0t+1}(P,x)\right]\right\} \\ & s.t. \\ & \sum_{s'} p_{s't}c_{s't} + p_{Ht}c_{Ht} \leq w_{st} + \tau_t, \end{aligned}$$

where $p_{s't}$ is the price of consumption good s' in period t, p_{Ht} is the price of the homogeneous good, w_{st} is the wage received by a worker in sector s, and τ_t are the per capita returns on the fixed factor. All these three functions are taken as given by the individuals. Let μ_{st} be the fraction of workers that choose to work in sector s.

The discounted expected utility at period t for a worker in the homogeneous product industry is:

$$\begin{aligned} W_{Ht}(P,x) = \quad & \max_c \{u(c_t) + \beta V_{0t+1}(P,x)\} \\ & s.t. \\ & \sum_{s'} p_{s't} c_{s't} + p_{Ht} c_{Ht} \leq w_{Ht} + \tau_t, \end{aligned}$$

where w_{Ht} is the wage received by a worker in the homogeneous sector. Let μ_{Ht} be the fraction of workers that choose to work in the homogeneous sector.

The discounted expected utility for an expert in sector s at period t is:

$$\begin{aligned} V_{st}(P,x) = \quad & \max_c \{u(c_t) + \beta [\pi V_{st+1}(P,x) + (1-\pi) V_{0t+1}(P,x)]\} \\ & s.t. \\ & \sum_{s'} p_{s't} c_{s't} + p_{Ht} c_{Ht} \leq e_{st} + \tau_t, \end{aligned}$$

where e_{st} is the wage received by an s-expert in period t.

From the consumers' problems I derive the demand functions for each good $i \in S \cup \{H\}$ of people in each of the occupations: workers in sector s, $c^w_{sit}(P,x)$, workers in the homogeneous industry, $c^w_{Hit}(P,x)$, and experts in industry s, $c^e_{sit}(P,x)$. Notice, once again, that these functions might differ since different occupations pay different wages.

2.2.2. Plants' problem (differentiated industry)

Production plants are good specific. A plant is suitable to produce only one of the consumption goods in the economy. I assume that the optimal size of a plant is small with respect to the economy, so that production plants take prices and aggregate variables as given. A plant producing good s, an

s-plant, hires s-experts, h_s, and workers, n_s, to maximize its profits. I assume free entry in each of the industries. In this situation, production plants will make zero profits, and operate at their minimum average cost. All plants in an industry have identical production functions.

Let $f(h,n)$ denote the plant's production function. It is assumed that it is of the form $f(h,n) = h^\theta g(n)$, where the function $g(n)$ is such that there exists $n^* \in (0,+\infty)$ such that $n^* = \arg\max \left\{ n^{\theta-1} g(n) \right\}$ and $f(h,n)$ is strictly concave.[5]

Following techniques by Hornstein and Prescott (1993) I can use aggregation theory to define a sector aggregate function, $F(H,N)$, that gives the aggregate output in each sector given the aggregate amount of inputs hired.[6]

Lemma 2.1. *Let $A = (n^*)^{\theta-1} g(n^*)$. If $f(h,n)$ is strictly concave, the individual production functions in each industry can be aggregated to the following aggregate production function:*

$$F(H,N) = AH^\theta N^{1-\theta},$$

where H and N are the total amount of experts and workers hired by the industry in the country and n^* is the optimal plant size.

From now on I work with the aggregate production function, keeping in mind that since production takes place in small plants, producers are price takers. The aggregate demand for experts and workers in each industry, denoted by h_s and n_s respectively, chosen in equilibrium solves the following minimization

[5] n^* is the optimal plant size. An example would be $g(n) = (n-d)^\alpha$, with $d > 0$ and $\alpha + \theta < 1$

[6] A detailed proof of the lemma can be found in a technical appendix to this paper, available upon request.

problem

$$\min \{e_s h_s + w_s n_s\}$$
$$s.t.$$
$$A_s h_s^{\theta_s} n_s^{1-\theta_s} \geq y_s$$

and

$$p_s y_s - e_s h_s - w_s n_s = 0$$

where p_s, e_s, and w_s were defined before and are, respectively, the price of the good, the wage paid to s-experts, and the wage paid to workers in sector s.

2.2.3. Homogeneous industry

Production in the homogeneous industry takes unskilled labor and land, L, (a fixed factor, normalized to 1 in both countries). The technology is represented by the production function:

$$F_H(n_H) = A_H n_H^{\theta_H} L^{1-\theta_H},$$

with $0 < \theta_H \leq 1$.

3. Equilibrium

In this section I define and characterize an equilibrium for this economy.

3.1. Definition of equilibrium

Definition 3.1. *An equilibrium for this economy, given initial conditions* $\left\{x_{s0}^k\right\}_{s,k}$*, is a set of sequences: (1) discounted utilities* $\left\{V_{0t}^k, V_{st}^k, W_{Ht}^k, W_{st}^k\right\}_{s,k,t}$*, (2) consumption vectors for workers and* *experts* $\left\{(c^w_{sit})^k, (c^w_{Hit})^k, (c^e_{sit})^k\right\}_{s,i,k,t}$, *(3) aggregate occupational choices* $\left\{\mu^k_{Ht}, \mu^k_{st}\right\}_{s,k,t}$, *(4) aggregate industry allocations* $\left\{h^k_{st}, n^k_{st}, y^k_{st}\right\}_{s,k,t}$, $\left\{n^k_{Ht}, y^k_{Ht}\right\}_t$, *(5) prices* $\left\{p_{st}, p_{Ht}, w^k_{st}, e^k_{st}, w^k_{Ht}\right\}_{s,k,t}$, *(6) distribution of experts* $\left\{x^k_{st}\right\}_{s,k,t}$, *such that:*

(i) consumers maximize expected discounted utility given their budget constraints,

(ii) the aggregate industry allocations solve the minimization problem stated above,

(iii) markets clear:

$$h^k_{st} = x^k_{st}$$

$$n^k_{st} = \mu^k_{st}(l^k - \sum_s x^k_{st})$$

$$\sum_s \mu^k_{st} + \mu^k_{Ht} = 1$$

$$\sum_{k,s} \left(x^k_{st}(c^e_{sit})^k + n^k_{st}(c^w_{sit})^k\right) + \sum_k n^k_{Ht}(c^w_{Hit})^k = y^1_{it} + y^2_{it} \quad i \in S \cup \{H\},$$

where μ_{st} *is the fraction of workers in industry* s *and* μ_{Ht} *is the fraction of workers in the homogeneous sector.*

(iv) $\left\{x^k_{st}\right\}_{s,k,t}$ *follows the law of motion of the distribution of skills:*

$$x^k_{st+1} = \pi x^k_{st} + \eta(x^k_{st})n^k_{st}.$$

The market clearing conditions simply state that in equilibrium the quantities demanded of experts and workers in each industry, as well as the total demand of consumption goods, have to be equal to the quantities supplied. The consistency condition has to do with the predictions taken by the consumers when making their decisions: the predictions made by the consumers have to coincide with the actual aggregate variables in equilibrium.

3.2. Characterization of equilibrium

The crucial decision in this model is the workers' decision on where to employ their labor. Workers choose the occupation that maximizes their expected lifetime utility. Therefore, if there are individuals willing to work for two different industries, their expected utility working in both industries has to coincide. Thus, in equilibrium, the fraction of workers working in industry s, μ_{st}, satisfies:

(i) $\mu_{st} = 0$ if $W_{st}(P, x) < V_{0t}(P, x)$

(ii) $\mu_{st} \in [0, 1]$ if $W_{st}(P, x) = V_{0t}(P, x)$.

Once individuals have made their occupational decision, they choose how much of their period's income to spend in each of the goods. Notice that since I do not allow borrowing or lending, individuals spend all their period's income in the period's consumption. The rest of the equations that characterize equilibrium are derived using standard methods.[7]

Under symmetry assumptions I am able to characterize the steady state of a simplified version of the model with two differentiated sectors and no homogeneous sector analytically. The dynamics of the model have to be studied numerically. In what follows I summarize the results of such characterization and present the behavior of the model with respect to initial conditions and the nature of the learning function. A formal derivation of these results is presented in the working paper version of this study.[8]

[7]The derivation is done in an appendix of this paper, available upon request.
[8]See Bajona (2002).

The nature of the equilibrium depends crucially on the characteristics of the learning function. If the probability of learning is constant (independent of the concentration of sector-specific expertise) the model has a continuum of steady states. These steady states have the same prices, wages, and worldwide fraction of experts in each industry, and only differ in the way the industry-specific experts are split across countries.[9] To which steady state the economy converges depends on the initial distribution of experts. The trade-to-income ratio stays constant along the equilibrium path.

If the learning function is increasing and concave with respect to the fraction of industry-specific experts (and, thus, there are positive effects on learning) the behavior of the model is drastically different. There exist only two types of steady states: an autarchic steady state, where both countries diversify, and two other steady states where both countries specialize, if the size of the countries is similar enough, or a partial specialization steady state where the big country diversifies and the small country specializes. To which of these steady states the economy converges depends on the initial distribution of experts. If countries start in autarchy, with the same distribution of experts in each country, they stay in autarchy forever. Otherwise, countries either completely specialize (if a complete specialization equilibrium exists) or partially specialize (if a partial specialization equilibrium exists). In other words, the autarchic steady state is unstable.

Even though countries converge to a specialization equilibrium, the model delivers convergence in terms of income levels. This result can be related to the literature on convergence and trade[10]. This literature has pointed out that in dynamic versions of the Hecksher-Ohlin model poor countries do not need to grow faster than rich countries and do not need to converge to the same income per capita. Crucial to these results is the existence of a continuum of steady state in their models. In the

[9] This result is analogous to the steady state results derived from dynamic Heckscher-Ohlin models, where steady state world capital and prices are determined, but not its distribution across countries. See for instance Baxter (1992) and Bajona and Kehoe (2002).

[10] See Ventura (1997), Atkeson and Kehoe (1999) and Bajona and Kehoe (2002).

model of this paper countries of the same size completely specialize in steady state. Therefore, I obtain convergence in income levels. An interesting result that I obtain here, though, is that there is divergence in the distribution of skills, and therefore, the trade to income ratio increases over time. That is, the model delivers trade in an environment where countries converge in terms of income levels. Whether relaxing the symmetry assumption would change the convergence results is left for further research, but preliminary results suggest that without making essential changes in the model the existing result will prevail. Further research will consider the case where the fraction of experts in each sector improves total factor productivity. This feature, together with asymmetries in the skill intensity of the goods, could lead to situations where countries do not converge in income levels.

4. Simulations of the model economy

In this section I simulate the model for a specific set of parameters. The objective of this exercise is to show in a numerical example how this model can generate, for reasonable parameters, an increase in trade over time that is similar to the one experienced in developed countries during the postwar period. The increase in trade is driven by gradual specialization in production.

In order to study the properties of this model I start by considering a simple case. I consider four differentiated manufactured goods, $S = 4$. I assume that both countries are of the same size: $l^1 = l^2 = 1$. Countries are symmetric in their initial distributions of skills in the following sense: for each sector s, there is another sector $s' \neq s$ such that $x_s^1 = x_{s'}^2$ and $x_{s'}^1 = x_s^2$. I characterize sectors s and s', as *symmetric*. A symmetric model implies that for each sector in the first country, there is another sector in the second country with the same distribution of experts. I take the technology in the differentiated industry to be the same across sectors. Under these assumptions, symmetric sectors behave identically in both countries. In what follows, I report simulation results for country 1. Country

2 behaves exactly like country 1 after accounting for the symmetry.

The next table presents the values for the parameters for the benchmark economy:

	Preferences					Pop.	Technology				Depr.
Parameter	a_s	b	ρ	β	γ	l	θ_s	θ_H	A_s	A_H	$1-\pi$
Value	0.25	0.65	1.0	0.95	0.5	1.0	0.6	0.5	1.0	1.0	0.2

I assume that all differentiated goods enter the utility function symmetrically. Therefore, I take $a_s = 0.25$ for all s. The differentiated good's share of consumption, b, is taken to be 0.65, consistent with Bergoeing (1996). The choice of β makes one period to correspond roughly to one year. Population is normalized to be equal to 1 in each country.

The key aspect of the model is the learning function. In this benchmark version, workers in sector s can only learn the skills involved in the production of good s. The probability of acquiring the skills depends on the fraction of the country's population that masters the know-how.

The main assumption about the learning function is that it is increasing and concave in the number of experts. If there are no experts in the economy, individuals can still learn the skills with a small probability. Concavity introduces diminishing returns on expertise in the learning technology.

The specific functional form chosen for the simulations is the following:

$$\eta(x) = d_0 + d_1(x/l)^{d_2}$$

For the benchmark economy the parameters chosen are: $d_0 = 0.1$, $d_1 = 0.7$, $d_2 = 0.9$. If there are no experts, 10% of workers in the sector can acquire the skills. We can think of this probability as coming from exogenous knowledge of the individual that allows him to figure out the production process on his own. In the end, even if all the population has expertise in the industry, the worker's probability of learning is 0.8.

In what follows I consider different initial distributions of expertise across sectors and report the different patterns of specialization as well as the evolution of the trade-to-income ratio. The initial conditions will be taken as a deviation of the symmetric steady state of the model, where both countries produce the same amount of all the goods and there is no trade. The distribution of experts for this symmetric steady state, given the parameters mentioned above, is $\hat{x} = 0.09385$.

Different initial conditions lead to different patterns of specialization. Let us consider first a situation in which country one has more experts in industries 1 and 2, and country two has more experts in industries 3 and 4. In particular, the initial conditions taken are $(x_1^1, x_2^1, x_3^1, x_4^1) = (0.9, 0.9, 0.7, 0.7)\hat{x}$ and $(x_1^2, x_2^2, x_3^2, x_4^2) = (0.7, 0.7, 0.9, 0.9)\hat{x}$.

Figure 4.1 shows the evolution of the distribution of experts in each industry for country one. Country two behaves symmetrically: industries 3 and 4 expand and industries 1 and 2 decay. Notice that we obtain symmetry between industries with the same endowments. In this case both countries gradually specialize in the production of the goods in which they have a relatively high endowment of experts. In the limit complete specialization occurs.

The explanation for gradual specialization is the following: to continue producing in the decaying industry, workers in this industry need to be paid higher wages than in the expanding industry (wages for unskilled workers in each of the industries are shown in figure 4). Therefore, fewer workers are hired in the decaying industry and fewer of them learn the skills and contribute to the stock of experts in that industry the period after. The stock of expertise gradually differs between both industries, defining the pattern of specialization. Notice that countries do not trade in the homogeneous good: due to the symmetry of the model, both countries produce the same amount of the homogeneous good.

Figure 4.2 presents the evolution of the trade-to-income ratio. Since each country gradually specializes over time, the ratio increases over time as well. This is the main qualitative result of the model. A careful calibration of the model is needed for any quantitative results, but we can see that with the parameters chosen, in a period of 35 years the trade-to-income ratio increases by more than a factor of 5. The model is able to produce huge increases in the trade-to-income ratio without the need of high elasticities of substitution between goods.

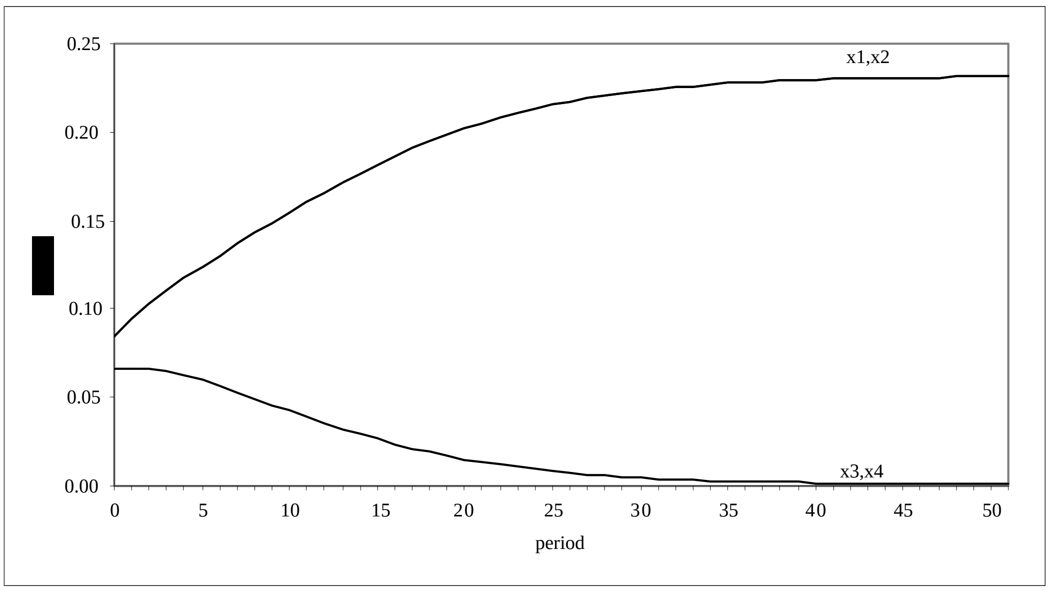


Figure 4.1: Example 1. Distribution of experts in country 1.

Figure 4.3 plots the wages received by workers in each industry. We observe that wages in the decaying sectors are higher than in the expanding sectors. To attract workers to a decaying sector higher wages have to be paid. Since the workers' probability of acquiring the skills in the decaying sectors is lower than in the expanding sectors, workers in the decaying sectors have to be compensated with higher wages. Wages in the homogeneous sector are consistently higher than in the differentiated industries, since there are no skills to be learned in that sector and, therefore, no expectations of higher

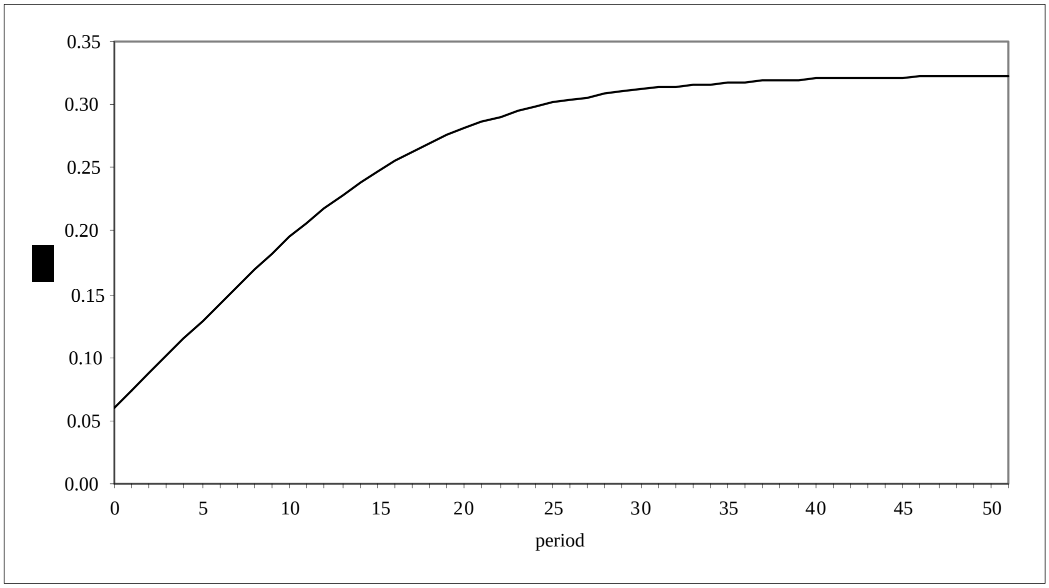


Figure 4.2: Example 1. Trade-to-income ratio.

paid jobs in the future.

The salaries of skilled people are plotted in figure 4.4. Notice that experts in sectors 1 and 2, the expanding industry, get higher wages than experts in the other sectors, and much higher wages than workers in any of the sectors. This, together with the lower wages for raw labor, indicates that the mixture of types of labor in the expanding industry is biased to raw labor. If we interpret skilled workers as workers who have been in the industry for some time, this model would imply that exporting sectors should have shorter job tenure than importing sectors. This shorter job tenure would be the result of higher mobility of workers within the sector: workers leaving their jobs to set up new firms in the same sector.

Comparing wages and salaries over time, we observe a reduction of the overall wage gap. This result seems at odds with the increase in the wage gap between educated and uneducated workers observed in the US data. It is important to keep in mind that this model only considers trade between *developed*

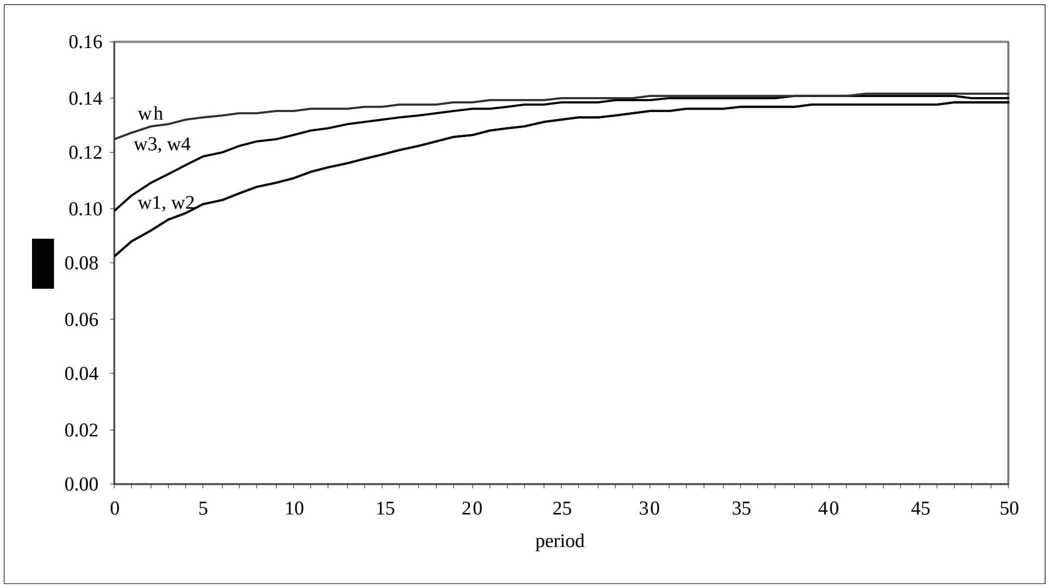


Figure 4.3: Example 1. Wages of unskilled workers in country 1.

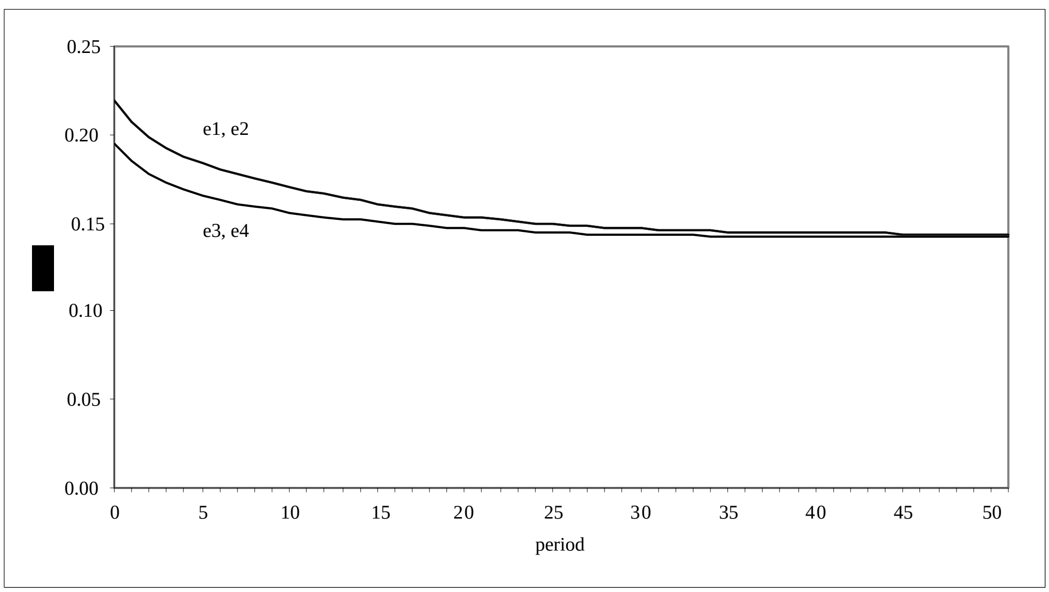


Figure 4.4: Example 1. Wages of skilled workers in country 1.

countries. Lovely and Richardson (1998) have found evidence of wage convergence in industries which products are traded with developed countries. Greater US trade with developed countries results in decreasing rewards to skills and increasing rewards to raw labor. This is precisely what this model predicts.

The plot also shows higher wage differentials among different levels of expertise in the expanding industry. This is given by the learning expectations: the higher the probability of acquiring the skills, the lower the wage that workers are willing to accept to work in the industry.

Finally, it is important to point out that given that the period utility is CES between the homogeneous and the manufactured industries, people spend a constant fraction of their income in each of the industries. The increase in trade in this model is not, thus, driven by an increase in the share of manufactured goods in consumption, as it is the case in Markusen (1986) and Bergoeing and Kehoe (1999).

In the next experiment, I slightly modify the initial conditions of the model to show how they can lead to a different pattern of specialization. I consider the case in which country 1 has more experts than country 2 in the first sector, and less experts in the second sector. Both countries start with the same experts in the second and third sector. I keep the symmetry assumption. The specific values for the initial conditions chosen are $(x_1^1, x_2^1, x_3^1, x_4^1) = (0.9, 0.7, 0.7, 0.5)\hat{x}$ and $(x_1^2, x_2^2, x_3^2, x_4^2) = (0.5, 0.7, 0.7, 0.9)\hat{x}$.

Figure 4.5 plots the evolution of the distribution of experts for these initial conditions. Country one specializes in the production of the good in which it has a relatively high endowment of experts to start with, good 1, and lets the sector with a relatively low endowment of experts, sector 4, decay. Since both countries have the same endowments of goods 2 and 3, both countries produce those goods and there is no exchange of any of these goods. Thus, the pattern of trade converges to partial specialization: both countries gradually specialize in the production of one of the manufactured goods, reduce production of another of the goods, and produce a positive amount of the other two.

In this case, the exports-to-income ratio does not experience such a big increase as in the first experiment. It increases by a factor of 3 in a 35 year period (figure 4.6). This value is close to the increase in the ratio observed in the data.[11]

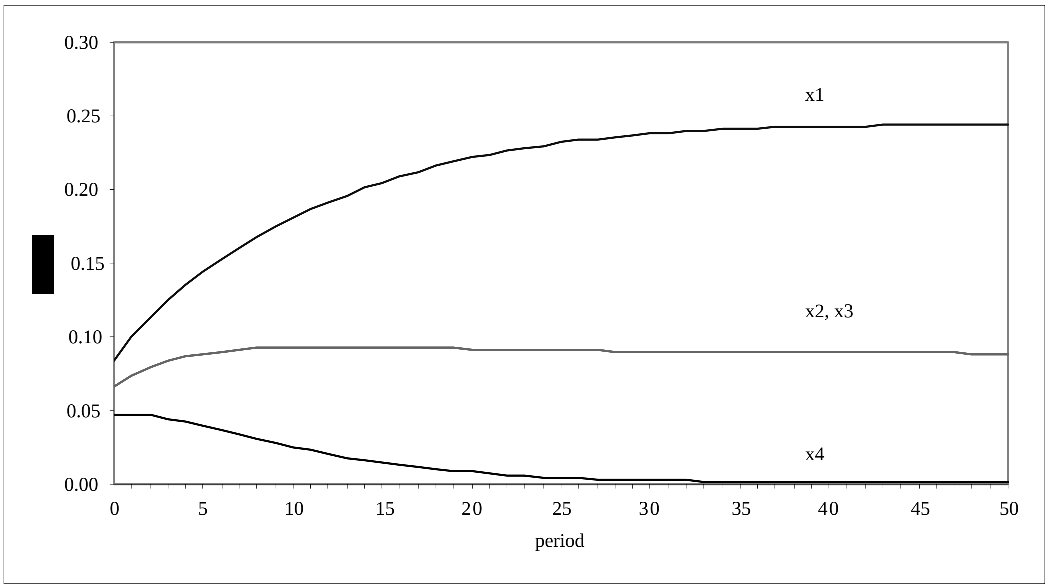


Figure 4.5: Example 2. Distribution of experts in country 1.

Changes in the parameters affect the speed of convergence to the steady state and the steady state's proportion of experts. The qualitative results of the model and the transitional dynamics of the pattern of specialization, given initial conditions, are not affected. In what follows I explain the effects of the learning parameters and the discount factor β. A more detailed analysis can be found in Bajona (2002).

[11] The pattern of specialization depends crucially on the interaction between sectors. Allowing for spillovers in knowledge across sectors (between sectors (1,2) and (3,4), for instance) would brake down the partial specialization equilibrium in the previous example. Country 1 would gradually specialize in sectors (1,2) and country 2 in sectors (3,4). If there are knowledge spillovers, a country's comparative advantage in a specific sector is determined not only by the country's endowments of experts in that sector, but also by the country's relative endowments of experts in the sectors that are knowledge-related to that specific sector.

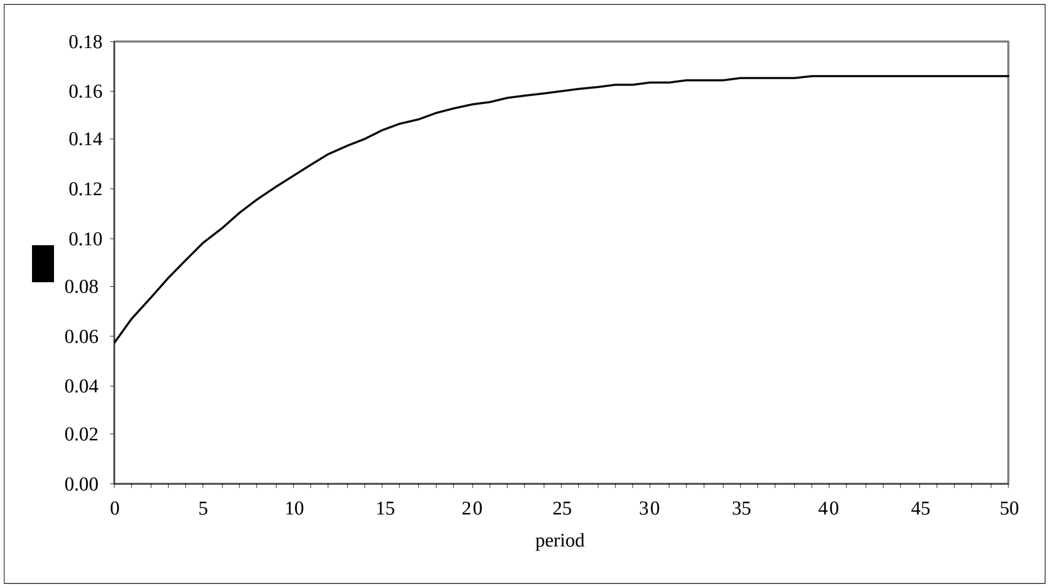


Figure 4.6: Example 2. Trade-to-income ratio.

Regarding the parameters of the learning function, increases in d_0 and d_1 or decreases in d_2 increase the amount of experts in steady state and accelerate convergence. Higher values of π imply slower convergence and lower number of experts in steady state, since it reduces the renewal rate.

Higher βs imply faster convergence. This result is not intuitive, since usually higher discount factors imply slower convergence.[12] In this model, though, β also represents the opportunity cost of changing jobs. The higher the β, the more costly it is to wait one more period to acquire the skills, the more workers have to be compensated to stay in the decaying sector and, therefore, the faster the sector decays.

[12] The higher the discount factor, the less people discount the future and, therefore, the shorter the periods are. More periods are needed to converge to the steady state.

5. Trade policy

The main message of this paper is that under positive external effects on learning the trade-to-income ratio may increase over time, as countries specialize, even if there is no change in trade policy. In this respect, this paper proposes a mechanism that amplifies the effect of any tariff reduction. In this section, I incorporate trade policy, in the form of tariffs to imports, to the version of the model discussed in section 3 and I study the effects of trade policy on the trade volume. Tariffs have two types of effects in this model: a static effect and a dynamic effect. On one hand, tariffs reduce the period's trade-to-income due to the protection that they offer to the sectors without comparative advantage. This is the *static effect*. On the other hand, tariffs keep the declining sectors operating for longer periods of time, slowing the specialization process. I call this effect the *dynamic effect.*

Notice that if tariffs are high enough they will offset any potential benefits of trade. In this case, countries will be in the autarchic equilibrium and, thus, will converge to the autarchic steady state with complete diversification and no trade. In what follows, I consider tariff rates that are small enough so countries are in a trading equilibrium. A detailed study of the effects of trade liberalization with prohibitive initial tariff rates on the trade pattern and the trade volume is the topic of ongoing further research.

To simplify the exposition, I restrict the study to the symmetric version of the two-good model, with $l^1 = l^2$, which I modify to allow for proportional tariffs on imports. Let p_s^w be the world price of good s and τ be the uniform tariff rate on imports. If country i is an importer of good s, the price of good s in country i, p_s^i is given by $p_s^i = (1+\tau)p_s^w$. In the symmetric version of the model the world prices of both goods are equal. I normalize the value of these world prices to be 1.

To get an idea of the magnitude of the static effect, I study the effects that tariffs have on the steady state equilibrium. Given that countries have the same technology, positive tariffs cannot sustain an equilibrium steady state with complete diversification.[13] Therefore, the only steady states of the model with positive tariffs are steady states with complete specialization. With symmetric tariffs and complete specialization, imports, m, in each country are given by

$$m = \frac{(1+\tau)^{1/(\gamma-1)}}{(1+\tau)^{1/(\gamma-1)}+1}\, y,$$

where y is the total production of the specialized good.[14] From this expression we can compute the tariff elasticity of the trade volume in steady state, which measures the percentage increase in the trade volume due to a one percent decrease in the tariff rate:

$$\varepsilon = \frac{(1-\gamma)(1+\tau)^{1/(\gamma-1)}+1}{(1-\gamma)(1+\tau)^{1/(\gamma-1)}+(1-\gamma)},$$

which is greater than one for any tariff rate. For a value of γ of 0.5, as I use in the simulations, this tariff elasticity is about 1.5 for low tariff rates of the order of 1% and 2%.

The dynamic effect of the trade policy consists of a slow down of the specialization process. In order to study the potential magnitude of this effect, I consider a benchmark model with a 2% tariff rate and I compare the evolution of the equilibrium trade-to-income ratio with this trade policy to the trade-to-income ratio of two other situations. In the first situation, labelled $t = 0$ in Figure 5.1, the tariff rate is equal to 1% since the first period, and in the second situation, labelled $t = 10$, there is a permanent reduction of the tariff rate from 2% to 1% after period 10, which fully predicted by agents in the economy. Figure 5.1 presents the evolution of the distribution of experts and the trade-to-income ratio in each of these situations. We observe two things: (i) specialization and trade slow

[13] Intuitively, with positive tariffs, given the assumption of identical technologies and diversified steady state, countries are always better off not trading. Cuñat and Maffezzoli (2002) obtain a similar result in a different version of a Heckscher-Ohlin model.

[14] Notice that the function m is equivalent to the consumption of the imported good.

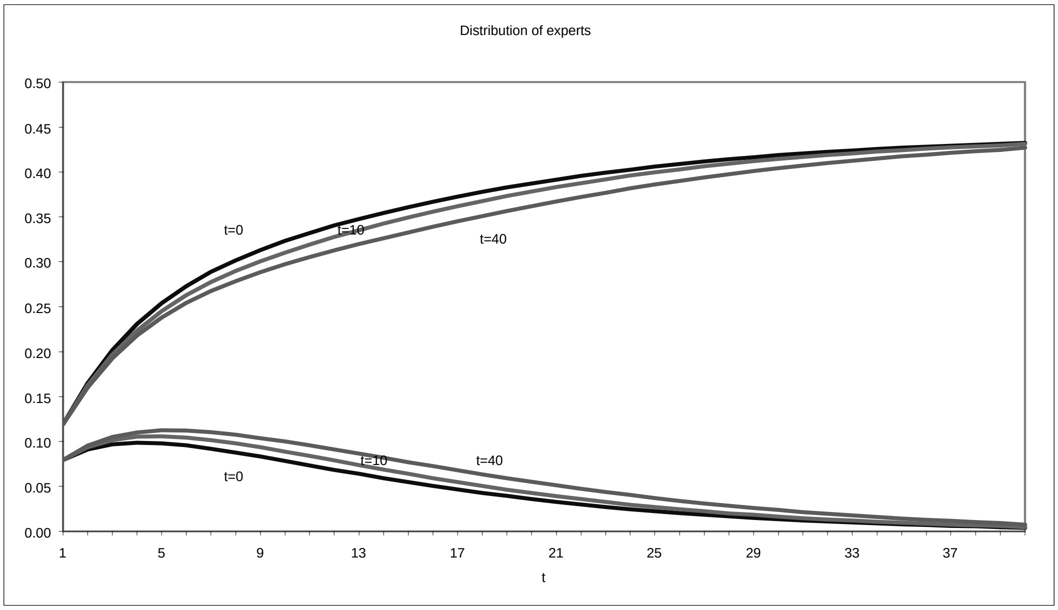
down over time (the dynamic effect), and, given the same degree of specialization, there is less trade when tariffs are high (the static effect). (ii) Knowledge of future trade liberalization speeds up trade. Notice that the effect of tariff reduction in the trade volume depends on the degree of specialization achieved by the countries. Comparing the situation with permanent 2% tariff rates with the situation with permanent 1% tariff rates, the trade-to-income ratio with a 1% tariff rate is 22% higher in the first period, increases to a 30% difference in the fourth period and it gradually decreases to about 1.5% in steady state. Therefore, a prediction of this model is that the potential gains of trade liberalization are higher when countries have similar production patterns and are lower when countries are already quite specialized in their production patterns.

6. Conclusion

In this paper I develop a general equilibrium model of trade between developed countries that can account for the increase in the trade-to-income ratio observed in the postwar period. The crucial hypotheses of the model are that (i) very specialized workers (industry-specific experts) are used in the production of the goods that these countries trade, that (ii) the specialized skills can be learned by nonspecialized labor through their day-by-day contact with the experts, and that (iii) there are positive effects in the learning device driven by the proportion of experts in the country. I find that even small positive effects in the learning generate a pattern of gradual specialization over time and, therefore, an increase in the trade-to-income ratio.

One implication of this model is that industrial policy (taxes of subsidies to specific sectors) and trade policy (tariffs) affect the dynamic evolution of comparative advantages across countries and, therefore, the pattern of trade and growth[15]. A result of the model is that the timing of liberaliza-

[15] I thank an anonymous referee for pointing out this feature of the model. See Baxter (1992).



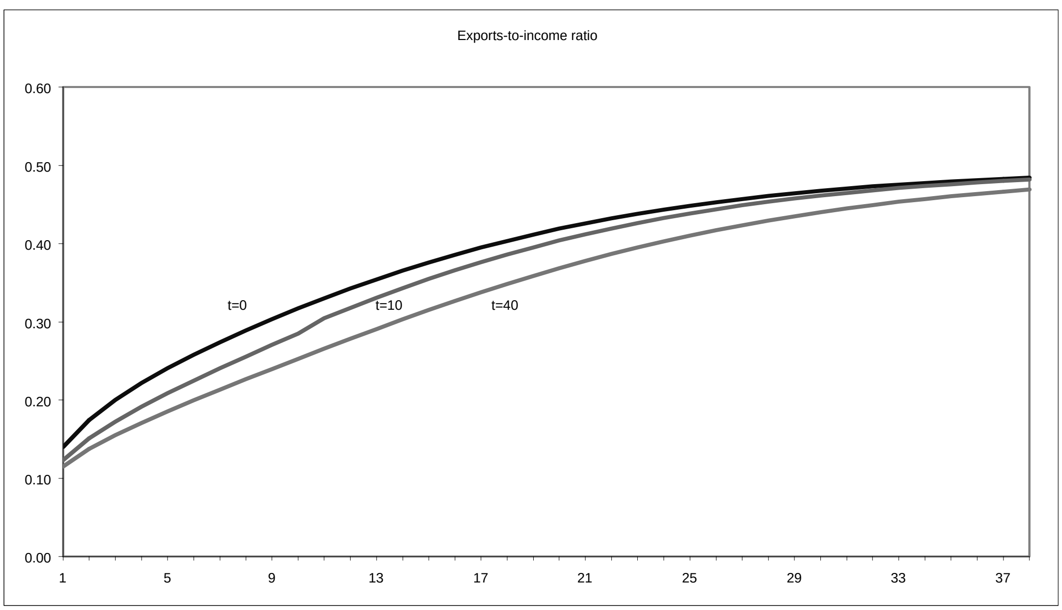


Figure 5.1: Tariff reduction

tion of trade barriers as well as different degrees of liberalization across sectors may be important in determining future comparative advantages. This is an interesting direction for further research that the author is already studying. A word of caution related to the policy implications of the model is, though, in place. One may be tempted to use this model to support infant industry type of arguments for economic policy: initial subsidies to specific sectors would speed up the accumulation of expertise and, therefore, drive the country to specialize in the subsidized sectors. Subsidies to sectors that are likely to have high spillovers to other sectors might also speed the industrialization process. I see two objections to this practice. First, it is hard to know the extent of the spillovers and which sectors are better at disseminating knowledge to other sectors. Second, a subsidy to one sector is always at the expense of another sector, in which the country might have advantage in the first place, possibly making the costs of the policy higher than the benefits.

There are some limitations of this model that suggest different directions for future research. First, the model does not take into account the introduction of new technologies or improvements of technology over time. A version of the model where the accumulation of expertise led to the introduction of better technologies, would be able to account for differences in technologies at the sectoral level found by some studies.

More importantly, the model does not consider the possibility of the creation of new goods. It is a fact that developed countries trade in goods that are very similar to each other, and that the amount of these similar goods, varieties, increases over time. The model in this paper can be considered as an example of the extreme case in which the varieties are perfect substitutes. In this case, my model could be interpreted as each expert setting up a new firm producing a different variety of a good in the same industry.

References

[1] Atkeson, A. and P. J. Kehoe, "Paths of Development for Early- and Late- Bloomers in a Dynamic Heckscher-Ohlin Model," Federal Reserve Bank of Minneapolis Staff Report # 256, 2000.

[2] Baier, S. L. and J. H. Bergstrand, "The Growth and Regionalization of Intenational Trade," mimeo, University of Notre Dame, 1998.

[3] Bajona, C, "Specific Factors, Learning, and the Dynamics of Trade", working paper, University of Miami, 2002.

[4] Bajona, C. and T. J. Kehoe, "On Dynamic Heckscher-Ohlin Models," mimeo, University of Miami, 2002.

[5] Bergoeing, R., "Studies on Trade," Ph. D. Disseration, University of Minnesota, 1996.

[6] Bergoeing, R. and T. J. Kehoe "Trade Theory and Trade Facts," Federal Reserve Bank of Minneapolis Staff Report # 284, 2001.

[7] Boldrin, M. and J. A. Scheinkman, "Learning-By-Doing, International Trade and Growth: A Note," in P. W. Anderson, K. J. Arrow, and D. Pines, eds., *The economy as an evolving complex system: The proceedings of the Evolutionary Paths of the Global Economy*, Santa Fe Institute Studies in the Sciences of Complexity 5 (London: Addison-Wesley, 1988).

[8] Chipman, J. S. "Intra-Industry trade in a Loglinear Model,". mimeo, University of Minnesota, 1992.

[9] Cuñat A. and M. Maffezzoli. "Trade Integration and Growth". manuscript, 2002.

[10] Devereux, M. B., "Growth, Specialization and Trade Liberalization," International Economic Review 38 (1997), 565-585.

[11] Feenstra, R., "Integration of Trade and Disintegration of Production in the Global Economy," Journal of Economic Perspectives 12 (1998), 31-50.

[12] Feeney, J., "International Risk Sharing, Learning by Doing, and Growth," Journal of Development Economics 58 (1999), 297-318.

[13] General Agreement on Tariffs and Trade, *International Trade,* Various issues.

[14] Helpman E. and P. Krugman, *Market Structure and Foreign Trade* (Cambridge: MIT Press, 1985)

[15] Hornstein, A. and E. C. Prescott, "The Firm and the Plant in General Equilibrium Theory," in R. Becker et-al., eds., *General equilibrium, growth, and trade. Volume 2. The legacy of Lionel McKenzie. Economic Theory, Econometrics, and Mathematical Economics series.* (San Diego; London: Harcourt Brace, Academic Press, 1993).

[16] Ishii, J. and K-M., Yi, "The Growth of World Trade,"manuscript, Federal Reserve Bank of New York, 1997.

[17] Krugman, p., "Growing World Trade: Causes and Consequences," Brookings Papers on Economic Activity 1 (1995), 325-377.

[18] Lovely, M. and D. Richardson, "Trade Flows and Wage Premiums: Does Who or What Matter?," Working Paper No. 6668, National Bureau of Economic Research, 1998.

[19] Lucas,R. E., "On the Mechanics of Economics Development," Journal of Monetary Economics 22 (1988) 3-42.

[20] Lucas, R. E., "Externalities and Cities," mimeo,. University of Chicago, 1998.

[21] Markusen J. R., "Explaining the Volume of Trade: An Eclectic Approach," American Economic Review 76 (1986), 1002-1011.

[22] Park, K. S., "A theory of on-the-job learning", International Economic Review 38 (1997), 61-81.

[23] Rhee, Y. W., "The Catalyst Model of Development: Lessons from Bangladesh's Success with Garment Exports," World Development 18 (1990), 333-346.

[24] Rodgers, J. R., "Analysis of Intra-Industry Trade Flows: The Case of Sweden," Ph. D. Dissertation, University of Minnesota, 1987.

[25] Rose, A. K., "Why has Trade Grown Faster than Income?," Canadian Journal of Economics 24 (1991), 417-427.

[26] Ventura J., "Growth and Interdependence," Quarterly Journal of Economics 112 (1997), 57-84.

[27] Yi, K.-M. "Can Vertical Specialization Explain the Growth of World Trade?," forthcoming, Journal of Political Economy, 2002.

[28] Young, A., "Learning by Doing and the Dynamic Effects of International Trade," Quarterly Journal of Economics 106 (1991), 369-405.